Urban Groundwater Development and Management

Report to the
Water Research Commission

by

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This report emanates from a solicited (directed) Water Research Commission (WRC) project entitled *Urban Groundwater Development and Management* (WRC Project No. K5/2741).

EXECUTIVE SUMMARY

1. Background

Groundwater is under-utilised for domestic supply in urban areas, where it is generally being mis-used or at least indirectly used with negative consequences. Groundwater resources local to and underlying the urban area are providing an un-recognised service of assimilation of reticulation water, stormwater, and wastewater (via leaking pipes, leaking WWTW ponds). However this comes at a price: the associated contamination and water quality impacts may render the groundwater resource most local to the urban area unsuitable for supply. In addition to water quality impacts from leaking sewer networks, groundwater is impacted in urban areas by underground storage tanks at petrol stations, industrial areas (i.e. dry cleaners), waste sites, cemeteries, nitrate from fertilisers mobilised by garden watering, and inadequate sanitation in informal settlements causing contamination of stormwater and groundwater. Recharge is also impacted with sealed surfaces reducing recharge, yet leaking and concentration of stormwater enhancing recharge. The sustainability challenge for urban water management is to remediate or at least isolate poor water quality, whilst making use of the local resources.

Groundwater use by urban areas urgently needs to shift from lack of active management of groundwater and indirect use (of groundwater's assimilative capacity) with negative implications, to active management leading to the potential for bulk water supply from urban groundwater resources. In cases where urban groundwater will not be used for bulk supply for whatever reason, active management of the urban groundwater is still required to protect the resource for other uses (ecological services, garden irrigation, food gardens). Contributing to this shift is the core motivation for this project; which aims to:

- understand the status quo of urban groundwater development and management in South Africa,
- compare these to best practice for urban groundwater management, and
- develop position papers and a tactical plan to address the gaps.

2. Status Quo

Five metropolitan municipalities currently use groundwater resources to varying degrees, including City of Tshwane, Nelson Mandela Bay Municipality (NMBM), City of Cape Town (CCT), Buffalo City (domestic supply to coastal villages) and Mangaung (domestic supply to rural Thaba Nchu). However, groundwater makes up only a small percent of the total supply, reaching 13.1% in the City of Tshwane. In addition, treated acid mine drainage (i.e. rebounding groundwater) is added to the Vaal Water Supply System (WSS), making up around 3% of the current supply to the metropolitan municipalities (MMs) of Gauteng.

Several MMs plan on expanding or initiating groundwater resource development as part of future reconciliation plans. Groundwater is planned to make up 25% of the "new" (non-surface) water resources for the CCT (CCT, 2017b). Groundwater (from treated acid mine drainage) will also make up an increased portion in Gauteng by 2020 (Engineering News, 2016). However, in some cases groundwater has received little attention, and the potential for groundwater resources to augment bulk supply is insufficiently understood (i.e. Mangaung, Johannesburg, Buffalo City and Ekurhuleni). In almost all cases, very little recognition is placed on alternative uses of groundwater, for example, dispersed use for non-potable purposes, to alleviate demand on the potable WSS.

Where groundwater use is intended, it would need to be reflected, planned and budgeted for in the Integrated Development Plan (IDP). For example, the necessary capital budgets to fund the planned groundwater development for NMBM are incorporated in the IDP (NMBM, 2017). The capture zone or protection zone of current and future wellfields, and in some cases recharge zones, should ideally be delineated in the Spatial Development Framework (SDF). This would enable appropriate protection measures to be put in place, and tailored to the particular water quality threats in the area. Aquifers are delineated and incorporated in (only) the SDF for CCT, however, these are not (yet) related to the current or planned future use of these resources, and protection measures (Table 2-3). Groundwater's support for the functioning of green infrastructure should also ideally be recognized in the SDF through (for example) the capture zone of an important wetland being delineated and linked to appropriate protection measures.

Water Sensitive Design (WSD) measures can also promote protection of groundwater resources for use, for example, by avoiding the hardening of surfaces in the recharge area which would otherwise limit the infiltration. WSD measures are promoted by some MMs, but the focus is primarily on stormwater management (i.e. Tshwane, CoJ, CCT) and the potential impact/ benefit of WSD measures on groundwater are not generally acknowledged. Water services or water supply by-laws provide another mechanism through which MM's can manage and protect groundwater. Most MMs incorporate the necessity for owner / occupier to notify the MM of the presence of boreholes on the property, and some enable the MM to impose conditions on the use of private boreholes (Tshwane, NMBM, and Mangaung); a measure that can enable the MM to manage resource competition should this be a potential risk.

The overarching finding from the analysis is that groundwater (use and management) is poorly integrated into the key statutory planning processes at the MMs. In no cases is a coherent plan for groundwater development and management evident from the MM, and integrated across each of the necessary and available planning documents.

3. Urban Groundwater Themes and Best Practice

Groundwater development and management challenges and opportunities that are specifically related to urban settings are termed urban groundwater **themes,** and are shown in Figure 1. These themes are described, along with case examples that either illustrate the challenge, or provide a best-practice example of the response to, or management of the urban groundwater challenge.

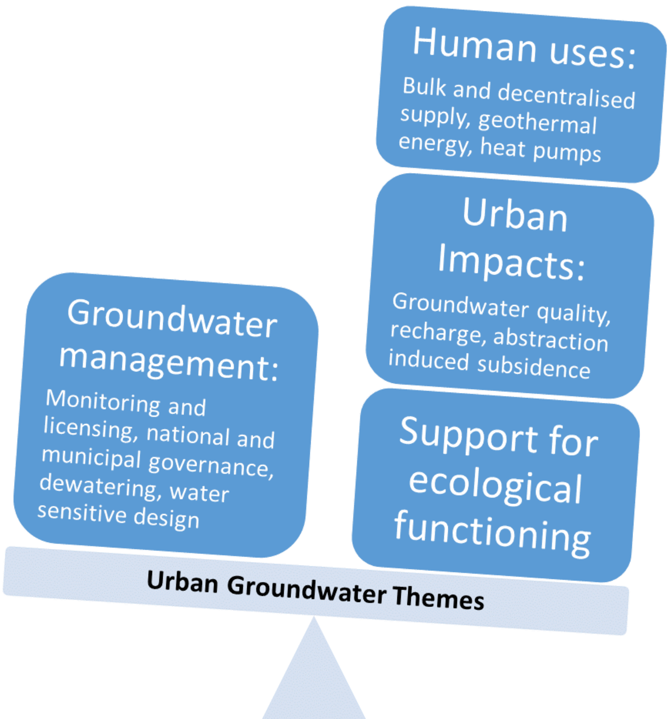

Figure 1. Urban Groundwater Themes

4. Gap Analysis

The urban groundwater themes were presented at an urban groundwater "think tank", which was attended by reference group members and metropolitan municipalities. Case studies of best practice were also presented, leading to a discussion of the most pressing urban groundwater challenges at the metropolitan municipalities. Combining the key remaining challenges highlighted at the think tank, with insights from the status quo assessment, a comparison has been made between the current status of urban groundwater development and management in South Africa with best practice examples (Table 1).

Table 1. Summary of Gaps between urban groundwater development and management in South Africa and international best practice

Urban Groundwater theme	Urban Groundwater subtheme (see section 3.2 for description)	Gaps: Status in SA MMs compared to best practice
Human uses	Bulk supply	Poorly developed: five (of eight) metropolitan municipalities currently use groundwater resources; and groundwater makes up only a small percent of the total supply, reaching 13.1% in Tshwane.
	Decentralised supply	Use of groundwater for decentralised supply is increasing, however governance to manage this use is lacking, and strong misconception and uncertainty exists over impact of decentralised use.
	Geothermal energy, ground source heat pumps	Not well developed in SA.
Support for ecological functioning	Support for ecological functioning	Lacking; some isolated examples in SA, e.g. the identification of groundwater dependent ecosystems, and exclusion zones for borehole drilling near rivers and wetlands.
Urban impacts on groundwater	Groundwater quality	Relatively widespread in SA's metros; related to inadequate monitoring.
	Impacts on recharge	Varying recognition in SA; some recognition as part of WSD measures.
	Abstraction induced subsidence	Some best practice examples from Gauteng (such as dolomite by-laws), however some gaps in management remain.
Groundwater management	Monitoring, adaptive management, licensing	Lacking: • insufficient registration and monitoring of private groundwater use; • insufficient regional resource monitoring networks for resource protection (contamination), and related to this insufficient collation of central storage of private datasets; • ineffective groundwater resource quantification and management methods (lack of centralised models) and related licensing inefficiencies.
	National and municipal governance	Governance – related challenges hinder urban groundwater use and management in SA; specifically related to ambiguity over roles and responsibilities and funding mechanisms.

Urban Groundwater theme	Urban Groundwater subtheme (see section 3.2 for description)	Gaps: Status in SA MMs compared to best practice
	Appropriate water resources classification and licensing mechanisms	Lacking in SA compared to international best practice; lack of modelling or groundwater resource quantification of key aquifers for licensing.
	Inclusion of groundwater in spatial & development planning	Some progress however lacking compared to international best practice.
	Beneficial use of groundwater dewatered for underground structures	Increasing in application, driven by resource constraints. Uncertainty over legislative requirements.
	Water sensitive design	Greater integration of groundwater in consideration of WSD measures is required

5. Position papers to support urban groundwater development and management

Four position papers have been developed detailing high-level solutions and best practice approaches to urban groundwater management challenges. Certain papers include data gathered during this project, some provide examples from previous work, and some are more opinion-based. They are intended as stand-alone papers so contain some repeats from previous chapters. The selection of urban groundwater themes for which papers were developed was based on the themes with the most critical gaps (between current status in SA and best practice). The papers developed include:

1. Groundwater Use and Urban Resilience
2. Beneficial use of groundwater dewatered from underground structures
3. Water Sensitive Design and Groundwater
4. Groundwater Source Protection Zoning.

*5.1 Groundwater use and urban resilience: **highlights***

There remains a perception that groundwater cannot provide sufficient yields for it to be a meaningful water supply source in urban areas. This paper intends to address this misperception and the successful reliance on groundwater as a supply source to a great number of towns and to the agricultural sector is outlined. Whilst groundwater is a dispersed resource compared to surface water which is concentrated via runoff to rivers and dams, the yields can still make significant contributions to urban resilience. Using the establishment of groundwater supply to priority health care facilities in Cape Town as an example, the paper also demonstrates that via decentralised supply even lower yielding aquifers can be developed for enhanced urban resilience. This message is aimed at the metropolitan municipalities, and water users within them (industry, services, other government departments such as departments of education and health).

Successful reliance on groundwater by towns

Groundwater resources account for >50% of the supply source in thirty six percent (36%) of settlements in South Africa. Where groundwater is used, it is dominantly making up 100% of supply, and only 25% of settlements have more than one supply source, demonstrating a lack of implementation of conjunctive use, which is a key to resilience. The main causes of failing groundwater schemes relate to operations and maintenance failures, rather than resources failure (Braune et al., 2014; Cobbing, 2013; Cobbing et al., 2015).

Successful reliance on groundwater by agriculture

The dominant user of groundwater is the agricultural sector, making up 59% of all groundwater use compared to 13% for domestic supply and 13% for mining purposes (Braune et al., 2014). The yields abstracted for agricultural purposes at aquifer scale greatly exceed any municipal or domestic supply wellfields. For example:

1) The irrigation demand of predominantly fruit crops in catchment H10B (Ceres basin, Western Cape) is almost solely met from groundwater, with total registered abstraction of ~9 million m^3/a. Although the summer groundwater levels decline significantly due to the abstraction impact, the abstraction appears to be maintainable, as evidenced by the complete recovery of groundwater levels each winter. The abstracted water is being derived from aquifer storage, which translates to lower discharge from the aquifers to surface waters; and the subsequent winter recharge is sufficient to replenish storage. The present ecological category for rivers in H10B is "C" reflecting that the ecology is "moderately modified from the Reference Condition, loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged" (DWS, 2017c, pg. 19); demonstrating that the ecological impact of any potential reduction in groundwater contribution to baseflow is (so far) inconsequential.

2) Irrigation demand in the Hex Valley, known for grape produce, is met from a combination of surface and groundwater. The total registered groundwater abstraction in the valley is over 17 million m^3/a. Similarly to H10B, there is a lack of suitable monitoring datasets from which to quantify the reduction in groundwater's contribution to baseflow due to abstraction. However, again, the present ecological category for the Hex River is "C" (DWS, 2017c, pg. 19); demonstrating again that the ecological impact of any potential reduction in groundwater contribution to baseflow is (so far) inconsequential

Successful reliance on groundwater for decentralised supply

The current drought in Cape Town led to a significant increase in the decentralised use of groundwater, and not only for non-potable sources. The Western Cape Government is one such user within the City of Cape Town that embarked on the development of "off grid" water supply for priority facilities. The "Water Business Continuity Planning Programme" aimed to establish groundwater supply to 54 priority facilities across Cape Town, with a total demand of 4463 kl/day, before "day zero", should it arrive. Results are presented for 17 of these 54 sites. Groundwater resources were successful in meeting the facility demand at all 17 sites, with the combined yield of the boreholes drilled onsite able to provide between 1 and 10 times the demand. Four of the sites were located in unfavourable hydrogeological conditions, with borehole yields around 0.1 l/s common. Nevertheless, the low demand at these sites could still be met by the yield achieved. Although the local groundwater resources are sufficient for supply, in many cases the groundwater quality requires extensive treatment, particularly true for the sites targeting basement aquifers. At one site in the basement with low yield, the installation is unlikely to proceed because of the treatment cost.

*5.2 Beneficial use of groundwater dewatered from underground structures: **highlights***

With supply schemes already constrained in some MMs, and becoming constrained in other areas, individuals, businesses, industries and municipalities are increasingly aware that measures that reduce demand are critical. In line with this is rising acknowledgement that wasteful practices should be avoided, and water re-used where possible. Whilst beneficial use of water that is abstracted in urban areas for dewatering purposes is not particularly innovative, prior to the current drought in Cape Town the practice was probably only practiced by a handful of forward-thinking newer buildings around Cape Town. The crisis spurred investment in alternative sources, and reduction of wasteful activities. This position paper outlines case studies of basement water use from Cape Town. Taking the lessons learnt from Cape Town, several sites with basements in Tshwane were investigated to determine the potential for beneficial use of the abstracted water. In addition, the yield, location and potential uses for groundwater ingress to the Gautrain tunnel was investigated.

Whilst the City of Johannesburg and Tshwane are not (currently) experiencing the same kind of water supply constraints as Cape Town is, the future outlook suggests that the Vaal Water Supply System will eventually face constraints, and both metros have been asked by DWS to implement WC/WDM measures. The paper aims to promote the beneficial use of ingress water by sharing information with potential users and regulators.

Cape Town's basements

Three buildings in the Central Business District (CBD) are presented. In each case groundwater collected in the basement sump is used (or planned for use) to offset some of this demand. In the case of the Towers Standard Bank building, the return on investment for setup of the basement water scheme for all non-potable demand in the building was only 3 years. Considering the potential across the City of Cape Town, it is feasible to imagine that up to 2 Ml/d could be available from basements, which would generate a notable reduction in reticulated demand if all was used.

Tshwane's Basements

Five buildings in the CBD are presented, each with significant volumes of basement water (4.3 kl/d to 155 kl/d in a basement with four levels). None of these buildings were making full use of the basement water, with it largely discharged to stormwater. In one building, up to 75% of the water demand is for air conditioning, and the feasibility of replacing this demand with basement water was investigated. The investment would require R1.5 million, which would be recovered in a 3-year period.

A hydrocensus of the CDB was conducted leading to an estimated total basement water yield of 1.1-2.3 Ml/d. Basement water therefore comprises a small, but potentially significant fraction of the total Tshwane's annual water demand (up to 0.74%).

The Gautrain Tunnel

The volume of groundwater ingress to the Gautrain tunnel is significant: the current average discharge of 5200 m^3/d equates to a total annual discharge of 1.90 million m^3/a, and emanates from three locations. Of these locations, only the Sandpruit Pumping Station (accounting for 15% of the discharge) discharges directly to surface water (river), and the remainder discharge to stormwater systems. While the total discharge is only 0.3% of CoJ's annual water demand, it remains a potentially significant amount considering that CoJ is a water insecure city with 98% of the water already allocated and faces projected water shortages by 2019 (CoJ, 2017). Multiple opportunities for use of the water are considered.

5.3 Water Sensitive Design and Groundwater: ***highlights***

Water Sensitive Design (WSD) is a holistic urban planning and design approach that integrates the entire urban water cycle into land use and development process with the aim of improving water quality and quantity, biodiversity, as well as adding economic, environmental and amenity value to cities. WSD incorporates all forms of urban water – potable water, stormwater, wastewater and groundwater – but with groundwater generally receiving the least consideration. This position paper aims to highlight the necessary consideration of groundwater in water sensitive design measures, and highlight cases that require special consideration.

Whether through water conservation measures or stormwater control, all WSD measures either directly or indirectly affect the spatiotemporal groundwater recharge patterns and the overall groundwater quality and viability as a water source. The most direct impact comes from MAR through periodical artificial aquifer recharge and abstraction schemes. To limit potentially detrimental effects, the abstraction points need to be positioned strategically within close proximity to the recharge points to fully contain and exploit the artificially stored water. Artificial groundwater recharge, especially of the subsurface injection type, introduces water of different chemical composition into the local groundwater system, which may cause various chemical or physical reactions. The space requirements needed by many of the WSD elements such as retention ponds or wetlands may be a limiting factor for implementation in many densely populated urban settlements and, therefore the potential for using WSD for aquifer recharge may also be limited. Furthermore, WSD measures may be limited in karstified limestone and dolomite aquifers where enhancing infiltration may be detrimental in terms of sinkhole formation and rapid transport of contamination.

5.4 *Groundwater Source Protection Zoning:* ***highlights***

The existing resource directed measures and the source directed measures require complementary policy for the protection of (ground)water *sources*. It is not only domestic supply that deserves this protection; also groundwater that supports sensitive ecological functions requires protection (groundwater "supply" to ecology), and any user that is reliant on the source at a particular quality (whether it be for domestic or industrial use). In order to do so, the area of aquifer that contributes to the discharge point must be identified (source or "capture zone"), and protected in spatial plans via the control of landuse ("source protection zone"). The definition of source protection zones and identification of them are relatively standard, and these are outlined. Two examples are included to demonstrate the approaches.

Lanseria Open Space Plan

The CoJ recently completed the open space plan for the Lanseria sub area, as part of the Spatial Development Framework. As part of the plan, the area contributing groundwater discharge to surface water systems were delineated using a numerical groundwater model. These areas – the "sources" for baseflow to surface water – were incorporated in the final open space plan for protection in terms of groundwater quality and quantity.

Cape Town

Source protection zones were identified for hypothetical abstraction sites in Cape Town using a numerical groundwater model, relating to 50 and 365 day travel. The zones are relatively small highlighting that the control of landuse in these areas could be readily achievable. Since this hypothetical exercise was carried out, groundwater development is currently underway for the City. "Aquifer protection zones" have been identified taking into account the main productive parts of the aquifer.

6. Urban Groundwater Plan

Various recommendations are made throughout the document, particularly within the position papers. These recommendations have been collected together to provide a **tactical plan for improved urban groundwater development and management**. The tactical plan was developed with a focus on using what is workable in current legislation, proposing new legislation or amendments to legislation where absolutely necessary, and listing actions that are readily possible with existing legislation. Whilst existing legislation is largely sufficient, new tools and approaches are recommended, some of which are already under development under concurrent initiatives.

Significant shifts are required in order to realise all aspects of the tactical plan for improved urban groundwater development and management. A wide range of recommendations are made in the National Groundwater Strategy (DWS, 2016d), and the tactical plan is intended to highlight what are the most important areas of required action in order to shift towards better (urban) groundwater management. There is no single body that can be responsible for the full implementation, but as the interest and motivation to initiate this study came from the WRC, it is recommended that the WRC, through follow-on studies, maintain oversight for each element of the plan.

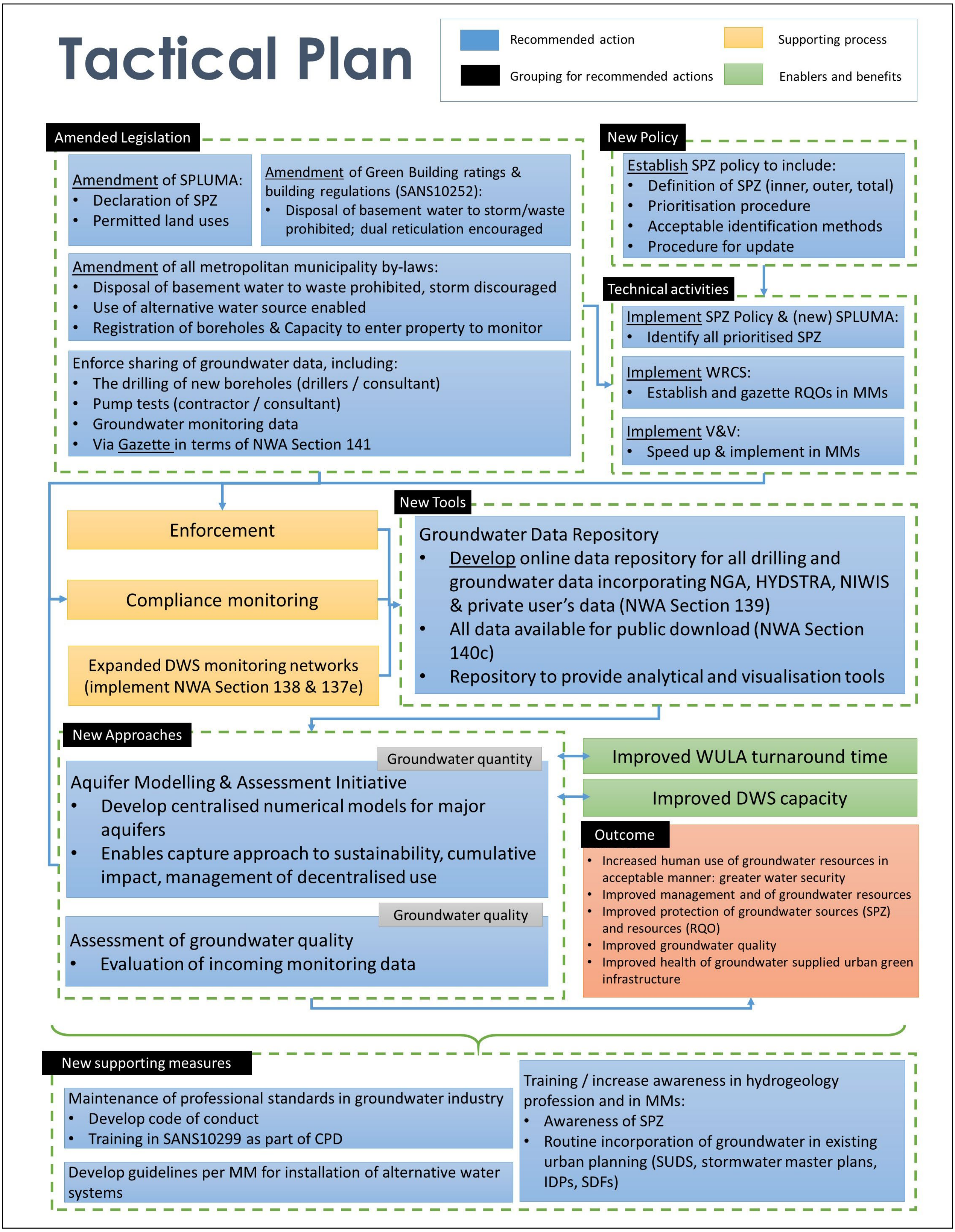

Figure 2. Urban Groundwater Plan

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Lastly, University of the Free State Masters students Thandilizwe Bengeza and Kgotso Mahlahlane are acknowledged for their contributions to the project, including sourcing and reviewing literature, assessing case studies, and assisting in administrative matters for the project. Their theses are referenced at the appropriate points in this report.

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List of Acronyms

DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical conductivity
IDP	Integrated development plan
GRA I	Groundwater Resources Assessment project (first phase)
GRA II	Groundwater Resources Assessment project (second phase)
GRA III	Groundwater Resources Assessment project (third phase)
GRDM	Groundwater resources directed measures
GW	Groundwater
K	Hydraulic conductivity
MAE	Mean annual evaporation
mamsl	Metres above mean sea level
MAP	Mean annual precipitation
MAR	Managed aquifer recharge
mbgl	metres below ground level
MM	Metropolitan municipality
mS/m	millisiemens per metre
NGA	National groundwater archive
NGDB	National groundwater database
NWA	National Water Act (Act 36 of 1998)
RQO	Resource quality objectives
SDF	Spatial development framework
SPZ	Source protection zone
SW-GW	Surface water-groundwater
V&V	Validation and verification (of water use, in terms of the NWA)
WARMS	Water Authorisation Registration Management System
WMA	Water Management Area
WRC	Water Research Commission
WRCS	Water resources classification system
WSD	Water sensitive design
WWTW	Wastewater treatment works

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1. PROJECT BACKGROUND

1.1. MOTIVATION

As South Africa continues its development trajectory, urban areas are growing and many rural areas stagnating, or seeing a decline in population, illustrated by the water demand projections in the Department of Water and Sanitation (DWS) All Towns Reconciliation project. This urbanization, in combination with population growth, leads to pressures on urban water supplies. Indeed, ***all*** of the metropolitan areas require new water resources to be developed in order to meet (30-year) future demand. The second National Water Resources Strategy states that readily available (surface) water is already fully allocated in several basins (DWS, 2013). Hence there is a need to look at alternatives especially for the growing urban areas, such as groundwater use, use of treated effluent, and desalination, alongside increasing efficiency and implementing water conservation and demand management measures. The additional pressure of climate change and increasing drought frequency in a water-scarce country requires diversification of supply to increase resilience. These pressures also increase the importance of groundwater for urban supply, given some aquifers have a slow response time and large storage capacity hence a capability to buffer droughts.

Groundwater is currently heavily relied upon in rural areas, indeed the spatial distribution of groundwater use across the country correlate closely with the locations of rural settlement, (i.e. in the Eastern Cape, and Limpopo), and agricultural use (e.g. Western Cape), and secondarily with the location of good aquifers (Le Maitre et al., 2017). Groundwater is also successfully relied upon by some smaller towns, fully or as part of the supply source. However, despite various success stories (i.e. Hermanus, Braune et al., 2014), the robustness that diversification of supply can bring, and the increasing demand, groundwater is not (currently) a significant supply source to any of the metropolitan areas. Three of the 8 metropolitan municipalities do not use groundwater, and groundwater makes up only a fraction percent of the supply (between 2-13.1%) in the remaining 5 metropolitan municipalities. Although some metropolitan areas plan on groundwater development as part of future reconciliation plans (i.e. Nelson Mandela Metropolitan Municipality using the Table Mountain Group aquifer in the Uitenhage basin, and the City of Cape Town using the Cape Flats and the Table Mountain Group Aquifer), groundwater is likely to still only make up a small (~10%) percentage, of their total available resources.

So groundwater is generally not being used for supply in urban areas, but furthermore, it is generally being mis-used or at least indirectly used with negative consequences: As urban areas establish and grow, the water supply generally comes from local resources. This was the case for both Johannesburg and Cape Town: both were initially supplied by local groundwater and surface water resources. As cities grow, imported water resources replace local ones, and water supply becomes centralized. Surfaces are sealed, preventing infiltration and recharge, generating massive runoff and stormwater, which is generally discharged downstream of the urban area. The reticulation and sewer network leak causing increased recharge. Groundwater resources local to and underlying the urban area are therefore providing an un-recognised service of assimilation of reticulation water, stormwater, and wastewater (via leaking pipes, leaking WWTW ponds). However, this comes at a price: the associated contamination and water quality impacts may render the groundwater resource most local to the urban area unsuitable for supply.

The water situation in urban areas is therefore highly contradictory: water is imported to meet growing supply needs, yet local runoff is high from hard surfaces, increasing surface water availability (if it can be captured), and leakage or anthropogenic recharge may increase groundwater availability. However, water quality impacts complicate the use of these local water resources. In addition to water quality impacts from leaking sewer networks, groundwater is impacted in urban areas by underground storage tanks at petrol stations, industrial areas (e.g. dry cleaners), waste sites, cemeteries, nitrate from fertilisers mobilised by garden watering, and inadequate sanitation in informal settlements causing contamination of stormwater and groundwater. The sustainability challenge for urban water management is to remediate or at least isolate poor water quality, whilst making use of the local resources.

The above generalized picture of urban areas is widely reported on for the Cape Flats aquifer (i.e. DWA, 2014 and CSIR, 2015), but is relevant for all urban areas in South Africa. In the three metropolitan municipalities in the Gauteng Province, some (not all) groundwater resources are impacted by mine dewatering and by acid mine drainage. This adds a level of complexity: un-impacted aquifers exist, and are currently used for example in the City of Johannesburg for irrigation of hockey fields and golf courses, and these aquifers should be a priority for protection.

To overcome these challenges, and specifically to address the contradictory nature of urban (ground)water resources, groundwater's role in Water Sensitive Design (WSD) must be strengthened. Groundwater's overall role in town planning (Spatial Development Frameworks) and, in development planning (Integrated Development Plans), must also be strengthened. Holistic management strategies are required, such as the newly developed Cape Flats Aquifer Management Strategy, which through various means (including actions related to WSUD), aims to remediate the pollution problems and enable use of the resource for bulk supply in ~20 years' time (DWS, 2016a). The integration of groundwater in WSD is critical, as several WSD interventions may not be beneficial to groundwater in particular aquifer settings. For example, reducing stormwater generation through permeable pavements increases infiltration and recharge to the aquifers underlying the urban area, and the impact of this should be understood as the underlying aquifer may no longer be able to accommodate the historical or natural recharge rates. A recent WRC study quantified these effects for Cape Town, and lessons are applicable to this study (Seyler et al., 2016).

Groundwater use by urban areas urgently needs to shift from lack of active management of groundwater and indirect use (of groundwater's assimilative capacity) with negative implications (i.e. pollution from urban activities), to active management leading to the potential for bulk water supply from urban groundwater resources. In cases where urban groundwater will not be used for bulk supply for whatever reason (perhaps more productive aquifers are beyond the urban area), active management of the urban groundwater is still required to protect the resource for other uses (ecological services, garden irrigation, food gardens, as illustrated in DWS, 2016a).

Contributing to this shift is the core motivation for this project; a project that aims to understand the status quo for urban groundwater development and management in South Africa; compare these to best practice for urban groundwater management in order to understand the gaps, and develop a research strategy and innovative technical solutions to address the gaps. The project therefore aims to provide high-level strategies and tools that will lead towards improved uptake of existing recommendations for enhanced groundwater use.

This report emanates from a solicited (directed) Water Research Commission (WRC) project named 'Urban groundwater development and management', project K5/2741.

1.2. FOCUS AREAS AND THEMES

Significant work has been carried out on necessary policy amendments for groundwater protection (Riemann et al., 2017), and on groundwater governance (major progress was made through Riemann et al., 2011), and what appears to be missing is innovative technical solutions that can move metros beyond the current contradictory nature of water in urban areas. Identifying innovative technical solutions has been added to the tools and strategies to be developed (task / deliverable 6). Therefore, the policy requirements developed by this project should focus on whatever is required to implement the innovative technical solutions. An illustration of an innovative technical solution that could be developed: almost 350 l/s (30 Ml/d) of groundwater infiltrates into the Gautrain tunnel (essentially a horizontal infiltration well). The water is generally good quality, although has elevated free chlorine content that is linked to leaking water supply network (Iliso Consulting, 2011). The infiltrating water is collected and pumped to sewer. What are the cost-benefits of diverting this water for use? Does existing policy allow for its use and if not, what amendments would be required?

The project terms of reference referred to urban groundwater, and the terms of reference for the project related urban areas to the metropolitan municipalities (MM), hence a decision was taken at project commencement to (at least initially) focus the project on groundwater in the metropolitan municipalities (Figure 1-1). They each represent different socio-economic-environmental settings, some incorporate large regions of rural areas, and together the major aquifers of South Africa are represented. As such, they are considered a good sample set to assess the state of "urban groundwater" in South Africa.

Urban groundwater is considered here to include the groundwater underlying an urban area, which is prone to contamination by urban activities, and also groundwater available for urban supply which may be outside of the urban area and not affected by urban contamination (the TMG in the Uitenhage basin for bulk supply to Nelson Mandela Metropolitan Municipality, Murray, 2012).

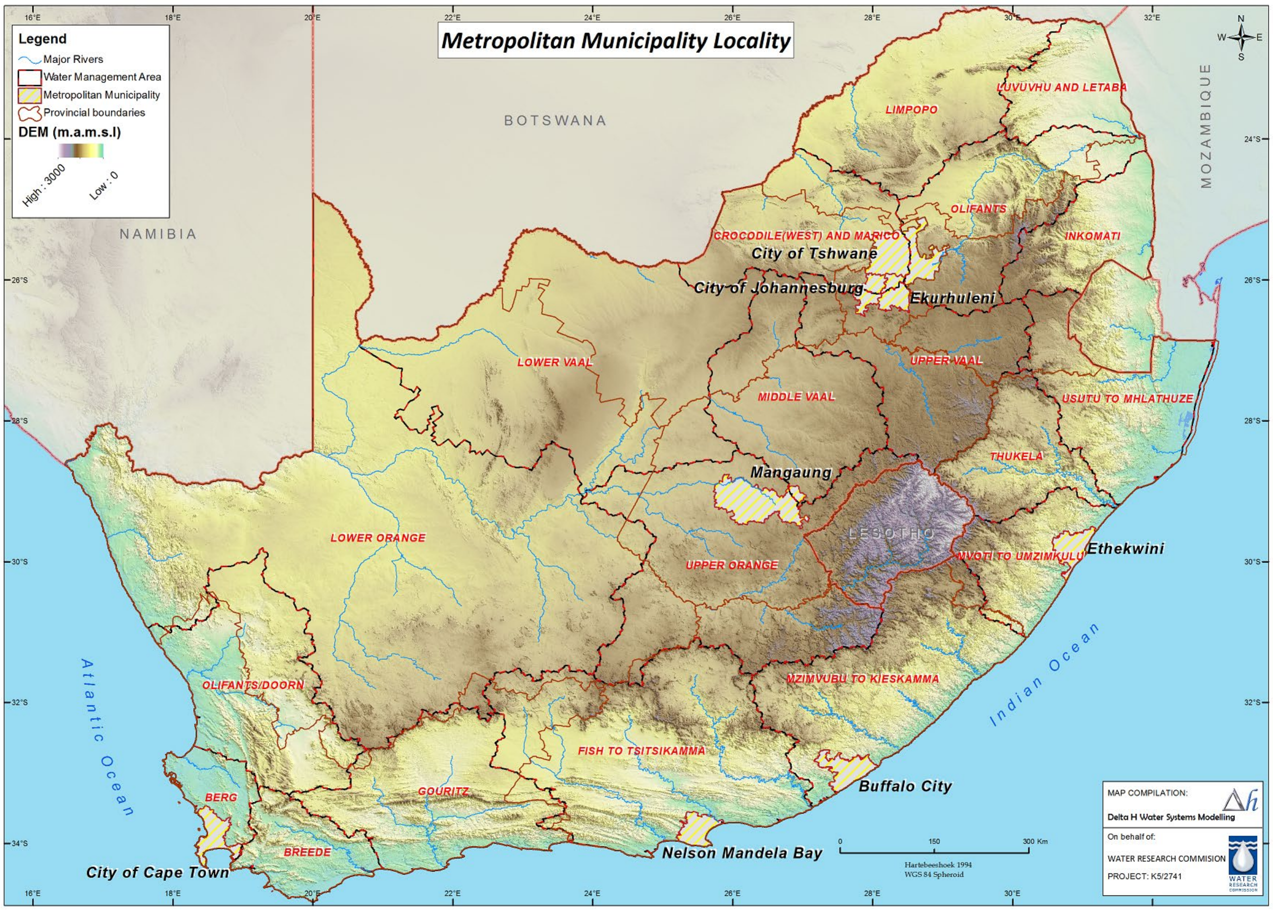


Figure 1-1 Map showing location of the 8 metropolitan municipalities in South Africa, with provincial and water management area boundaries

1.3. RESEARCH AIMS

The aims of the 2-year research project are:

1. Assess the current state-of-the-art and gaps on groundwater resources in urban areas in terms of groundwater demand, groundwater use, groundwater levels, and groundwater quality.
2. Develop and suggest a research strategy for developing and managing urban groundwater resources.

3. Suggest policy requirements that can deliver a holistic resource protection at all government spheres, departments, agencies, industries and communities.
4. Suggest high-level innovative technical solutions for groundwater use in urban areas.

2. STATUS QUO ASSESSMENT

2.1. APPROACH

The assessment of the status quo, or "state-of-the-art" of urban groundwater plans, was designed to assess four elements:

1. The current municipal water requirements and water resources with a focus on municipal groundwater use (if any).
2. The future municipal water requirements compared to available resources, and future water resource interventions, with a focus on groundwater supplies (if any).
3. Characteristics of aquifers relevant to the municipality, i.e. those underlying or downstream of the MM, or distant to the MM but relevant for supply. Specific attention was paid to the urban influences on groundwater (availability and quality).
4. The degree to which groundwater management is mainstreamed into potentially relevant planning processes and structures, commenting on the current state of groundwater planning at the metropolitan municipality.

Explicit information on current municipal groundwater use and plans for future groundwater development in the metropolitan areas is contained within the water master plans or water services development plans (WSDP) and information from these is reflected in the Integrated Development Plan (IDP), and in the Department of Water and Sanitation (DWS)-led reconciliation strategies completed for all major water supply schemes and hence MM's. Where information on urban groundwater is not well documented within these plans (i.e. perhaps better documented in research reports), then these reports were also consulted.

Water resources, and groundwater, is a cross cutting element for which there should not be a single MM plan, but groundwater should be integrated across all potentially relevant planning processes and structures. For example, groundwater is relevant in the IDP for bulk supply plans, and also for any other users to support the planned development. The Spatial Development Framework (SDF) may further contain plans that have impact on groundwater, such as planned development in recharge zones, or promotion of Water Sensitive Design (WSD). The SDF needs to contain the spatial description of any development plans that might be supported by groundwater, for example protecting groundwater fed wetlands due to their ecosystem services, or use of groundwater for irrigation of food gardens. Groundwater also has relevance in by-laws for protection measures the MM may want in addition to the National Water Act (NWA). As such, these documents were assessed per MM to determine the degree to which groundwater management is mainstreamed into potentially relevant planning processes and structures, commenting on the current state of groundwater planning.

The intention of the review is not to simply repeat information, but rather to critically review it from a scientific perspective. For example, if the aquifer characteristics are favourable for development, yet groundwater is not forming part of future development plans, this will be highlighted for further investigation of the potential reasons.

2.2. GROUNDWATER SETTING OF METROPOLITAN MUNICIPALITIES

The eight MMs investigated in this report are located across the whole of South Africa and are characterised by various lithological and climatic environments which directly control the properties of the underlying aquifers and hence the degree to which the groundwater systems may be potentially utilised by the MMs.

The underlying lithology and aquifer types are highly variable across all of the MMs (Figures 2-1 and 2-2). In general, except for the Gauteng MMs (City of Tshwane, City of Johannesburg and Ekurhuleni MMs), all of the MMs are located solely on sedimentary formations with either intergranular or fractured characteristics and have borehole yields ranging between <0.5-2.0 ℓ/s (except for a small area in City of Cape Town MM which has an average yield of up to 5 ℓ/s).

Meanwhile, the Gauteng MMs are more geological diverse and in addition to the sedimentary formations, also include outcrops of both extrusive and intrusive volcanics, tillites and karstic dolomites, the latter of which are associated with high yields of over 5 ℓ/s.

Aquifer recharge is largely correlated with the incoming precipitation patterns (Figure 2-3). Most of the recharge occurs along the south-western and eastern coast of South Africa, therefore eThekwini and City of Cape Town MMs have the highest groundwater recharge. A part of the City of Tshwane also receives high (100-150 mm/a) recharge, due to the high infiltration capacity of dolomites. Meanwhile, the City of Johannesburg, Ekurhuleni, Mangaung and Nelson Mandela Bay MMs have only moderate groundwater recharge rates ranging between 5-65 mm/a.

The national distribution of groundwater use appears related to major aquifer types with the location of dolomites and Table Mountain Group (and associated alluvial sediments) corresponding to the areas of highest registered use (per input area). The registered use at the MMs appears to correlate with population density and the degree of industrialisation (Figure 2-4). The densest groundwater usage can be found in the Gauteng MMs, Mangaung MM and the City of Cape Town MM, while eThekwini, Buffalo City and Nelson Mandela Bay MMs have only marginal groundwater usage density. Furthermore, this distribution appears to reflect not only the underlying aquifer's potential yield, but also the MM's water management strategy and mind-set of groundwater as a viable resource.

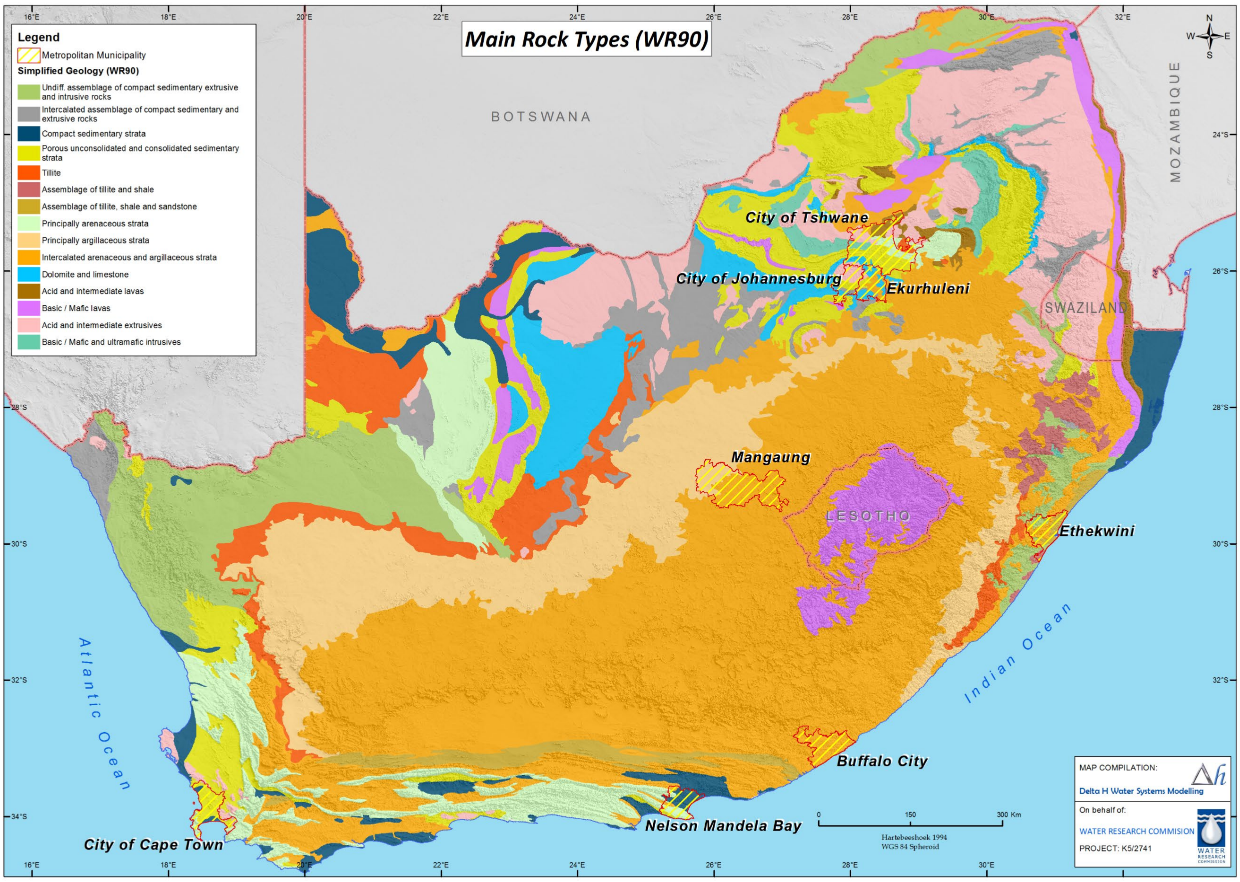


Figure 2-1 **Geological map (rock type) of South Africa (WR90)**

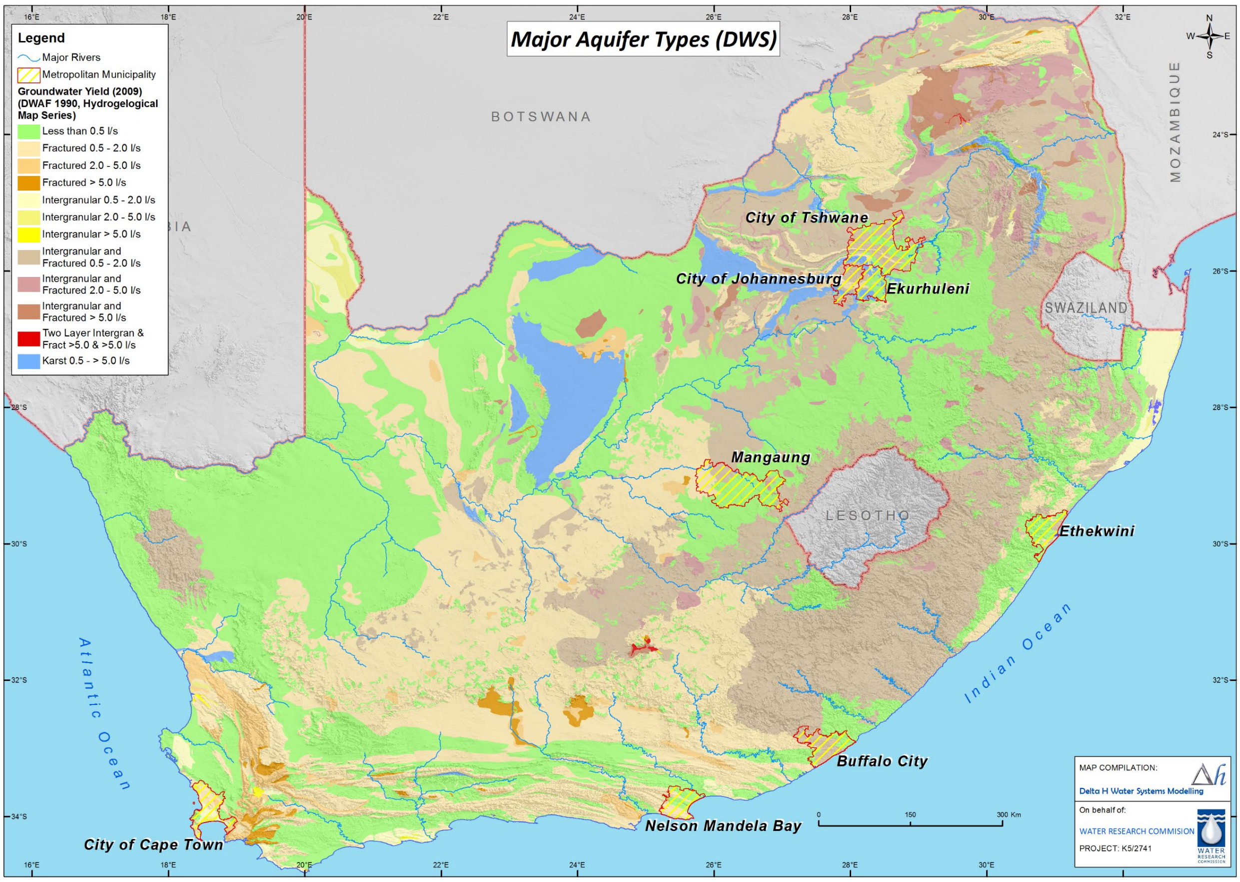


Figure 2-2 **Map of aquifer types in South Africa (DWS)**

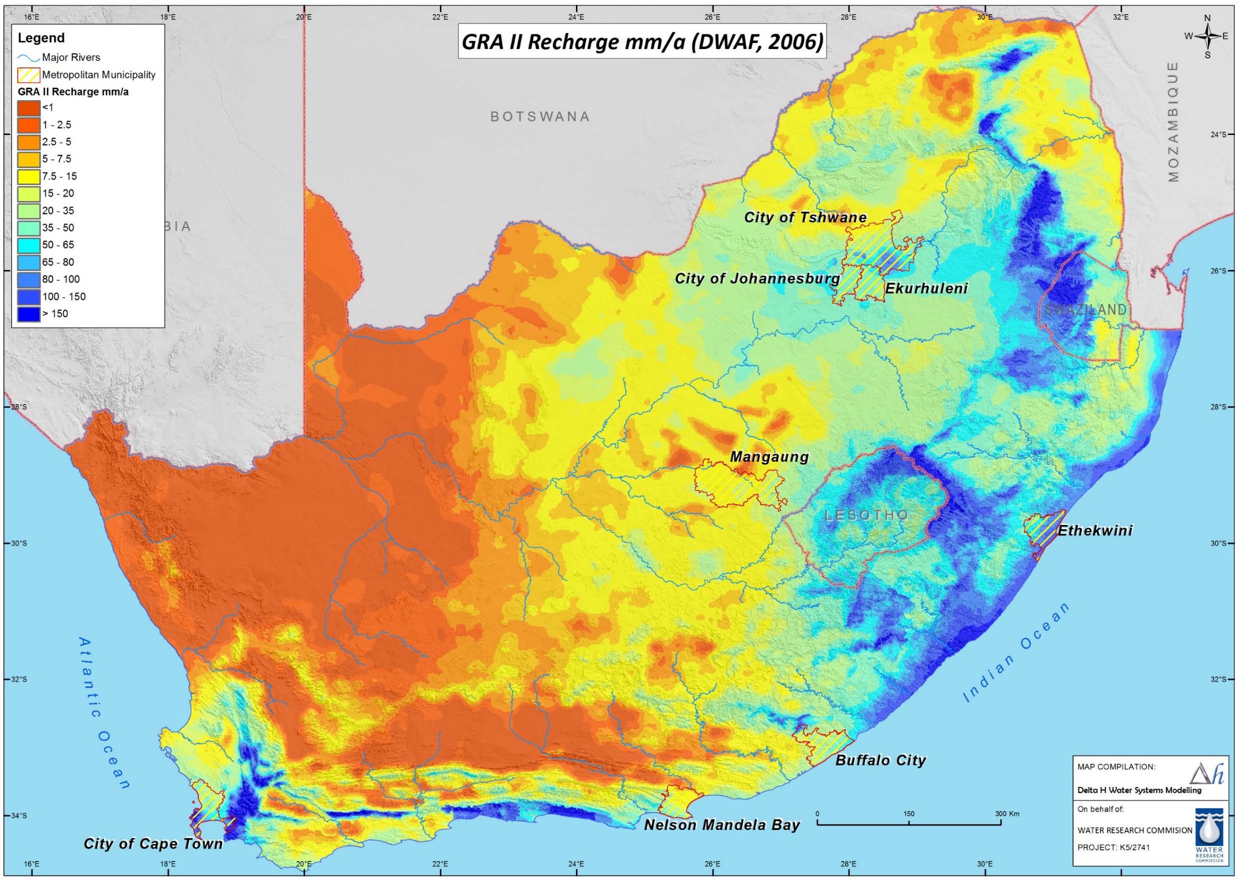


Figure 2-3 **Groundwater recharge in South Africa (GRA II, DWS, 2006)**

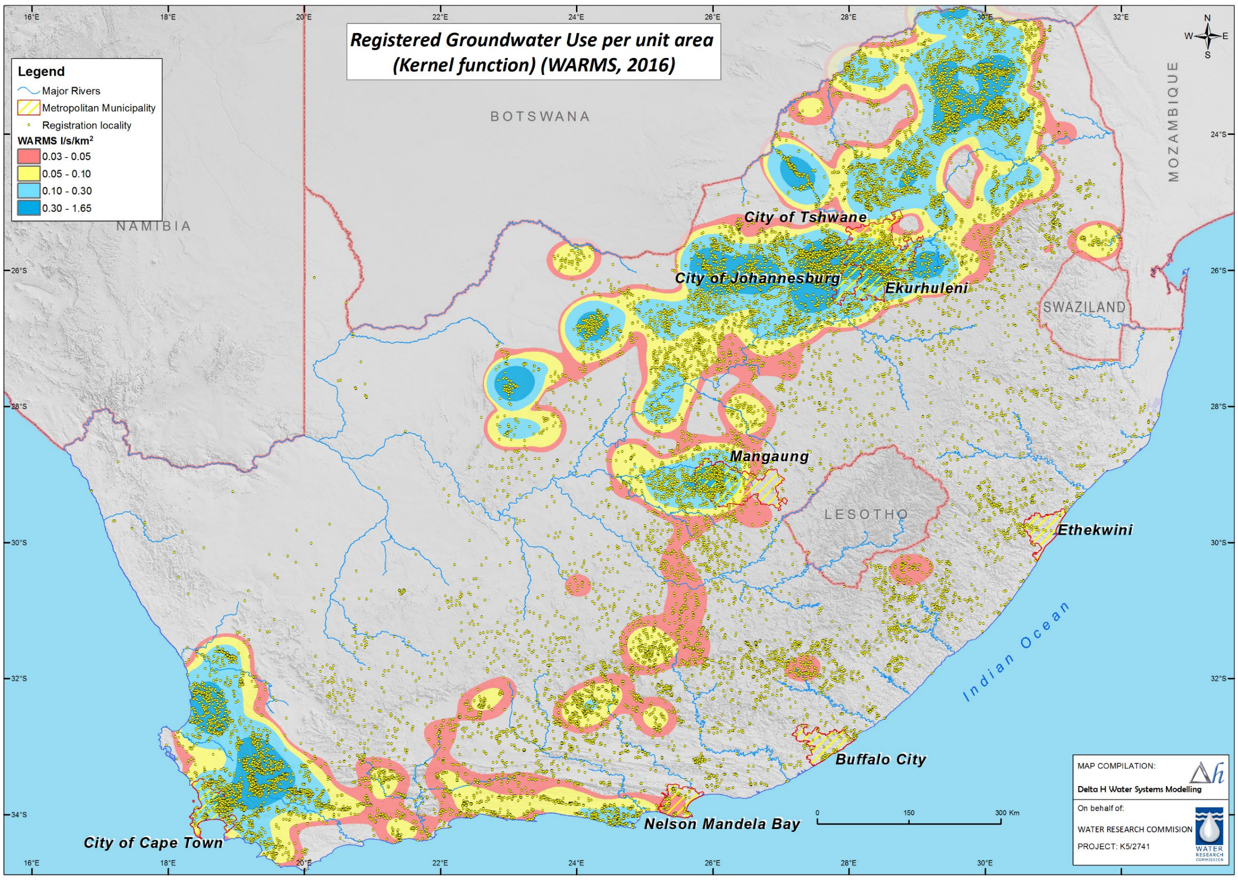


Figure 2-4 Registered groundwater use in South Africa (WARMS, DWS, 2014), as a yield density (l/s/km²)

2.3. Results

2.3.1. City of Johannesburg MM

Status Quo

City of Johannesburg's Metropolitan Municipality (CoJ MM) is provided with water by the Water Service Provider (WSP) Johannesburg Water (JW). All of CoJ's bulk water supply is bought from Rand Water and imported from the Vaal Water Supply System (VWSS), supported by a number of storage and inter-basin transfer schemes from the Upper Vaal Catchment and an international transfer from the Lesotho Highlands Project (CoJ, 2011). 95% of CoJ households have access to piped water (CoJ, 2017), with the rest supplied by private boreholes and tankers; groundwater is also an important source of water in the agricultural and mining sectors (Pietersen et al., 2001).

The Johannesburg hydrogeological map (Barnard, 1999) identifies four aquifer types in the CoJ area:

1. Karstic Malmani Group dolomite aquifers (Chuniespoort Supergroup) which are further categorised into chert-rich Monte Christo and Eccles Formations dolomites, and chert-poor Oaktree, Lyttleton and Frisco Formations dolomites. The aquifer is interspersed by low-permeability vertical and sub-vertical intrusive dykes which compartmentalise the system, and because of the high permeability associated with karstic aquifers, the water table level often does not follow the topography and may in places be more than 100 m below ground's surface (CoJ, 2014b). The karstic dolomite aquifers are the most significant and high-yielding source of groundwater in the CoJ area, with reportedly more than half of the boreholes producing more than 5 ℓ/s and a maximum of 126 ℓ/s (Abiye et al., 2011; CoJ, 2014b). Furthermore, the aquifer is associated with high-yielding springs like the Ngosi Spring in the adjoining West Rand MM yielding >100 ℓ/s (Abiye et al., 2013).

2. Up to 30 m thick intergranular alluvial deposit aquifers located in lowlands along several river valleys, most notably the Crocodile River downstream of the Roodekopjes and Vaalkop dams. While of much more limited spatial extent compared to the dolomites, this aquifer type generally has a strong hydraulic connection with the adjoining river which in most cases results in blow yields of >5 ℓ/s, and a maximum reported yield of 16 ℓ/s (Barnard, 2000).
3. Fractured aquifers of the meta-sedimentary shales and quartzites of the Witwatersrand and Ventersdorp Supergroups and Waterberg Group. In general the yields are <2 ℓ/s, though up to 5 ℓ/s have been reported (Barnard, 2000). The water table generally occurs 1-30 m below ground's surface, and the groundwater quality is good with low salinity (EC= 26-60 mS/m) and suitable for all uses (Barnard, 2000).
4. The intergranular and fractured aquifers associated with the crystalline rocks (mostly granitic gneiss, quartzite and volcanics) of the Basement, Bushveld and Alkaline Complexes, and the Ventersdorp and Transvaal Supergroups, as well as the mudstones, shales and sandstones of the Karoo Supergroup. The yield ranges from 0.01-0.98 ℓ/s for poorly drained crystalline aquifers and up to 1.0-14.6 ℓ/s for weathered and fractured aquifers (Abiye et al., 2011).

Though variable and dependant on local conditions, natural groundwater quality (with the exception of the intergranular and fractured aquifers for which no water quality information could be found) is generally good with low salinity (EC <63 mS/m) and is suitable for all uses (Barnard, 2000). However, elevated levels of nitrate, chloride and sulphate have been introduced into the groundwater systems through agricultural fertilisation, sewage plant effluents, cattle kraals and pit latrines in informal settlements, as well as through various mining activities (Barnard, 2000). Therefore, groundwater quality protection measures, e.g. recharge zone pollution control, are essential in order for the aquifer to be a viable source of water; this is true for all aquifers, but especially so for the high transmissivity, quick-responding and highly vulnerable karstic Malmani Group dolomites.

Extensive processes for the measurement of dolomite groundwater levels and control of dolomite abstractions are provided by the by-laws (CoJ, 2015):

1. The CoJ shall establish, maintain and actively monitor, a dolomite GW level monitoring network of adequate coverage in CoJ;
2. The CoJ can require a private developer to install a monitoring borehole on site, with a servitude established in favour of the CoJ MM;
3. The by-laws enable the CoJ to instruct parties causing drawdown of dolomites to cease abstraction "as is appropriate";
4. Written consent from the Dolomite Risk Management Section is required prior to any groundwater abstraction in dolomite, and boreholes abstracting from dolomite prior to the promulgation of the by-laws must register within 12 months of promulgation, and their licenses (presumably with DWS), may be revoked in the interest of safety concerns.

The purpose of these measures is to maintain safety and prevent the development of sinkholes and land subsidence, but neglects groundwater quality protection from pollution. Furthermore, there are currently no measures within the SDF (CoJ, 2016b) that specifically target protection of groundwater resources or their recharge areas, as well as no mention of groundwater source exploration and exploitation in the water supply reconciliation plans.

CoJ used 584 million m^3/a water in 2015/2016 (CoJ, 2017), which is expected to increase by 20% to 704 million m^3/a in 2030 (high growth projection; DWAF, 2009). The IDP recognises that CoJ is a water insecure city highly reliant on imported water with 98% of the water already allocated, that the growing demand exceeds supply and that the city faces projected water shortages by 2019 (CoJ, 2017). Some of the water stress will be alleviated upon completion of the Lesotho Highlands Scheme Phase 2 by 2020/2021. IDP has stated as one its strategic goals to protect and develop natural resources in a sustainable manner paying special focus on (1) the impact on natural environment, namely the "blue" and "green" natural resources for their ecological integrity, i.e. water bodies, biodiversity areas and open spaces, (2) environmental (including water) pollution, and (3) natural resource (e.g. water) consumption (CoJ, 2017).

The IDP has outlined plans to implement these goals through the following programmes:

1. Open Space Planning, which aims to manage and protect (among other targets) water catchments. This programme recognises that open space provides aquifer recharge and explicitly states the importance of hydrogeological studies and Water Sensitive Design (WSD) for developing an integrated (both surface and groundwater) open space management plan. The importance of open space has also been discussed in the SDF, though without mention of groundwater.
2. Water Resource Management focuses on pollution of waterbodies from sewer spills, acid mine drainage, landfills and other potential pollution sources. It aims to secure identified natural assets and rehabilitate them to ensure they are functioning "properly". However, it only mentions protection of rivers and lakes, and not of aquifers even though they (especially the karstic dolomites) may be just as vulnerable.
3. Water Conservation and Water Demand Management (WCWDM), which aims to implement a range of conservation and demand reduction management strategies. WCWDM, in one form or another, has been promoted in CoJ since the 1980s and still remains a key water management strategy. The recently implemented Pressure Management, Soweto Infrastructure Upgrade and Renewal, and Mains Replacement projects have decreased yearly water demand increase from 2.4% to approximately neutral (CoJ, 2017). The current IDP (CoJ, 2017) outlines three five-year "milestones":
    a. Water conservation in the form of retrofitting, pressure management, pre-paid meters and awareness programmes to reduce the Unaccounted-for Water (i.e. loss through leaks and unbilled water use) to less than 17% by 2021 (compared to >30% in 2011).
    b. Rainwater harvesting as an alternative water source. CoJ has partnered with two private sector initiative – Vodacom and Sasol – projects. The results of these projects indicate that rainwater harvesting, if implemented on hospitals, warehouses, malls, etc. may source significant amounts of yield. For example, a potential of 24 Ml/a of rainwater may be harvested from the Charlotte Maxeke Hospital alone (CoJ, 2014a).
    c. Exploration and expansion of groundwater use, though no current or future projects towards this milestone have been stated.

    A significant budget is allocated to WCWDM (R240 million over 3 years from 2017), however, it is not explicit how much is allocated towards each milestone (CoJ, 2017). One of the biggest challenges facing JW in regard to the implementation of the WCWDM measures is the lack of capacity to effectively enforce water services by-laws (CoJ, 2011). It should be noted that CoJ's water services by-laws are focused towards surface water bodies and the mains and sewage system, and do not provide for groundwater protection nor require the registration of boreholes, with the only reference to groundwater in that the Council must install a monitoring meter if water abstracted from a private borehole is discharged into the sewage disposal system (CoJ, 2008).

With these proposed programmes, the IDP largely follows the path laid down by the CoJ's long-term development strategy '2040 Vision' (CoJ, 2011). One key aspect of this plan regarding water management, however, is missing (though perhaps will be implemented in future IDPs): strategic water reclamation, which aims to promote the use of recycled wastewater, potable water, stormwater and grey water (particularly for new developments). Another potential source of water for industrial use is mine water, provided that affordable treatment options can be effectively implemented. For example, an AMD pumping project commenced in 2012, which provides a yield of 76 million m^3/a (CoJ, 2011). The CoJ has an Acid Mine Drainage technical task team advising its Disaster Management Advisory Forum, however, it deals only with the hazards posed by the AMD, and not of potential water re-use (CoJ, 2017)

WSD principles have been referenced by both IDP and SDF as a means of promoting water security, reduce environmental degradation, mitigate flood risks, and build resilience in the face of climate change; groundwater's role in WSD is not specifically considered (CoJ, 2016b; CoJ, 2017). CoJ also has stormwater by-laws aiming to improve the management of stormwater associated with new developments and to ensure on-site attenuation, slow release and environmental protection (CoJ, 2010).

Opportunities

CoJ is a water insecure city with projected water shortages in the near future, and is currently overly reliant on surface water purchase and import from inter-basin transfer schemes. However, there exists some potential in developing "alternative sources" within the MM itself, including rainwater harvesting, water recycling, and acid mine drainage treatment. The groundwater resources in CoJ are currently largely unexplored and underutilised even though the reported aquifer yields suggest that there exists a significant potential – mainly from the dolomites, but also locally from the alluvial deposits and meta-sedimentary and meta-volcanic rocks – for their development as an augmentation to the bulk water supply, irrigation and/or drought emergency support.

The largest setback facing the use of this resource is the groundwater pollution risk – especially from acid mine drainage ingress into aquifers – and the lack of appropriate groundwater over-abstraction and quality protection measures in the form of borehole registration and monitoring and recharge zone protection. CoJ is unique compared to the other MMs investigated in this study in that it has by-laws specifically targeted at dolomite aquifer protection, however, they are aimed at the ground's structural stability and could be further improved by including provisions for, e.g. groundwater quality monitoring and pollution prevention.

2.3.2. Ekurhuleni MM

Status quo

Ekurhuleni Metropolitan Municipality (EMM) is supplied with bulk water by the water service provider Rand Water which is also responsible for the planning and monitoring of the utilised water sources. Rand Water mainly sources water from the Vaal River Supply System (VWSS). The scheme is further supported by water purchases from neighbouring WSAs such as the City of Johannesburg, as well as by the international inter-basin transfer Lesotho Highlands Scheme (Pieketh et al., 2013; EMM, 2015b). No water is sourced from wastewater re-use, and there is only one reported borehole with a 60 Mm^3/a licensed bulk water abstraction for a semi-rural community, though it is currently inactive (EMM, 2017a). EMM's bulk water supply scheme provides water for 98.5% of the EMM population, with the rest, mainly outside the urban development boundary, supplied through water vendors, stream/river water or private boreholes (EMM, 2018).

EMM is located on a transition zone between a granite batholith on its western border and the Witwatersrand and Transvaal Supergroups dominated by dolomites largely overlain by Karoo Supergroup sediments and interspersed with volcanic intrusions, i.e. dykes and sills (EMM, 2008). According to the hydrogeological map '2526 Johannesburg' (Barnard, 1999), the Witwatersrand Supergroup has a fractured groundwater regime with an approximate yield of 0.5-2.0 ℓ/s, while the karstic Chuniespoort Group dolomites (subgroup of Transvaal Supergroup) is the main aquifer with an approximate yield of >5.0 ℓ/s, while EMM (2008) reports that yields of >10.0 ℓ/s are common. Furthermore, the dolomites are associated with high yielding springs at impermeable boundaries (EMM, 2008). Lastly, the groundwater potential of the Dwyka Group tillites (subgroup of Karoo Supergroup) is generally low (EMM, 2008). Groundwater quality in EMM is generally accepted for any use, though both agricultural and acid mine drainage pollution has been recorded (EMM, 2008).

It is estimated that EMM's bulk water supply requirements will increase from 354 million m^3/a in 2007 (EMM, 2017) to 488 million m^3/a in 2030 (DWAF, 2009; high growth projection). No mention has been made of 'alternative' water sources such as groundwater, wastewater treatment or rainwater harvesting as part of EMM's reconciliation strategies (DWA, 2012d; EMM, 2017a). Instead, the supply requirements are planned to be met by increasing abstraction from VWSS and inter-basin transfer – the Phase 2 of the Lesotho Highlands transfer scheme is expected to become active by 2020/2021 supplying an additional 182 million m^3/a (which could be further improved to 465 million m^3/a), as well as by implementing WC/WDM measures focusing on metering and billing, and reducing unaccounted-for water from 34% to 20% in 10 years (Quantum Leap programme, still in planning stage; EMM, 2017a), partly by replacing much of the existing pipeline and reservoir infrastructure over the next 50 years (EMM, 2015b). A similar scheme – 'Project 15%' aiming to reduce demand by 15% by 2015 in all Gauteng Municipalities through WC/WDM measures – was largely unsuccessful in EMM as the total water demand is still currently increasing following a high demand scenario projection with no WC/WDM interventions; the reason for the failure appears to have been the lack of sufficient budget.

In 2005, EMM introduced a Growth and Development Strategy 2025 (EMM, 2005), though at this point it appears to have been largely superseded by the more regional and long-term Gauteng Development Strategy 2055. Complying with this strategy, EMM's IDP has stated as part of its 2018-2022 goals to protect the natural environment and promote sustainable water use in the form of wastewater reclamation and rain water harvesting policy (EMM, 2018). To this effect, EMM has committed to a WC/WDM programme, grey water recycling for agricultural use, rainwater harvesting policies and pollution prevention to protect the existing water resource capacity (EMM, 2018). However, there has not been any mention of groundwater development or protecting the vulnerable karstic dolomite aquifers even though groundwater pollution hazard has been identified as 'Extremely High' (EMM, 2018). EMM's Water Services Development Plan (WSDP) was presented as part of the IDP and aims to ensure 'viable and sustainable water and wastewater services'. To this effect, it is supported by a WSDP forum comprising representatives from all departments in order to ensure integration of water management (EMM, 2017a).

There are no measures within the SDF that specifically target groundwater resource protection via, e.g. protection of the recharge area (EMM, 2017b). It does, however, recommend that areas with low groundwater potential are more suitable for rainfed crops and livestock production, while areas with high arable potential and available water are retained for irrigated farming purposes; however, it defines water availability only in terms of access to rivers and sewage treatment plants and makes no explicit mention of groundwater as a potential source. Furthermore, it recognises that the impacts of past mining activities (e.g. acid mine drainage) on the environment need to be addressed and rehabilitated (EMM, 2017b).

EMM's SDF (but not IDP) recognises the benefits of WSD and has developed the Ekurhuleni Urban Design Policy Framework which promotes green roofs, retention systems (e.g. swales and retention ponds), rainwater harvesting, permeable paving and channelization of water into planting areas, as well as promotion of water recycling technologies and rainwater collection (EMM, 2017b). Groundwater's role in WSD is not specifically recognised, and the focus is on stormwater management.

EMM has fairly robust by-laws regarding the control of boreholes. The by-laws (EMM, 2001) state that (1) the owner of a borehole, well or wellpoint existing prior to the promulgation of the by-laws, has 90 days to notify EMM of its existence and potential/actual yield, (2) all new boreholes must be approved by the Council with conditions that their locations are clearly marked, unsuccessful boreholes are sealed, and geological information, borehole depth, discharge capacity and standing water levels are recorded, (3) no existing boreholes may be replaced or deepened without Council's consent, and (4) the Council has authority to enter the property to monitor private boreholes and impose a maximum abstraction limit. Lastly, the by-laws also have provisions for prevention of water body pollution, however, it references only streams, reservoirs and aqueducts, and does not include protection of aquifers or boreholes.

Opportunities

EMM's groundwater resource potential is currently unexplored and unquantified even though groundwater may be exploited for bulk water supply, emergency drought support and non-potable uses (e.g. agriculture) which would reduce EMM's reliance on importing surface water from VWSS and inter-basin transfers. Indeed, the existing research indicates that the karstic dolomites, and to a lesser extent the fractured aquifers and tillites, may provide potentially significant amounts of water as evidenced by boreholes in the City of Tshwane from the same lithological units. However, there is currently a critical lack of groundwater protection measures (e.g. recharge zone protection) which are especially important considering the vulnerable and fast-reacting nature of the karstic dolomite system. Indeed, the SDF actively encourages farmland development over areas with available water supply (implying also groundwater) but does not recognise the potential risk it causes to the groundwater quality through agricultural diffuse pollution.

2.3.3. City of Tshwane MM

Status Quo

City of Tshwane (CoT) is the Water Service Authority (WSA) for the Tshwane MM (TMM). Most of the water supply to the Pretoria Water Scheme is provided by Rand Water (71%) which sources water from the Vaal Dam, and by Magalies Water's Roodeplaat Dam (10%). The rest is supplied by TMM-owned Rietvlei Dam (5.9%) and groundwater sources (the Fountains Springs, the Rietvlei and Grootfontein Springs, and the Valhalla and Rietvlei boreholes; 13.1% overall) (DWAF, 2010c). Access to water is good in TMM compared to other MMs, with only 3.4% of the population not having access to piped water (TMM, 2014). In addition to supplying the WSS, groundwater is also used in rural areas at the central north part of the TMM, though no yields have been reported (TMM, 2014).

Groundwater resources in the TMM area are sourced (both as springs and boreholes) from the karstic Malmani dolomites (which are divided into Oaktree, Monte Christo, Lyttelton, Eccles and Frisco subgroups), which are part of the Chuniespoort Group (Transvaal Super Group). The Malmani group is criss-crossed by a series of E-W, N-S and NW-S trending impermeable dykes (Pilanesberg Dyke Swarm) which divide the dolomites into isolated or semi-isolated compartments, e.g. the Fountains West and Fountains East springs belong to different compartments despite being only 500 m apart (Naidoo, 2014). The dolomites are bound to the north by the Pretoria Group (Timeball Hill formation), i.e. weakly metamorphosed mudrocks and quartzitic sandstones; no information could be found on the groundwater potential of this group.

The hydrogeological map '2526 Johannesburg' (Barnard, 1999 as cited in Trollip, 2006) indicates that the TMM region has a good groundwater potential with the median borehole yield exceeding 5 ℓ/s. The main currently exploited sources of groundwater are the East and West Fountains Springs (total of 8.03 million m^3/a), the Rietvlei Spring and borehole (1.46 and 2.92 million m^3/a, respectively), and the Valhalla borehole (0.73 million m^3/a), which in 2009 contributed a total of 13.14 million m^3/a to the TMM's domestic water supply (compared to 100.2 million m^3/a from surface water sources) (DWAF, 2010c). The yield from the Grootfontein Spring is unknown and does not appear to have been included in the recon strategy's groundwater yield calculations.

Various groundwater management measures are included in the by-laws. TMM can 1) by public notice, request notification of all existing or planned boreholes, 2) require owners / occupiers of premises to conduct an Environmental Impact Assessment (EIA) before sinking a borehole, 3) require owners / occupiers of premises with boreholes to obtain approval from the MM for use of borehole for potable supply, and 4) impose conditions for potable use of borehole water. Furthermore, provisions have been made against wasting of water, pollution of the WSS, and to require the owner / occupier of premises with boreholes to provide and maintain a meter measuring the total quantity of water abstracted and discharged as industrial effluent into the sewers. The by-laws grant TMM sufficient control over borehole users to manage groundwater overexploitation and mitigate adverse effects on local ecosystems and other water users in terms of water quantity, however, what is currently lacking are provisions against contamination of the groundwater source (i.e. the aquifer) by non-borehole users, which is especially important considering the vulnerable and fast-reacting nature of the karstic systems (TMM, 2003).

Future TMM water requirements predict (using high growth scenario with the water production rates existing in 2007) a water supply shortfall of 52.65 million m^3/a by 2030 (DWAF, 2010c). A number of reconciliation options have been investigated by the Department of Water Affairs (DWAF, 2010c):

1. Expanding surface water supply from Rand Water (Vaal Dam) and, if the availability of additional sustainable yield is confirmed, from Roodeplaat and Rietvlei Dams. In 2010 it was predicted that this option would be enough to meet the entire 2030 shortfall by sourcing an additional 52.65 million m^3/a by as early as 2015, though no more recent information regarding the current state of affairs could be found.
2. Promoting a WC/WDM meter maintenance and replacement policy (with emphasis on the 200 largest water consumers) which is estimated to save 21.58 million m^3/a by 2030 (high growth prediction).
3. Construction of additional boreholes in the Malmani dolomites to increase the groundwater yield. The groundwater yield available to augment the WSS is conservatively estimated at 5.11 million m^3/a, though the groundwater potential in the area is largely unknown and extensive studies are required to constrain it.
4. Rainwater harvesting was considered but discarded due to assessed low potential.

TMM's long-term development strategy has been outlined in 'Tshwane Vision 2055' which aims to create a 'resilient and resource efficient city' by managing natural resources more effectively and reducing impact on the environment (TMM, 2014). A strong emphasis has been placed on sustainability by:

1. Adapting a holistic management approach of the potable, wastewater and stormwater systems using methods such as minimising wastewater generation, treating urban wastewater and stormwater for re-use opportunities (domestic, industrial and agricultural) and/or discharging to surface waters.
2. Promoting WSD elements such as street side infiltrations (i.e. swales) and enhanced tree pits, which act to reduce stormwater runoff, increase groundwater recharge and filter pollutants.
3. Increase TMM's own water supply by exploring and implementing additional sustainable alternative sources of raw water, e.g. groundwater, water re-use and rainwater harvesting.
4. Reduce dependence on "foreign" water (i.e. Rand Water) as it is judged that Vaal River is not economically sustainable as a potable source of water because of the costs associated with the increasing surface water pollution trends.
5. Promoting green and climate-resilient treatment technologies and infrastructure, it-for-purpose variable quality water that matches use, and demand management / conservation at a personal level (per capita saving).

TMM's SDF is in agreement with Vision 2055's goals by promoting the Green Economy concept, i.e. encouraging sustainable development in all its forms, including sustainable water management (TMM, 2012). Furthermore, it recognises WSD, particularly avoiding the transformation of natural surfaces into impermeable ones to avoid generation of stormwater runoff (geological conditions permitting). The SDF also incorporates and refers to several features of the Gauteng SDF such as informing open space and green system planning decisions by the provincial dolomite belts, soil fertility for purposes of agricultural activity, conservation areas, ridges, watercourses and heritage sites (TMM, 2012).

The reconciliation strategy (discussed above) was proposed 4 years before the release of Vision 2055, hence is not perfectly aligned with the TMM's long-term goals. The two key differences are that the reconciliation strategy aims to solve the water supply shortfall by further increasing reliance on Rand Water and it side-lines alternative water sources like groundwater; the possibility of wastewater and stormwater treatment and re-use was not even considered as a potential recon option despite the claim by Vision 2055 that using the wastewater treatment return flow would reduce MM's dependence on Vaal River from 71% to 54% in 'the near future' (TMM, 2014).

TMM's IDP largely follows the plan set out by Vision 2055. It has set as one of its key goals to protect the natural resources and the environment in a sustainable manner in order to increase and improve service delivery by implementing water conservations measures (pressure and flow controls in the conveyance system), improving communication and education regarding the need to conserve water, maintaining and/or refurbishing bulk water services, encouraging water re-use and investigating options to expand the purification of local water resources (TMM, 2017).

However, there is some disagreement between the two strategic plans. Vision 2055's outlined plan projected that by 2020 the use and reliance upon groundwater would be expanded, while the 2017-2021 IDP makes no explicit mention of groundwater. Furthermore, the IDP does not include plans (or mention the need) for bulk water supply increase by the WSA to meet future water requirements, however, such measures may not (yet) be required if the recon strategy's plan of expanding Rand Water supply by 2015 was successfully implemented, in which case water supply requirements are assumed to be met until 2030 (DWAF, 2010c).

Opportunities
TMM appears to be cognizant of its groundwater resources and has far greater reliance on groundwater for its bulk supply needs (13.1%) than the other MMs investigated in this report. An assessment is required of the groundwater potential and sustainable yields to evaluate the possibility of expanding its use to meet future water supply needs, further decrease reliance upon surface water and provide support for the rural communities and agriculture. Furthermore, considering the high reliance on groundwater, it is critical to create stronger aquifer protection laws and guidelines to protect the highly vulnerable karstic groundwater system from contamination sources such as agricultural pollution, spillages, waste dumping, encroaching brick factories with associated stripping of protective clay layers, etc.

Lastly, TMM recognises the need and the potential beneficial effects of WSD, however, it should develop a more holistic approach and assess the role of the groundwater system, i.e. the effect of WSD stormwater infiltration measures on the groundwater quality and the risk of groundwater flooding.

2.3.4. eThekwini MM

Status Quo
The water supply infrastructure in the eThekwini Metropolitan Municipality (eTMM) is managed by the regional Water Service Provider (WSP) Umgeni Water. The water is currently supplied entirely from surface water sources: 1) 84.1% from Midmar, Albert Falls, Nagle, Henley and Inanda dams on the Mgeni River, 2) 14.4% from the Mearns Weir and Spring Grove Dam on the Mooi River which is part of the Mooi-Mgeni Transfer Scheme (MMTS), and 3) 1.5% from the Hazelmere Dam on the Mdloti River which supplies eTMM's northern suburbs (Le Maitre et al., 2017; DWA, 2009).

eTMM is part of the Lower uThukela Groundwater Region, which is part of the larger Kwazulu-Natal Coastal Foreland Hydrogeological Region. Lower uThukela is characterised by a basement of largely impermeable granites of the Basement Complex and overlain by compacted sedimentary rocks of the Natal Group Sandstone (NGS), which form a secondary / fractured aquifer. Furthermore, NGS is unconformably overlain by the Karoo Supergroup (i.e. Dwyka Group tillite and Ecca Group mudstones / shales) deposits which form a secondary (intergranular and fractured) aquifer (Demlie et al., 2010).

Umgeni Water (2018b) reports NGS as the overall most productive aquifer (median yield 0.33 ℓ/s with the highest percentage (8%) of boreholes yielding >4.5 ℓ/s), followed by the Ecca Group (median yield 0.4 ℓ/s), granite / gneiss basement (median yield 0.18 ℓ/s) and the Dwyka group (median yield 0.14 ℓ/s, 40% dry boreholes) (Umgeni Water, 2018b). Overall, the groundwater resource potential in eTMM is considered moderately poor to marginal with 89% of the boreholes reporting yields less than 3 ℓ/s (Umgeni Water, 2012). However, other studies suggest that the potential yields may be understated. Demlie et al. (2010) report the NGS yield ranging up to 20 ℓ/s with more than half (of 48 analysed) of the boreholes having yield in excess of 3 ℓ/s, and King (1997) found the Dwyka group tillites to have the best development potential, especially where the unit is heavily fractured or faulted.

Local groundwater schemes are largely used to supplement the reticulated surface water WSS for communities and households at the MM boundary and rural areas, mainly for irrigation and stock watering (Umgeni Water, 2018a). In-yard boreholes are reported as the third most important source of water in eTMM, supplying water to 8% of the population (Umgeni Water, 2018a). High yielding boreholes (39 ℓ/s) have been drilled in the Nottingham Road and Rosetta areas, and in the Howick area groundwater is abstracted and bottled for commercial purposes. Groundwater is also used as a domestic water supply at the formal settlement of Mfolweni with a yield of approximately 23 ℓ/s (Umgeni Water, 2018b). Lastly, groundwater is used within eTMM for industrial purposes, however, no yields have been stated (DWAF, 2008d).

The SDF recognises that there is insufficient water supply to deal with any further long-term development as planned by the SDF. The measures taken by SDF to improve the available water yield include upgrading water conveyance infrastructure to reduce leakage, reduce water theft and manage water pressures in the pipe network, as well as to decrease the dependence on river water as the only potable water source by implementing "alternative supply" projects such as re-use of treated water and seawater desalination (see below), as well as rainwater harvesting (eTMM, 2016). The SDF makes no mention of utilising or protecting groundwater either currently or in the future, nor does it acknowledge the role groundwater plays in ensuring healthy ecosystems (e.g. wetlands and river base flows) and urban flooding, instead focusing on the exploitation and protection of surface water resources, especially dams (eTMM, 2016). Umgeni Water (2018) has stated as one its goals to increase the use of groundwater, however, no target yields or time periods have been outlined.

Despite the recent construction of the Spring Grove Dam (as part of the Mooi-Mgeni Transfer Scheme Phase 2 (MMTS-2)), which increased the water yield in the Mgeni System by 60 million m^3/a, the level of assurance of the Mgeni System is still less than 99%, hence water restrictions are very likely if the annual rainfall drops below the long-term average (eTMM, 2016). Potential interventions to ensure assurance of water supply for eTMM were assessed in the reconciliation strategy Phases 1 and 2 (DWAF, 2009; DWA, 2010b, respectively) – neither of which even mention groundwater. It appears no assessment was taken of the potential for groundwater resources, perhaps discounted during inception phase. The recon strategy is based on scenarios involving the implementation and timing of three key sources of water:

1. The uMkhomazi Water Supply Project (uMWP) comprises the construction of a new dam at Smithfield, water conveyance infrastructure and a treatment plant in the uMlaza Valley in order to transfer raw water (estimated yield 220 m^3/a) from the undeveloped uMkhomazi River to the Umgeni Water bulk distribution network in the uMgeni Catchment (DWS, 2015b). Earliest completion and operation date of Phase 1 is 2026 (Umgeni Water, 2018b), and the project has a budget of R20 million between 2018/2019 and R2 680 million between 2018/2019-2041/2042 (eTMM, 2016).

2. Construction of two 150 Mℓ/d (estimated yield 60 m^3/a) seawater desalination plants at Lovu and Tongaat for a total cost of R3 400 million (DWS, 2015b). A feasibility study was completed in 2015 and a pilot plant will run from March 2018 until March 2019 (Umgeni Water, 2018a).

3. Re-use of treated domestic effluent for potable use from the KwaMashu and Northern wastewater treatment with an estimated yield of 45 million m^3/a (DWS, 2015b). A feasibility study was carried out in 2009 and the Environmental Impact Assessment process was begun, however the process was halted due to public concerns and negative sentiment, therefore this option will likely not be pursued further (DWS, 2015b; eTMM, 2016). Nevertheless, potential exists for re-use of treated effluent for industrial use as evidenced by a 45 ML plant operated by the eThekwini Water Services (eTMM, 2016).

The reliance on surface water in eTMM WSS may be explained by the much larger surface runoff resources compared to the groundwater potential, which are (between the Mvoti and uMzimkhulu catchments) 433 million m^3/a and 6 million m^3/a, respectively (Umgeni Water, 2018a). However, as discussed above, the groundwater yields in eTMM may be underestimated. Furthermore, the ambient groundwater quality in the Lower uThukela is generally excellent with 83% of the recorded electrical conductivity measurements being < 450 mg/ℓ (70 mS/m) and therefore does not pose a limit to exploitation (Umgeni Water, 2012). There is very little discussion within eTMM reports of groundwater quality and pollution threats within eTMM, though contamination is likely from typical urban pollution sources, e.g. industrial spillages, leaky sewage, septic tanks and landfill leachates. 12 monitoring boreholes are located within eTMM, however the data quality is poor and discontinuous (DWAF, 2008a).

One of the key IDP's strategic priorities is promoting an environmentally sustainable city and ensuring ecological integrity within the eTMM to protect the ecosystem and finite natural resources by "[Investing] in measures to ensure water security and healthy catchments, rivers and wetlands and continuous improvement in management and sustainable disposal of waste" (eTMM, 2017a, p. 194). IDP promotes increased water resource sustainability by reducing water overconsumption and through whole catchment management approach (including areas outside the MM boundary), therefore promoting cooperation and shared responsibility with adjacent municipalities to optimise catchment management, i.e. alien vegetation clearing and water quality (pollution, illegal extraction and erosion). However, as with the SDF and reconciliation strategy, there is no explicit mention of groundwater or its protection (though the stated goals can be interpreted to loosely apply to groundwater).

By-laws state that the eTMM can, by public notice, request notification of all existing or planned boreholes, as well as, if water abstracted from a borehole is discharged into the Council's sewerage system, to install a meter in the pipe leading from a borehole to its discharge point (eTMM, 2017b). However, no provisions have been made to protect boreholes or groundwater from pollution, to meter the total groundwater abstraction, to sustain sufficiently high / low groundwater levels to provide minimum water requirements for the ecosystems and prevent (basement) flooding.

The reconciliation strategy has some evidence of surface water-based WSD principles such as WC/WDM, rainwater harvesting and effluent re-use (DWS, 2015b). However, these ideas are largely ignored in both SDF and IDP, though they (especially SDF) do recognise the need for improving the efficiency and sustainability of water resource use.

Opportunities

The groundwater in eTMM is currently underutilised with less than 25% of the potentially available groundwater recharge being abstracted (Umgeni Water, 2012). Therefore, there is potential for development of local groundwater abstraction schemes in villages and public institutions, e.g. schools and hospitals, for irrigation purposes, as well as an emergency source of water in case of water shortages; some reports indicate the average yields may be underestimated, so the potential may be much greater than currently believed. However, this would require a more comprehensive assessment of the existing groundwater resource quantity, quality and overall availability for exploitation, a more extensive and detailed groundwater monitoring network, as well as introduction of groundwater resource management and protection in the by-laws, SDF and IDP. Lastly, eTMM would benefit for placing a stronger emphasis on the WSD principles to improve the efficiency of the existing water resources.

2.3.5. City of Cape Town MM

Status Quo

City of Cape Town (CCT) is supplied by the Western Cape Water Supply System (WCWSS): a system of 6 dams, 5 of which are in the Berg River Catchment (Berg River, Voëlvlei, Wemmershoek, Upper and Lower Steenbras Dams) and one of which is in the neighbouring Breede River Catchment (Theewaterskloof Dam) and transfers water into the Berg Catchment. In 2014/15, CCT accounted for 61% of the water requirements on the WCWSS, agriculture 31%, and the remainder made up by smaller towns (Stellenbosch, West Coast District Municipality) (DWS, 2015).

In addition, CCT has several local sources which make up a small portion of the water requirements:

1) Groundwater from the Atlantis Aquifer is abstracted for use in Atlantis.
2) Some springs emanating from the Peninsula aquifer on the Cape Peninsula are captured and diverted for non-potable uses in the city (irrigation of sports fields), alleviating pressure on the WSWSS (CCT, 2012).
3) Thousands of wellpoint boreholes at individual homes.

The low-lying and coastal areas of the CCT MM area is characterised by the marine and aeolian sedimentary deposits of the Sandveld Group (i.e. across the Cape Flats, and the Atlantic seaboard beyond Atlantis). The Sandveld Group overlies the weathered Malmesbury Group and Cape Granite Suite basement rocks, which outcrop in areas such as the Durbanville and Tygerberg Hills, and at the base of the Peninsula (i.e. Lion's Head, Simon's Town) respectively. Areas of rugged topography are formed by the Table Mountain Group (TMG) which unconformably overlies the basement rocks (i.e. forming Table Mountain and the Peninsula, and the Hottentots Holland Mountains and Cape Fold Belt beyond the MM boundary) (Johnson et al., 2006).

Each of these major geological groupings (basement, TMG, Sandveld) form aquifers with varying characteristics. The basement generally forms aquitards (low hydraulic conductivity units) or aquicludes (impermeable units) (Umvoto Africa, 2012). However, where their surfaces are weathered (certainly in outcrop), both form low-yielding (1 ℓ/s) or minor weathered (regolith) or intergranular and fractured aquifers, and basement aquifers are used extensively for irrigation in the Durbanville and Tygerberg Hills and Malmesbury area beyond the MM boundary. The Peninsula Formation of the TMG forms the potentially high yielding (borehole yields of 5-10 ℓ/s) secondary or fractured Peninsula aquifer (Umvoto Africa, 2012). On the Cape Peninsula, the Peninsula Formation is limited in its extent, and exposed on all sides forming mountain slopes, but it does however give rise to several ephemeral and perennial springs, i.e. around Newlands, that are currently utilised to varying degrees (CCT, 2012; GEOSS, 2015). The Peninsula Formation is the target of the TMG aquifer exploration in the Hottentots Mountains for supply to CCT (CCT, 2004).

The various lithologies of the Sandveld Group in the region form the heterogeneous, stratified, (and at the regional scale) primary or intergranular unconfined aquifer known as the Cape Flats aquifer in the Cape Flats region, and the Atlantis aquifer in the Atlantis region (hydraulically connected as one geological unit, but sub-division is possible based on flow divides where the aquifer is thin). The Sandveld aquifers are almost wholly saturated with water levels within a few metres of ground level across most of the area (excluding dunes where water levels will be deeper), and in several cases the ground surface intersects the water table giving rise to wetlands, e.g. Kuils River wetland system (DWAF, 2008a). Rising groundwater tables in response to winter rain is thought to contribute to winter flooding.

Under the WCWSS Reconciliation Strategy several pre-feasibility and feasibility studies were carried out into alternate supplies. Investigations of the potential for the TMGA, in the Hottentot Holland Mountains and beyond, to augment supplies were initiated in 2002 (CCT, 2004), and since then significant exploration drilling and monitoring has been carried out. However, decisions on the implementation of the first major intervention option were continually postponed by CCT (i.e. production from groundwater did not commence), due to CCTs progress made with reducing water requirements via water conservation and water demand management (WC/WDM) measures (DWS, 2014). Nevertheless, the 2016/17 drought has accelerated the implementation of several interventions, and CCT recently commenced exploration drilling in the TMGA, (speech given by De Lille, 1 May 2017), which plans to see 2 Ml/d (23 ℓ/s) abstracted from the TMGA.

Use of the Cape Flats aquifer has received less attention since 2007 than the TMGA, although both groundwater resources were listed in the original WCWSS Reconciliation Strategy (DWAF, 2007). Attention in the Cape Flats got caught up in (and was perhaps side-lined by) the potential for use of treated effluent, as suggestions were made of using the Cape Flats in conjunction with use of treated effluent, i.e. managed aquifer recharge by treated effluent to increase groundwater yields and assist in treatment (DWS, 2015). Interest in the Cape Flats was re-initiated (in terms of bulk supply sources) in ~2014, with the development of the Cape Flats Aquifer Management Strategy, under the WCWSS Recon Study (DWA, 2014; DWS, 2016). This strategy details various suggestions for uses (bulk and other) for groundwater from the Cape Flats, and the potential for bulk supply is predicated by the assumption that groundwater in the Cape Flats is contaminated, and therefore requires remediation prior to use for bulk supply. However, with the 2016/17 drought, use of Cape Flats as a bulk supply source has been brought under the spotlight again, and CCT intends to develop a wellfield in the southern portion.

Developed during the 2016/17 drought, CCT's IDP captures the city's current bulk water supply development plans described above, including planned use of groundwater from the TMGA and the Cape Flats aquifer (CCT, 2017). The IDP recognises the necessity to diversify the current surface water-dominated water supply. The need to create a balance between urban development and environmental protection is recognised as "spatial priority 2" which highlights the need to "make more efficient use of non-renewable resources, such as land, water and biodiversity, including protecting and maintaining existing surface and groundwater resources and sustainably managing existing and future water supplies"(CCT, 2017, p. 54).

The drought has also accelerated interest in the use of the Peninsula-fed springs emanating from Table Mountain. The IDP highlights that CCT intends to increase the use of this resource as a non-potable supply source to alleviate some of the pressure on the City's potable water reserves (CCT, 2017), implementing the recommendations made by GEOSS (2015).

The SDF is the primary input strategy towards the IDP, and vice versa: the plans within an IDP are to be spatially delineated in the SDF. Water resources, including groundwater resources, are closely integrated to all relevant aspects of the SDF (CCT, 2012). The bullets below demonstrate how water (specifically groundwater) features in the SDF:

- Natural and cultural environment and resource capacity is listed as a key driver of urban growth in Cape Town;
    - As part of this discussion, the future potential supply from the TMGA is referenced: "Water from groundwater sources (especially the Table Mountain Group Aquifer, located to the east of the Cape Fold Mountains), water recycling, and sea water desalination are potential ways of accommodating future water demand" (CCT, 2012, p. 22)
    - The impact that urbanisation has on the natural resource capacity is also noted under hydrological and hydraulic impacts: "Through development and the associated hardening of surfaces (such as the paving of lawns and construction of carports), hydrological catchment areas are becoming increasingly impervious to water, resulting in increasing stormwater runoff and flood risks in certain catchment areas" (CCT, 2012, p. 23).
- The implications for spatial planning of these key drivers of urban growth in Cape Town are discussed. It is stated that "new urban development should be directed towards locations where its impact on critical biodiversity areas, water bodies and agricultural areas will be minimised" (CCT, 2012, p. 27).
- Following drivers of growth, numerous strategies are constructed each with associated policy statements and policy guidelines.
    - Key strategy 1 is to plan for employment, and improve access to economic opportunities. Transport systems are a key part of this and policy 14 details parking policies. It is listed that "all parking areas and transport depots should comply with water-sensitive urban design (WSUD) principles" (CCT, 2012, p. 48), which is a measure that would limit the potential reduction in recharge by converting to hard surfaces.
    - Key strategy 2 is to manage urban growth, and create a balance between urban development and environmental protection. It is recognised that "the protection and maintenance of existing surface

water and groundwater resources and the sustainable sourcing and use of existing and future water supplies are critical" (CCT, 2012, p. 52). Policy 26 aims to achieve this and is detailed in Table 2-1. The associated Map 5.6 outlines areas of high and moderate "aquifer productivity" (not necessarily recharge zones).

Table 2-1 Policy 26 of CCT SDF (reproduced from CCT, 2012, p. 62)

Policy Statement	What this means / requires	Policy Guidelines
Policy 26 Reduce the impact of urban development on river systems, wetlands, aquifers, aquifer recharge areas and discharge areas	The City will ensure that the water flow requirements an quality of river systems and wetlands, as well as their ability to support their natural flora and fauna, are not unduly compromised, by: • identifying adequate floodlines and ecological buffers / setback lines to permit the full range of flow regimes and flood attenuation, and protect the integrity and functioning of adjacent aquatic ecosystems; • identifying adequate measures to reduce impacts such as quality impairment and erosion to all receiving surface and groundwater systems; • promote the sustainable use and sourcing of water supply; • mapping all aquifer recharge areas; and • policing of illegal water extraction.	P26.1 All land use management decisions should be guided by the development guidelines in the relevant District SDP. P26.2 Land use management decisions should take the following WSUD principles into account: • maintain the natural hydrological behaviours of catchments; • protect water quality of surface and groundwater systems • minimise demand on the potable water supply system; • minimise sewage discharges into the natural environment; and • integrate water with the landscape to enhance visual, social, cultural and ecological values. P26.3 Development should not compromise the freshwater ecosystems, especially the high productivity aquifers and their ability to be utilised as water sources.

Water bodies are incorporated in the spatial planning categories. Planning category "Core 2" includes ecological corridors; critical ecological support areas; significant coastal and dune protection zones; major river corridors and water bodies, excluding wastewater treatment works (CCT, 2012, p. 81). To give effect to policy 26 (and others), it is planned that Environmental Impact Management Zones (EIMZs) be identified in the District SDFs, and that the EIMZs include moderately and highly productive aquifers.

Policy 14 within key strategy 1, listed above, references CCTs commitment to WSD. The CCT has embraced the principles of WSD and is promoting them throughout Cape Town (CCT, 2014). The city has established an internal WSD group that cross-cuts the relevant departments, and has developed and implemented a policy requiring new developments to use surfaces that minimise contribution to stormwater drains and maximise infiltration. Much WSD research carried out by the University of Cape Town has centred on Cape Town as a case study site. Taking into account various WSD type interventions that might be proposed for Cape Town, and the proposed uses of CFA described in the DWS (2016) strategy, a research study was recently completed that tested the feasibility of various WSD type scenarios, including bulk use of the Cape Flats without and in conjunction with MAR of treated effluent (Seyler et al., 2016). In the coming years (and as this project develops) CCT should implement the various recommendations made by DWS (2016) and Seyler et al. (2016).

Opportunities

Compared to other MMs, groundwater is well incorporated into planning in CCT, with current use of groundwater, plans to considerably increase the use of groundwater for bulk supply, and other plans for use of groundwater also in place (dispersed supply for non-potable uses). The potential exists to use CCT as a best practice study for comparison to other MMs in the next phase of the project.

Nevertheless, there are improvements CCT can make with respect to groundwater use and planning. The following aspects are worth considering:

- Although the protection of current water resources is mentioned in the IDP, there is no explicit mention of the Atlantis aquifer and its current infrastructure-related challenges and under-utilisation. Use of the resource should be maximised, which requires infrastructure investment. In terms of spatial development, the recharge area for the Atlantis aquifer is not explicitly defined and protected, and invasions of alien vegetation will undoubtedly be reducing potential infiltration rates.
- The IDP does not describe or promote uses of groundwater other than bulk supply, i.e. those uses listed in the Cape Flats Aquifer Management Strategy (irrigation of gardens, schools, sport fields, parks and open spaces, firefighting (DWS, 2016)) are not repeated, and nor are they included in the SDF. Furthermore, the issues associated with excessive and unregulated use of private boreholes and wellpoints are not recognised.
- The intention to protect water resources for current and future supply in the IDP and SDF is not accompanied by detailed plans, even though information is currently known that would support more detailed planning. For example, the risk to groundwater quality from informal settlements is known, yet not used to prioritise those areas that require upgrading of current services (i.e. those in most productive groundwater areas / closest to locations of potential future use).
- Related to the protection of groundwater resources, although areas of moderate and high aquifer productivity are listed in the SDF:
    - If these areas are to be linked to specific management or land use planning criteria in future, it should be borne in mind that these areas are not necessarily equivalent to the recharge area for these sources, particularly in the case of the TMGA aquifer. A preferable approach would be to identify current and future likely target areas for bulk supply, identify the capture zone, and ensure this is protected.
    - These only cover the area within the CCT MM, and since proposed TMGA resources are beyond the MM boundary, CCT should expand this assessment to include recharge areas to the proposed TMGA, in order to assess their threats and management requirements.

2.3.6. Nelson Mandela Bay MM

Status Quo

In NMBM and surrounding small towns, irrigation users are supplied by the Amatole Water Supply System (AWSS), which includes dams in several basins, and a transfer from the Orange River. The water requirements of the area supplied by the AWSS matched the available yield (at 98% assurance of supply) in 2009 (no more recent information could be found), and with projected increases in water requirements, the interventions proposed include surface water schemes, groundwater use, use of treated effluent, and desalination (DWA, 2011). With the 2009/10 drought, several water supply schemes were fast-tracked for emergency implementation.

The AWSS supply area lies in the eastern-most extent of the Cape Fold Belt, with the resistant quartzites of the TMG forming the mountains and ridges, and valleys infilled with younger sediments of the Cretaceous. The TMG outcrops in the mountain ranges ~40-60 km northwest of Port Elizabeth (recharge area for the TMG), with the sediments of the Cretaceous age Uitenhage and Algoa Group overlying the TMG in the Uitenhage Basin (largely aquitard). These cretaceous sediments are in turn overlain in places by quaternary alluvial sediments (primary aquifer) (Maclear, 2001). The TMG is confined by the overlying Cretaceous sediments and is artesian beneath the basin, hence the area is referred to widely as the Uitenhage Artesian Basin. The currently-used Uitenhage spring emanates from the TMG at the base of the foot of the Grootwinterhoekberge, approximately 8 km north-northeast of Uitenhage town (Maclear, 2001).

Goedhart et al. (2004) identified several groundwater domains in the area from Humansdorp to Alexandria (broadly the area supplied by the AWSS), including several within the Uitenhage Artesian Basin and some beyond it. Seven domains were investigated as part of the reconciliation study, and the combined available groundwater yield has been estimated at 30 million m^3/a based on groundwater balance approaches (availability some portion of recharge minus use minus groundwater contribution to baseflow) (Murray, 2012). Of these domains, the 4 with highest potential have been incorporated into the reconciliation strategy for groundwater development: Bushy Park, Van Stadens, Coega, and Jeffreys Arch, with Bushy Park being investigated during the 2009/10 drought (DWA, 2011).

Of these four domains, the Coega Ridge area, within the Uitenhage Artesian Basin, is the most important. It is an area formed by isolated koppies (inliers) of TMG projecting through the soft Cretaceous strata in the coastal area and along Coega Ridge (Maclear, 2001). The ridge is the south-eastern extension of the TMG outcrop in the Grootwinterhoekberge. The Coega Ridge has the highest estimated groundwater yield (8 million m^3/a), and hence was prioritised for development, and several high yielding boreholes have been drilled. The Coega Ridge exploration is ongoing, with 15% of the planned boreholes completed in 2017 (NMBM, 2017). The IDP includes completion of the scheme as a Key Performance Indicator under the theme "improved water sustainability" (NMBM, 2017).

Importantly, these reconciliation study plans for groundwater development are adopted in the IDP, and following budgets for groundwater exploration are set aside: R19 million for 2017-18; R12 million for 2018-19; and R23 million for 2019-2020. Furthermore, the IDP lists "Groundwater Problem Elimination Northern Areas" as a budget item totalling R1 million, however no more information is given (as to the problem).

In addition to direct use of groundwater for bulk supply, the possibility of using quaternary sand deposits close to the coastline to filter (pre-treated) effluent from the Fish Sands WWTW for re-use has been investigated (Murray, 2013). DWA (2013b) state that "The sands south of the harbour are too thin and unsuitable. Three areas north of the harbour are being further investigated to establish their thicknesses. If suitable, wastewater could be fed into the sands at the top of the slope, and withdrawn several hundred meters down-slope after natural filtration" (p. 3).

However, there is no explicit mention of the existing Uitenhage Spring and protection of the associated aquifer, and its recharge area, in the Water Services Master Plan, the SDF, the IDP, or the by-laws (NMBM, 2006; SDF; NMBM, 2017; by-laws, respectively).

Other uses of groundwater (dispersed supply, use by ecology) or other protection measures (protection of aquifers underlying urban areas to ensure they meet ecological requirements, protection of urban pollution), are not discussed in the SDF or IDP. Although the NMBM appears to be actively seeking innovative technologies for water resources, wanting to improve resilience through diversification of supply (demonstrated through the plans for re-use, considering re-use and groundwater conjunctively), there is no specific discussion of incorporating Water Sensitive Design measures in future development plans. Wetlands, and ecological corridors, and green infrastructure are mentioned and protected with various measures in the SDF, however the groundwater resources potentially supporting green infrastructure (i.e. supplying a particular wetland) is not described, delineated, and similarly protected.

The by-laws protect any groundwater supply sources, through several measures controlling "municipal water services infrastructure" (NMBM, 2010). However, it is not clear what area this would apply to, i.e. perhaps the wellfield / borehole / spring infrastructure only, rather than the resource. Measures are in place that would enable the MM to manage private (potentially competing) use of groundwater resources, as the MM has the ability to impose conditions on use (in addition to the conditions that would be in a Water Use Licence from DWS, according to the NWA). However, there are no measures to protect groundwater resource quality, where that groundwater is not part of municipal water services infrastructure. The NMBM by-laws refer to preventing pollution of a water supply system, whereas the Buffalo City MM by-laws refer to prevention of pollution of any natural water course including groundwater.

Opportunities

Groundwater is currently used for supply in NMBM and significantly increased use for bulk supply is part of the future planned resources. All formal households have access to water through an erf connection and all households located in informal settlements within the urban edge receive water through communal standpipes or water tank within 200 m (NMBM, 2017). Nevertheless, there are several opportunities for interventions to improve upon or optimise urban groundwater management protection in NMBM. These include:

1. *Best practice management of groundwater resources for bulk supply.* Certain aspects of the groundwater supply are unknown, which could be assessed analytically or ideally with a numerical groundwater model, including (1) the impact of abstraction from the TMG at Coega Ridge on the existing upstream discharge at Uitenhage Springs, and (2) the risk of saline intrusion from abstraction at Coega Ridge.
2. *Develop (and pilot) the necessary agreements for management of resources beyond area of jurisdiction.* The recharge area for the TMG aquifers supplying the Uitenhage Spring and targeted at Coega Ridge, falls outside of the MM boundary, in the Grootwinterhoek Mountains. The MM therefore has no easy mechanisms to control activities in the recharge area, as it is not contained within the SDF or IDP. Some of the land is a designated nature reserve (Groendal Nature Reserve), but not all is protected. The Uitenhage Artesian Basin was a declared Government Control Area, and the area (including recharge area) has also been delineated as a strategic groundwater source area (Le Maitre et al., 2017). Work to establish guidelines for protection of strategic groundwater source areas is currently occurring in parallel to this project and are expected to be completed by March 2018. There may be an opportunity to implement the recommendations coming from Le Maitre et al. (2017) for protection of GWSAs in the NMBM area. This could include measures such as NMBM making agreements with landowners in the recharge area regarding alien vegetation clearing, limiting the use of pesticides, etc.

2.3.7. Mangaung MM

Status Quo

Mangaung Metropolitan Municipality (MMM) is supplied by Bloem Water from the Greater Bloemfontein Water Supply System (GBWSS), which includes the following sources: 1) the Welbedacht Dam and Knellpoort off-channel storage dam on the Caledon River, and 2) the Maselspoort Scheme on the Modder River, which includes the Rustfontein and Mockes Dams, which receive water transferred from the Caledon River via the Novo Transfer Pump Station at Knellpoort Dam.

Fractured and intergranular / fractured aquifers of the Karoo Supergroup (consisting of sandstones, shales and mudstones) underlie MMM. The Karoo Supergroup in the MMM (and beyond) has been extensively intruded by dolerite sills and dykes, particularly in the north and east of MMM. Groundwater availability in Karoo formations is generally limited, due to high clay content (low permeability), however Steyl et al. (2011) highlight that groundwater availability can significantly increase:

- at the contact zone between the dolerites and the sandstone lithologies;
- in fractured fault zones, especially if related to tensional stresses;
- at zones of extensive weathering, which often develop in dolerite sills that are situated in low lying and well drained areas.

Groundwater augments the domestic supply in several small towns within the area supplied by GBWSS (Wepener, Dewetsdorp, Reddersburg, Edenburg, and Excelsior). These towns lie beyond the MMM boundary, and within the MMM, groundwater is only used for domestic supply by rural villages surrounding Thaba Nchu, via boreholes owned by Bloem Water (DWA, 2010; Akwensioge, 2012). In addition, groundwater is used across MMM by individuals for irrigation of gardens in residential areas and used extensively for agricultural purposes in the Bainsvlei / Kalkveld area (small holdings within the MMM southwest of Bloemfontein) (DWA, 2012c). Groundwater is also utilised by small industries for bottling of water as well as micro-irrigation of vegetables and nurseries (garden centres), which are in close proximity to the MMM boundaries (DWA, 2012c).

Water requirements of the GBWSS reached available yields in 2010, and the reconciliation strategy proposes various interventions to increase water supply. Groundwater resources are not part of the final recommended interventions for the MMM area of the GBWSS, only for the small towns beyond the MMM boundary. The reconciliation strategy study did however consider "groundwater development in Bloemfontein" as a potential intervention in the preliminary screening. The possibility of Bloemfontein using groundwater in the Bainsvlei irrigation area, an area with "known source of groundwater in relative large volumes" (DWA, 2010, p. 33), was discussed. A potential yield of 28 million m^3/a was listed based on recharge rates to the area. However, the option was discounted because:

i. accessing the yield would require 645 boreholes (the study appears to assume a borehole yield of 1.4 ℓ/s);
ii. a wellfield would cover a significant area;
iii. groundwater would need to be pumped 15 to 20 km to Bloemfontein;
iv. abstraction by the MMM would "result in the cessation of all commercial irrigation activities" (DWA, 2010); and
v. lack of MMM owned land in the area (DWA, 2010).

No groundwater resource assessment was completed (or was completed but is not published) to support the above listed reasons. The borehole yield assumed in reason (i) is considered an underestimate (see below), and the claim of impact on irrigation activities requires an assessment to determine aquifer yield, the yields used and allocated to agriculture, the remaining available yield at which impacts on existing users are acceptable. The conveyance of groundwater 15-20 km should not be considered a deciding factor, given the surface water pipeline lengths in the GBWSS (>50 km from Welbedacht dam with several 5-20 km pipelines connecting the other small dams). The potential for the development of wellfields along existing pipeline routes is also flagged as a possibility, however it was not selected for further study and no reasons were given (DWA, 2010).

Steyl et al. (2011) considered the potential groundwater contribution to bulk supply for Bloemfontein (considering a smaller area around the city only, not the entire MMM), based on a presentation of recharge values, and an analysis of dolerite structures. They conclude that around 1.4 million m^3/a groundwater could be available from boreholes targeting dolerite structures within the city, with a dispersed array of ~67 boreholes, at 250 m intervals. The calculation appears to be based on an average borehole yield of 0.7 ℓ/s (pumping continually), which is a significant underestimate. Boreholes drilled by the Central University of Technology target the contact with a dolerite dyke and yield 17 ℓ/s and 11 ℓ/s (Steyl et al., 2011). Steyl et al. (2011) conclude that groundwater is underutilised by MMM and could be a viable source for bulk supply, or at least drought support.

The studies carried out to date have not adequately established the potential for groundwater to augment bulk water supplies to MMM, and the disregard of groundwater from future water resource interventions appears unjustified.

Akwensioge (2012) demonstrates that the groundwater supplies in the Thaba Nchu rural areas have been significantly affected by nitrate contamination, likely from pit latrines, kraals, and agricultural land. 65% of the groundwater samples collected in the southern villages of Thaba Nchu had nitrate concentrations that exceeded the recommended drinking water standards limit of < 11 mg/L. Measures are in place that would enable the MM to manage private use of groundwater resources, as the MM has the ability to impose conditions on use (in addition to the conditions that would be in a Water Use Licence from DWS, according to the NWA). However, there are no measures to protect groundwater resource quality (or restriction of activities in the vicinity of boreholes, i.e. pit latrines in Thaba Nchu). The MMM by-laws refer to preventing pollution of a water supply system, whereas the Buffalo City MM by-laws refer to prevention of pollution of any natural water course including groundwater.

Although the IDP promotes various measures that are in line with Water Sensitive Design (rainwater harvesting, promotion of WC/WDM), there is no explicit promotion of WSD (MMM, 2017). The IDP lists "Water scarcity and lack of security of water supply from source" as a significant threat to MMM, and lists implementation of a bulk water supply augmentation scheme as a priority. However, there is no real discussion of alternative sources, or diversification of the surface water dominated supply from Bloem Water and the GBWSS. All 'opportunities' listed relate to increased surface water supplies (from Gariep Dam), and to rainwater harvesting (MMM, 2017).

Opportunities

There is a need to strengthen bulk water supply and water resources planning at MMM. An assessment is required of groundwater availability for bulk supplies and / or other uses. Groundwater could play a role in improving the water supply to currently unserved areas. There are also preliminary plans to encourage subsistence farmers to move towards commercial production, and three commonages have been identified for this purpose (MMM, 2017). The potential for groundwater to support agriculture should be assessed.

2.3.8. Buffalo City MM

Status Quo

Groundwater is currently used as the sole supply source in several coastal towns within the MM that are not serviced by the Amatole Bulk Water Supply Scheme (ABWSS) (6800 households; FutureWorks, 2014). Very little information could be sourced on the towns supplied by groundwater, the status of this groundwater supply, and their potential future supply sources. The towns / villages are not included in the DWS All Towns Reconciliation Strategy Study, because it falls within an MM.

Apart from the groundwater use by coastal towns, groundwater is generally not seen as a current nor future bulk supply source, largely because: 1) the existing surface water supply from the ABWSS is sufficient to provide water requirements until 2032 if current operating rules are amended and WC/WDM measures are implemented, and 2) because there is a lack of significant aquifers in the region, and local groundwater yields are low (DWAF, 2008a).

A desktop groundwater investigation was undertaken as part of the ABWSS reconciliation strategy study, to determine the potential for groundwater use, and for integrating groundwater to the ABWSS. The area is underlain by the intergranular and fractured aquifers of the Beaufort Group of the Karoo Supergroup (mudstone and subordinate sandstone). The majority of existing groundwater use is for domestic supply, either for individual households or small villages. There are no large-scale irrigation supply schemes in the area which are supplied by groundwater. The analysis conducted showed that structural features such as dolerite dyke intrusions and faulting have the dominant control on increasing borehole yields (DWAF, 2008a). The WSDP (BCMM, 2015b) provides little information on the quality of groundwater resources except that they are generally poor (high EC). Water quality data assessed by DWAF (2008) was only available for boreholes at the wastewater treatment works (WWTW) and at industrial land at the Industrial Development Zone (IDZ), and show some contamination.

A simplified groundwater balance was presented for the ABWSS area, and calculated that available groundwater resources sum to 41.8 million m^3/a, based on recharge (46.0 million m^3/a) minus groundwater contribution to baseflow (4.2 million m^3/a) (DWAF, 2008a). However, it was cautioned that while the theoretically available groundwater is significant, it is dispersed over a significant area, and aquifers appear to be limited and yields from boreholes to date have generally been low, i.e. "harvesting" this yield for bulk contribution to ABWSS is not realistic. The WSDP (BCMM, 2015b) suggests that the groundwater potential in Buffalo City MM is generally not good, resulting in low borehole yields (generally below 2 ℓ/s) and high salinity waters. Based on the distribution of the groundwater balance results, and the distribution of boreholes with yields greater than 5 ℓ/s, DWAF (2008) identified R30E as the "most promising quaternary catchment", suggesting that groundwater is targeted along the Nahoon River, upstream of the Nahoon Dam. The estimates for groundwater yield in the area range from 0.2 to 1.2 million m^3/a, and conjunctive use is suggested as a possibility.

No other uses of groundwater (small scale or dispersed use, for irrigation or other, support and protection of groundwater recharge areas where these maintain ecologically important wetlands or other ecosystem services) are contained in various development documents (IDP, SDF) (Table 2-3). There are some fairly generic protection mechanisms listed in the by-laws.

Opportunities
No other uses of groundwater are planned, however the IDP highlights that (only) 89.93% of households have access to piped water in dwelling/ yard or within 200 m, and that 2 658 households get water at a distance more than 200 m from the yard (BCMM, 2016). The IDP reflects that plans exist to extend the services from ABWSS in several bulk water provision projects, presumably to reach the currently un-serviced dwellings and increase the percent of households with piped water in dwelling or at least within 200 m. It is not clear (at this stage, from the documents), whether there is potential (or whether the potential has yet been assessed) for dispersed groundwater use to service currently un-serviced dwellings. It is likely that this was assessed as part of the reconciliation strategy (DWAF, 2008a) but needs confirmation.

The IDP does list 17 sports fields (out of 84) as having a current water supply challenge (BCMM, 2016). The potential for dispersed groundwater use to service these 17 sports fields should be assessed.

The SDF (and subsequently the IDP) highlights that "further investment in rural areas over and above the basic level of service prescribed by the constitution should ideally be aimed at those rural areas where water, soils and topography could sustain 'productive agricultural environments'. It is further proposed that market garden living environments be supported where commercial scale agriculture could be sustained" (BCMM, 2013, p. xii). Whether these areas have been identified is not clear, and the potential for groundwater use to support small-scale agricultural use should be assessed (to determine locations, yields, etc.).

2.3.9. Summary

The analysis of status quo for urban groundwater is summarised over Table 2-2 and Table 2-3. Table 2-2 describes the current and future bulk supply to the metropolitan municipalities, with a focus on groundwater sources. Table 2-3 assesses groundwater's integration to municipal planning, protection and management by considering:

1) The key urban impacts on groundwater in the MM
2) Whether Water Sensitive Design (WSD) is planned for / embraced by the MM, and whether groundwater's role in WSD is acknowledged or planned for
3) Whether the MM has identified potential uses of urban groundwater in their IDP and / or SDF other than bulk supply (such as dispersed use for garden watering or irrigation, or identification and protection of groundwater where its discharge supports ecologically sensitive or important areas), and whether the SDF includes protection mechanisms to enable this use.
4) Whether the MM has any additional protection mechanisms for groundwater, i.e. in their by-laws

Table 2-2 shows that five metropolitan municipalities currently use groundwater resources to varying degrees including City of Tshwane, Nelson Mandela Bay Municipality (NMBM), City of Cape Town (CCT), Buffalo City (domestic supply to coastal villages) and Mangaung (domestic supply to rural Thaba Nchu). However, groundwater makes up only a small percent of the total supply, reaching 13.1% in the City of Tshwane. In addition, treated acid mine drainage (i.e.

rebounding groundwater) is added to the Vaal Water Supply System (WSS), making up around 3% of the current supply to the metropolitan municipalities (MMs) of Gauteng.

Several MMs plan on expanding or initiating groundwater resource development as part of future reconciliation plans. Groundwater is planned to make up 25% of the “new” (non-surface) water resources for the CCT, and may equate to 25% total supply if the current drought exhausts surface water supplies (CCT, 2017b). Groundwater (from treated acid mine drainage) will also make up an increased portion in Gauteng by 2020 (Engineering News, 2016). However, in some cases groundwater has received little attention, and the potential for groundwater resources to augment bulk supply is insufficiently understood (i.e. Mangaung, Johannesburg, Buffalo City and Ekurhuleni). In almost all cases, very little recognition is placed on alternative uses of groundwater, for example, dispersed use for non-potable purposes, to alleviate demand on the potable WSS.

Where groundwater use is intended, it would need to be reflected, planned and budgeted for in the Integrated Development Plan (IDP). For example, the necessary capital budgets to fund the planned groundwater development for NMBM are incorporated in the IDP (NMBM, 2017). The capture or protection zones of current and future wellfields, and in some cases recharge zones, should ideally be delineated in the Spatial Development Framework (SDF). This would enable appropriate protection measures to be put in place, and tailored to the particular water quality threats in the area. Aquifers are delineated and incorporated in (only) the SDF for CCT, however, these are not (yet) related to the current or planned future use of these resources, and protection measures (Table 2-3). Groundwater’s role in providing support for the functioning of green infrastructure should also ideally be recognized in the SDF through (for example) the capture zone of an important wetland being delineated and linked to appropriate protection measures. Open Space Plans are planned for completion across the City of Johannesburg (CoJ), and do require groundwater’s role in protecting green infrastructure to be assessed (CoJ, 2017a; CoJ, 2017b).

WSD measures can also promote protection of groundwater resources for use, for example, by avoiding the hardening of surfaces in the recharge area which would otherwise limit the infiltration. WSD measures are promoted by some MMs, but the focus is primarily on stormwater management (i.e. Tshwane, CoJ, CCT) and the potential impact/ benefit of WSD measures on groundwater are not generally acknowledged. Water services or water supply by-laws provide another mechanism through which MM’s can manage and protect groundwater. Most MMs incorporate the necessity for owner / occupier to notify the MM of the presence of boreholes on the property, and some enable the MM to impose conditions on the use of private boreholes (Tshwane, NMBM, and Mangaung); a measure that can enable the MM to manage resource competition should this be a potential risk.

At some MMs, some of the above listed ways in which groundwater should be represented in the MMs key statutory planning processes are met. However, no single MM achieves the ideal representation of groundwater in all relevant planning documents. The overarching finding from the analysis is that groundwater (use and management) is poorly integrated into the key statutory planning processes at the MMs. In no cases is a coherent plan for groundwater development and management evident from the MM, and integrated across each of the necessary and available planning documents.

Table 2-2 Current and planned future Bulk Supply to Metropolitan Municipalities, with a focus on groundwater information

MM	Current Water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
City of Johannes-burg (CoJ)	584 million m^3/a (actual use, 2015/16) (CoJ, 2017)	CoJ requirement from Vaal (River) Water Supply System (VWSS): 704 million m^3/a in 2030, high growth projection (DWAF, 2009)	Rand Water supplies CoJ with water from the VWSS. The VWSS consists of a series of interlinked dams and inter-basin transfers into and out of the Upper Vaal Catchment, and an international transfer from the Lesotho Highlands Project Phase 1 (DWAF 2009b, Le Maitre et al., 2017). Pumping and treating of acid mine drainage (AMD) commenced in 2012 and augments VWSS by 76 million m^3/a (CoJ, 2011)	Planned augmentation interventions for the VWSS (DWA, 2012d): • Water Conservation / Water Demand management (WC/WDM) (related to "Project 15%" under which DWS issued directives to the Water Service Authority's (WSA's) (i.e. MM's) in Gauteng requiring reduction in demand) • Phase 2 of Lesotho Highlands Water Project • Increased treatment and use of mine water effluent under DWS's "long – term AMD solution project" (Engineering News, 2016) CoJ (following a directive from DWS) aims to reduce unaccounted-for water (UAW) to <17% by 2021, and is promoting exploratory studies of the use of rainwater harvesting and groundwater (CoJ, 2017).	The crystalline meta-sedimentary and meta-volcanic rocks of the Johannesburg Dome outcrop between Johannesburg and Pretoria. Shales and quartzites of the Witwatersrand Supergroup, and in turn the Karoo Supergroup unconformably overlie the Dome. These rocks can form intergranular and fractured rocks, although their yields are typically low. Intergranular alluvial deposit aquifers along the Crocodile River with limited spatial extent but good yields. The Malmani Subgroup Dolomites of the Chuniespoort Group (Transvaal Supergroup) form a high yielding karst aquifer, and outcrop almost on all sides of Johannesburg beyond the Dome and Witwatersrand and Karoo Supergroup (and largely beyond the CoJ boundary)
Ekurhuleni (EMM)	354 million m^3/a (bulk purchase 2017) (EMM, 2017)	Water requirement from VWSS: 488 million m^3/a, in 2030, high growth	Rand Water, East Rand Water Care, and Johannesburg Water supply water to Ekurhuleni, all ultimately from the Vaal Water Supply System (VWSS)	Planned augmentation interventions for the VWSS (DWA, 2012d), listed for CoJ apply. DWA (2012d) list that EMM will have to embark on a major WC/WDM programme in order to achieve intended	Significant groundwater resources occur in EMM, which is dominated by dolomite of the Malmani Subgroup of the Chuniespoort Group (Transvaal Supergroup) and, to a lesser extent, tillites of the Dwyka Group and the

MM	Current Water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
		projection (DWAF, 2009)		savings. EMM plans to reduce NRW from 34% to 20% in 10 years (EMM, 2017a). EMM has committed to a WC/WDM programme, grey water recycling for agricultural use, rainwater harvesting policies and pollution prevention to protect the existing water resource capacity (EMM, 2018).	fractured aquifers of the Witwatersrand Supergroup.
City of Tshwane (TMM)	113 million m^3/a in 2015 (based on high growth projection from 2007) (DWAF, 2010c)	Water requirement from VWSS: 166 million m^3/a in 2030, high growth projection (DWAF, 2010c)	71%: Rand Water supplies water from VWSS 10%: Magalies Water provides water from Roodeplaat dam 5.9%: supplied from TMM's own Rietvlei dam 13.1%: TMM's springs and boreholes (Total groundwater yield was 13.1 million m^3/a in 2007) (DWA, 2010c).	Recommended interventions for Tshwane include (DWA, 2010): • WC/WDM meter maintenance and replacement policy • Increased provision from Rand Water and Magalies Water • Expanded groundwater exploration is recommended as a long-term strategy TMM in addition plans to augment water supply with both direct and in-direct re-use of Wastewater Treatment Works (WWTW) return flow aiming to reduce demand on the VWSS from 71% to 54% in the 'near future' (TMM, 2014).	Groundwater is abstracted from the Fountains Upper and Lower Springs, The Rietvlei Spring, the Grootfontein Spring Rietvlei borehole, and the Valhalla borehole, all of which emanate from and boreholes target the karstic aquifer formed by the dolomites of the Malmani Subgroup of the Chuniespoort Group (Transvaal Supergroup) (DWA, 2010c).
eThekwini (eTMM)	Approximately 400 million m^3/a in 2015 (DWS, 2015b) for Mgeni WSS, which includes areas northwest of eTMM, but excluding an area beyond Umhlanga supplied by the Mdloti-	Approximately 540 million m^3/a in 2035 (DWS, 2015b) for Mgeni WSS.	Current supply is 100% derived from surface water; 84.1%: from dams on the Mgeni System originating in the Southern Drakensburg 14.4%: transfer from Mooi River as part of the Mooi-Mgeni Transfer Scheme (MMTS)	Reconciliation scenarios involve varying the timing / order of the following options (DWS, 2015b): • Use of treated effluent (45 million m^3/a) • Desalination of sea water (estimated yield 60 m^3/a) • the uMkhomazi Water Project (transferring 220 m^3/a surface water	Natal Group sandstone forms a secondary / fractured aquifer, unconformably overlain by the secondary (intergranular and fractured) Dwyka Group and the Ecca Group rocks of the Karoo Supergroup (Demlie et al., 2010).

MM	Current Water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
	Mvoti WSS, and the area south of Amanzimtoti supplied by the South Coast WSS.		1.5%: the Hazelmere Dam on the Mdloti River (Le Maitre et al., 2017; DWA, 2009)	from a new dam on uMkhomazi River to the Mgeni system) SDF also suggests exploring rainwater harvesting (eTMM, 2016).	
Cape Town (CCT)	334.7 million m^3/a in 2014/15 for CCT only; 547.26 million m^3/a in 2014/15 for the whole Western Cape Water Supply System (WCWSS) (DWS, 2015a)	Approximately 750 million m^3/a (Low Growth Scenario), 940 million m^3/a (High Growth Scenario), in 2035; for whole WCWSS (DWS, 2015a)	98%: Surface water from the Berg and Breede River, via the Western Cape Water Supply System 2%: Groundwater from Atlantis Aquifer and the Peninsula Springs (Le Maitre et al., 2017; DWS, 2015a)	Planned interventions for the WCWSS (DWS, 2015a): 1. Continued WC/WDM 2. Voëlvlei augmentation scheme (surface water) 3. Re-use of treated effluent 4. Use of groundwater from the Table Mountain Group (TMG) aquifer in the Hottentots Holland Mountains 5. ASR in West Coast (Langebaan Road and Elandsfontein Aquifer systems) 6. Desalination The abstraction of 36.5 million m^3/a from groundwater is being fast-tracked following 2016/17 drought, to be distributed from the Cape Flats, Atlantis, the TMG in Hottentots Holland, the TMG in the Peninsula (springs) (CCT, 2017b).	The coastal Cenozoic deposits of the Sandveld Group outcrop across the majority of the low-lying areas in the MM and wider Berg Catchment, and form the primary aquifers of the Cape Flats, Atlantis, and the Langebaan Road and Elandsfontein Aquifer systems. Fractured quartzites of the Table Mountain Group (TMG) form the secondary TMG aquifer, present on the Cape Peninsula (where it is exposed, and unconfined), and also in the Holland Hottentots Mountains, beyond the MM boundary. The Malmesbury Group and Cape Granite Suite of the basement form a secondary intergranular and fractured aquifer (Johnson et al., 2006; Umvoto, 2012).
Nelson Mandela Bay (NMBM)	For Algoa WSS: 149.7 million m^3/a in 2011/12 For NMBM only: 89.7 million m^3/a in 2011/12 (DWA, 2012b)	For Algoa WSS: 188 million m^3/a (Low Growth Scenario), 241	The Algoa WSS currently comprises two major dams in the west, several smaller dams and the groundwater-fed Uitenhage spring situated near to NMBM	In order of priority for implementation (DWA, 2011): • WC/WDM • Improved operation of Kouga Loerie (existing surface water) System • Seawater desalination • Increased allocation – Orange River	The AWSS supply area lies in the eastern most extent of the Cape Fold Belt, with the resistant quartzites of the TMG forming the mountains and ridges, whilst valleys are infilled with younger sediments of the Cretaceous.

MM	Current Water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
	NMBM makes up 59% of the water requirements for Algoa WSS, which also supplies other small towns, the IDZ, irrigation.	million m^3/a (High Growth Scenario) in 2035 (DWA, 2011; DWA, 2012b)	(central region), and an inter-basin transfer scheme from the Orange River via the Fish and Sundays rivers in the east. The Uitenhage Spring currently provides 2.3% of total requirements (DWA, 2011, Le Maitre et al., 2017).	• Groundwater at Bushy Park • Re-use from Coega WWTW for Coega IDZ • Groundwater at Van Stadens, Coega, & Jeffrey's Arch • Re-use from Fish Water Flats WWTW for Coega IDZ • Replacement & raising existing Kouga dam	The fractured quartzite formations of the TMG form the most significant aquifers in the region. The Uitenhage Spring emanates from the TMG (Maclear et al., 2001)
Mangaung (MMM)	83 million m^3/a in 2009 for the Greater Bloemfontein Water Supply System (GBWSS) which supplies several small towns beyond the MM boundary (Wepener, Dewetsdorp, Reddersburg, Edenburg, and Excelsior). 79.5 million m^3/a in 2011 (to MMM only) (DWA, 2012c).	~108 million m^3/a (Low Growth Scenario), >170 million m^3/a (High Growth Scenario) in 2035, for GBWSS (DWA, 2012c)	MMM receives water from the Greater Bloemfontein Water Supply System (GBWSS) via Bloem Water. The GBWSS utilises surface water sources, from several dams and transfers on the Caledon River and Modder River (DWA, 2012c). In addition, groundwater is used for domestic supply in the Thaba Nchu rural area of MMM (supplied by Bloem Water).	Planned interventions for GWBWSS include (DWA, 2012c): • WC/WDM, • Surface water interventions; • Re-use of treated effluent; • Groundwater (only for small towns within GBWSS and outside MMM).	Fractured, and intergranular and fractured aquifers of the Karoo Supergroup (consisting of consists of sandstones, shales and mudstones) underlie MMM. The Karoo Supergroup in the MMM has been extensively intruded by dolerite sills and dykes, particularly in the north and east of MMM. Groundwater availability in Karoo formations is generally limited, however the high yielding zones can be found related to highly weathered areas, to fault systems, and at the contact zone between the dolerites and the sandstone lithology's (Steyl et al., 2011).
Buffalo City (BCMM)	Approximately 84 million m^3/a in 2012 (DWAF, 2008a)	Approximately 78 to 113 million m^3/a (low and high	81% of MM population: Various dams on the Buffalo and Nahoon Rivers forming	Intervention options for the Amatole WSS include (DWAF, 2008a, DWA 2012, BCMM, 2015a):	Fractured and intergranular aquifer. Beaufort Group of the Karoo Supergroup (mudstone and subordinate sandstone). These

MM	Current Water requirement	Future requirement	Current supply source(s) and yield	Future supply source(s)	Significant aquifers
	For Amatole Water Supply System (AWSS) which supplies communities in addition to BCMM, and irrigation water requirements along the Buffalo and Nahoon Rivers (DWAF, 2008a)	scenario) in 2030 (DWAF, 2008a)	part of the Amatole Water Supply System (AWSS) 14% of MM population: SW resources in Keiskamma via Sandile and Peddie Regional Water Supply Schemes. 5% of MM population (coastal villages): serviced by groundwater alone (~6800 households) (FutureWorks 2014)	• Maximising existing surface water yield through optimisation of system • WC/WDM • Water re-use • Surface water augmentation schemes	aquifers can be productive where weathered and where structural controls increase yield, but limited groundwater availability for consideration as large-scale bulk supply (FutureWorks 2014, DWAF, 2008a)

Table 2-3 Integration of groundwater to municipal planning, protection, and management mechanisms

MM	Urban GW impacts	(Water Sensitive) Development and spatial planning	Groundwater protection
City of Johannes-burg MM (CoJ)	The most significant water quality impact on groundwater in the Johannesburg area comes from mining activities generating Acid Mine Drainage (AMD).	Groundwater use (presumably dispersed use) is listed in the IDP as a water demand management measure to meet a 5-year plan towards environmental sustainability. No other details related to this planned groundwater use are provided (CoJ, 2017). There are no measures within the SDF that specifically target protection of groundwater resources (or recharge area). The IDP does, however, require "Open Space Plans" to be completed across CoJ, to inform future spatial planning (CoJ, 2017; CoJ 2017b). "Open Spaces" are recognised for their environmental social and economic benefits (including provision of recharge to groundwater, and groundwater's role in maintaining ecosystems). CoJ references Water Sensitive Design principles as a means to promote water security, reduce environmental degradation,	CoJ's water services by-laws do not provide for groundwater protection nor require the registration of boreholes (CoJ, 2008). CoJ developed Dolomite risk by-laws which require the establishment of a Dolomite Risk Management Section within the City of Johannesburg, who will be responsible for mitigation of land subsidence issues. The by-law control the CoJ's emergency response to sinkhole formation, and the necessity for dolomite risk assessments at site developments on dolomite land. Extensive measures requiring CoJ to monitor dolomite groundwater levels, and enabling control of dolomite abstraction, are provided with the purpose of maintaining safety (CoJ, 2015).

MM	Urban GW impacts	(Water Sensitive) Development and spatial planning	Groundwater protection
		mitigate against flood risks, and build resilience in the face of climate change. Groundwater's role in WSD is not specifically considered (CoJ, 2017). WSD principles are included in the stormwater management by-laws (CoJ, 2010).	
Ekurhuleni (EMM)	Most significant urban influence on groundwater in the region is from mining via dewatering and AMD. Contamination sources within the MM threaten to impact the dolomitic aquifers beyond the MM; the groundwater pollution hazard of the dolomite aquifers has been identified as 'Extremely High' (EMM, 2018). Furthermore, industrial areas, informal settlements and insufficient stormwater management, and WWTW effluent all pose a risk to groundwater (EMM 2017a)	EMM has made a broad commitment to WC/WDM measures and promoted expansion into bulk supply augmentation schemes through wastewater reclamation and rain water harvesting policy but does not consider groundwater as a potential resource (EMM, 2018). There are no measures within the SDF that specifically target (ground)water resources protection via protection of the recharge area, though it does suggest some guidelines for land use which account for the presence of groundwater. EMM promotes WSD within its SFD through the initiation of the Ekurhuleni Urban Design Policy Framework which encourages green roofs, retention systems (e.g. swales and retention ponds), rainwater harvesting, permeable paving and channelization of water into planting areas, as well as promotion of water recycling technologies and rainwater collection (EMM, 2017b). Groundwater's role in WSD is not specifically recognised, and the focus is on stormwater management.	Various groundwater management measures are included in the by-laws, including that (EMM, 2001): • The owner of a borehole (or well, or wellpoint) existing prior to the promulgation of the bylaws, has 90 days to notify EMM of its existence, and provide required details • Prior approval is required to drill, deepen or replace a borehole. • Allowance is made for EMM to a) enter property to monitor private boreholes and b) determine the maximum abstraction allowable from a borehole However, the prevention of pollution policy references only streams, reservoirs, and aqueducts (EMM, 2001).
City of Tshwane (TMM)	There is very little discussion (within TMM documents) of pollution threats to urban groundwater. As groundwater is abstracted from dolomitic aquifers, structural instability is a risk, and due to mining in the	The potential to increase groundwater supply is listed by DWA (2010c), and increased groundwater use is listed in the Vision 2055 as a strategic action to be completed by 2020, under water demand and water conservation programme (presumably dispersed use to alleviate supply) (TMM, 2014). However, groundwater use (bulk supply or other) does not (yet) translate to budgeted / planned projects in the IDP (2017-2021), and nor	Various groundwater management measures are included in the by-laws (TMM, 2003), including that: • the MM can, by public notice, request notification for all existing and planned boreholes • the MM may require owners / occupiers of premises who intend to sink a borehole to conduct an EIA

MM	Urban GW impacts	(Water Sensitive) Development and spatial planning	Groundwater protection
	wider area, AMD will pose a risk. Pollution is also likely a threat from typical urban sources (industrial areas, leaking effluent infrastructure, cemeteries, waste sites).	is any other bulk supply augmentation scheme listed (TMM, 2017). There are no measures within the SDF that specifically target (ground)water resources protection, via, i.e. protection of the recharge area. WSD is included in the Vision 2055, as a philosophy and in the promotion of stormwater harvesting, wastewater re-use, fit for purpose uses of water resources, etc. The SDF also recognizes WSD, particularly avoiding the transformation of natural surfaces into impermeable ones to avoid generation of stormwater runoff (TMM, 2012).	• the MM may require owners / occupiers of premises with boreholes to obtain approval from the MM for use of borehole for potable supply • the MM may impose conditions for potable use of borehole water. • owner / occupier of premises with boreholes must provide and maintain a meter measuring the total quantity of water abstracted and discharged as industrial effluent into the sewers
eThekwini (eTMM)	There is very little discussion (within eTMM documents) of pollution threats to urban groundwater. However, pollution is likely a threat from typical sources (industrial areas, leaking effluent infrastructure, cemeteries, waste sites)	In line with the reconciliation strategy, the IDP shows no plan for the inclusion of groundwater (bulk supply) to support future development (eTMM, 2017a). There are also no other uses of (or protection of) groundwater planned. There are no measures within the SDF that consider groundwater or specifically target protection of groundwater resources (eTMM, 2016). eTMM does not directly promote WSD in its IDP nor SDF, though the reconciliation strategy is based on the WSD principles (eTMM, 2016, eTMM, 2017a).	By-laws state that the eTMM can, by public notice, request notification for all existing and planned boreholes and install a meter to monitor abstracted groundwater discharge into sewerage system (eTMM, 2017b).
Cape Town (CCT)	Potential pollution sources to the Sandveld aquifers (particularly the Cape Flats) include waste disposal sites, WWTWs, cemeteries, industrial areas and leakage of underground petrol and diesel storage tanks, leakage of reticulation and sewage network, informal settlements	The groundwater resources planned as part of the WCWSS reconciliation study, are reflected in the IDP and SDF (CCT, 2012; CCT, 2017a). Various aquifer resources are delineated in the SDF, however, there are no specific measures that target protection of the recharge area (or wellfield capture zone) for the current and proposed future groundwater resources (CCT, 2012). Other uses of groundwater (dispersed use, i.e. sports field irrigation, supporting urban agriculture, firefighting) are recommended in DWS (2016).	Various groundwater management and protection measures are included in the by-laws, including that (CCT, 2010) • A borehole (or well, or wellpoint) owner can be called upon to provide CCT with any information regarding the borehole as may be required • The borehole may not cause an adjacent well, borehole or underground source of water to become polluted or contaminated. • Prior approval to sink a borehole is required

MM	Urban GW impacts	(Water Sensitive) Development and spatial planning	Groundwater protection
	and agricultural areas (DWA, 2014, CSIR, 2015).	CCT explicitly embraces WSD in the IDP (CCT, 2017a). WSD research studies have been carried out with CCT as a case study, including an assessment of the impact and benefit of various WSD interventions on groundwater (Seyler et al., 2016).	• CCT may request a study be undertaken, to assess any impact of proposed boreholes prior to establishment.
Nelson Mandela Bay (NMBM)	There is very little discussion (within NMBM documents) of pollution threats to urban groundwater. The groundwater resources considered for bulk supply are somewhat protected from direct urban pollution (as a confined aquifer, with recharge in largely pristine mountains). However, pollution to groundwater in the urban area is likely a threat from typical sources (industrial areas, leaking effluent infrastructure, cemeteries, waste sites)	The groundwater resources planned as part of the reconciliation study are fully planned for (i.e. budgeted) in the IDP (NMBM, 2017). No other uses of groundwater are planned other than bulk supply. The future groundwater supply source is not reflected in the SDF, and there are no measures within SDF that specifically target protection of the recharge area for the current and proposed future groundwater resources (NMBM, 2015). The NMBM does not explicitly embrace WSD within the SDF, or IDP (NMBM, 2015; NMBM, 2017)	Assuming that the existing groundwater supply from Uitenhage Spring is classified as "municipal water services infrastructure", it is extensively protected in the NMBM by-laws, by measures such as controlled access, controlled activities in its vicinity, prevention of illegal abstraction, and prevention of pollution (NMBM, 2010). Furthermore the by-laws specify that (NMBM, 2010): • the MM should be notified of existing and intended boreholes • the MM may require owners / occupiers of premises with boreholes to obtain approval from the MM for use • the MM may impose conditions for use and may impose a fixed charge for the use.
Mangaung (MMM)	There is very little discussion (within MMM documents) of pollution threats to urban groundwater. However, urban groundwater pollution is likely to be a threat from typical sources (industrial and mining areas, leaking effluent infrastructure, cemeteries, waste sites, agricultural activities). Groundwater in Thaba Nchu is	The IDP for MMM reflects the contents of the GBWSS Reconciliation Strategy, and groundwater resources are not considered to play a role in future development needs, through bulk supply nor any other uses (MMM, 2017). There is no mention of the management requirements of the existing groundwater supplies in Thaba Nchu (MMM, 2017). There are no measures within the SDF that specifically target protection of recharge areas (MMM, 2017). MMM does not directly promote WSD in its IDP nor SDF. However, some elements of WSD are promoted in the IDP	Various groundwater management measures are included in the by-laws, including that (MMM, 2013): • the MM can, by public notice, request notification for all existing and planned boreholes • the MM may require owners / occupiers of premises with boreholes to obtain approval from the MM for use • the MM may impose conditions for use and may impose a fixed charge for the use.

MM	Urban GW impacts	(Water Sensitive) Development and spatial planning	Groundwater protection
	impacted by nitrate contamination, (Akwensioge, 2012).	including the WC/WDM strategy and rainwater harvesting (MMM, 2017).	
Buffalo City (BCMM)	Potential pollution sources include industrial effluent discharges, sewer leaks, wastewater treatment, and bacterial loading (informal settlements). (DWA, 2012a). Groundwater quality in coastal villages is potentially threatened from sea level rise and coastal flooding (FutureWorks, 2014).	In line with the AWSS Reconciliation Strategy, groundwater resources are not considered (in the IDP) to play a role in future development needs, through bulk supply nor any other uses (BCMM, 2016). There is no mention of the management requirements of the existing groundwater supplies (BCMM, 2016). There are no measures within the SDF that specifically target protection of recharge areas (BCMM, 2013). BCMM does not directly promote WSD in its IDP nor SDF.	Various groundwater management and protection measures are included in the by-laws, including that (BCMM, 2011): • greywater, wastewater, treated effluent, cannot be discharged into groundwater, except in accordance with NWA • the MM can request notification for all existing and planned boreholes • French drains may not contaminate boreholes

3. URBAN GROUNDWATER THEMES AND BEST PRACTICE

3.1. INTRODUCTION TO URBAN GROUNDWATER THEMES

Urban areas are densely populated hotspots associated a unique combination of hydrology, chemistry and groundwater usage characteristics that make it distinct from other groundwater environments. The key differences are (Lerner, 1996):

1. Degraded aquifer quality caused by the high density of services and industries and the subsequent groundwater pollution from non-uniformly distributed sources such as leaking sewer pipes and WWTW, underground fuel storage tanks, industrial areas, waste sites, and cemeteries.
2. Highly spatially variable groundwater recharge caused by simultaneous sealing of surfaces (i.e. non-permeable pavement) reducing direct precipitation recharge and by positive water input from leaking water infrastructure and stormwater recharge.
3. Anthropogenic impacts from, e.g. dewatering from deep basements, tunnels and pilings, and land subsidence / saline intrusion from excessive abstraction.
4. The need for complex groundwater management strategies attempting to reconcile the need for water abstraction while maintaining sufficient support for the local ecology and dealing with a multitude of potential pollution sources.

The groundwater development and management challenges and opportunities related to urban settings are termed **themes** in this report. An overview of key urban groundwater themes is shown in Figure 3-1 with a description of each of these provided in Section 3.2, in which case study examples are mentioned in **blue**. Some case studies simply illustrate the challenge, and in other cases these provides a best-practice example of the response to or management of the urban groundwater challenge.

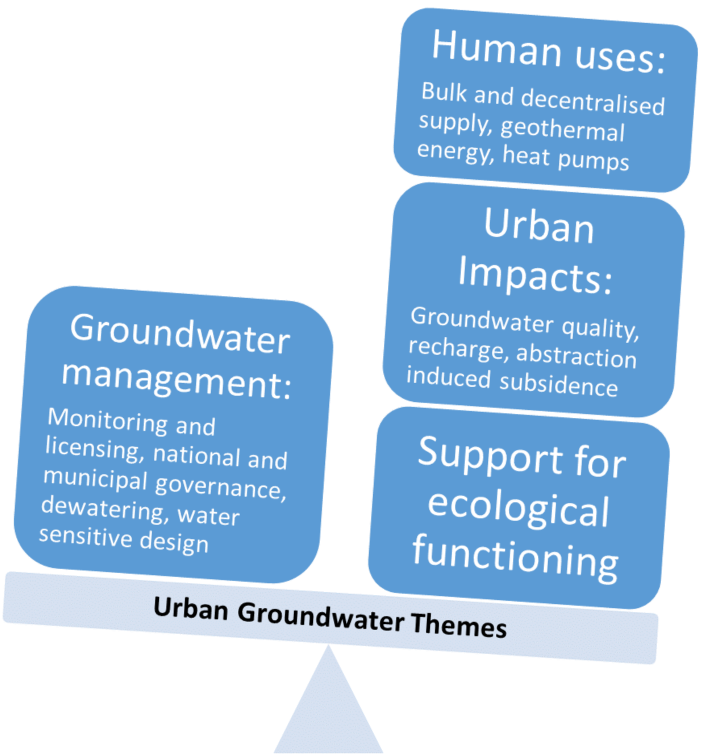


Figure 3-1 Overview of urban groundwater development management challenges, and opportunities ("themes")

3.2. Description of Themes with Case Studies

3.2.1. Theme 1: Human uses

Sub-theme: Bulk Supply

Groundwater resources are viable for bulk supply to urban areas, and yet only five (of eight) metropolitan municipalities currently use groundwater resources to varying degrees. However, groundwater makes up only a small percent of the total supply, reaching 13.1% in Tshwane (Section 2.3.3). Groundwater resources for bulk supply may come from within the urban area, or from further afield where significant groundwater resources are identified beyond the urban area. These two situations may in some cases be related to planned versus spontaneous development of urban water supply (Figure 3-2).

- Groundwater is successfully relied upon for the majority of municipal bulk supply, for example, in Dire Dawa, Ethiopia and **Denmark** (Case study 1).

Case study 1 – Denmark

Denmark is entirely dependent on groundwater as a source of water supply for drinking, agriculture and industry (Lisbeth et al., 2017). It has led to the development of extensive groundwater management legal framework, practices and technologies which have successfully maintained drinking-quality water standard without the need of special treatment or purification. This was achieved by setting ground water protection as one of the Danish government's top priorities and introducing a number of protective measures:

- Introduction of various strict and enforced water policies (e.g. Water Supply Act, Environmental Protection Act) which control groundwater abstraction, drinking water quality requirements, groundwater protection areas and set out regulations for wastewater, industry and agriculture (e.g. pesticide approval scheme and fertilizer limits). For example, non-revenue water (NRW) has been reduced to 7% by enforcing penalties for utilities with NRW of >10% (Pederson and Kaagaard, 2016).

- Imposition of tariffs for water use and wastewater discharge to public treatment works under the 'polluter-pays' principle to ensure full cost recovery by the water and wastewater utilities (Lisbeth et al., 2017). Furthermore, the water utilities operate on a non-profit basis with the prices and cost elements set by the governmental authorities to prevent the risk of water utilities evolving into private, monopoly-driven businesses.

The effectiveness of the regulations can largely be attributed to the high level of public and stakeholder awareness, knowledge and participation, as well as the data-based management approach, i.e. the decisions of water use are made based on information submitted by groundwater users (e.g. well location, yield and chemical analysis), nation-wide groundwater mapping and monitoring, as well as regional groundwater modelling (Pederson and Kaagaard, 2016). Lastly, there is a clear assignment of responsibilities: (1) the state is responsible for setting legislative framework, international obligations and research and development, (2) the regional level is responsible for issuing permits for groundwater abstraction and exercising protection of the groundwater resources and regional monitoring, and (3) the local level (i.e. municipalities) is responsible for planning future water use development and assurance of the drinking water quality standards from the water suppliers.

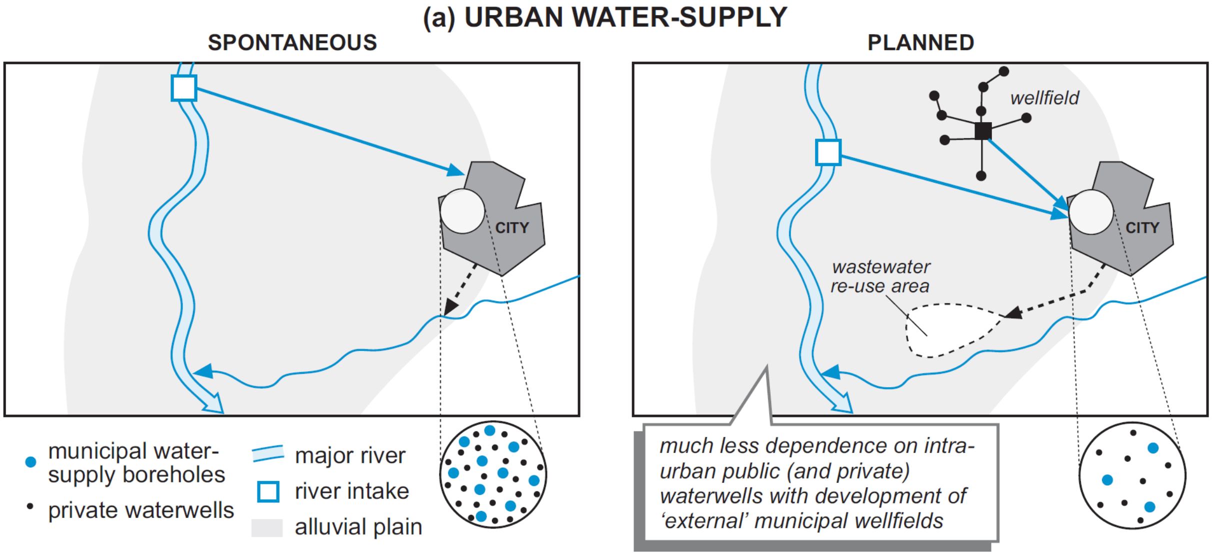


Figure 3-2 Illustration of private and municipal groundwater abstraction coming from within the urban area, compared to municipal supply derived from external groundwater resources (from Foster & Tyson, 2015).

Including groundwater in the supply source for urban areas can bring great merit from the **diversification of supply sources**: critical for South African MM's, which generally have a reliance on surface water derived water supply. The over-reliance on one source can be problematic when that source is threatened, as illustrated by the current severe drought in the Western Cape, and specifically in the City of Cape Town MM. Although the drought is considered a "1:1000 year event", this is based on historical climate patterns and with changing climate, diversification of supply is critical. Although climate variability also impacts groundwater (reduction of recharge), groundwater has a greater buffer capacity, as aquifers generally store several year's recharge (~5 to >100), whereas dams generally store ~2-5 years of runoff. Conjunctive use of surface and groundwater has been a major contributor to the ability of some areas to manage the current drought impact more successfully, for example, in Hermanus, Overstrand Local Municipality, South Africa.

Financing is often a problem for the development of bulk water resources at MM level (expanded upon under the governance theme). Groundwater resources can also be intentionally **over-utilised (groundwater mining)** for urban supply, to support development and / or whilst the funds are raised for other potentially more capital investment intensive interventions like desalination for coastal MMs. This can be acceptable if the impacts of that over-utilisation are understood and the benefits outweigh the costs. However, groundwater resources are often considered unreliable for bulk supply, and groundwater mining is often automatically considered unacceptable. These misperceptions relate in part to the incorrect application of water balance approaches to quantify groundwater resources and the lack of understanding of the source of groundwater when pumped (capture principle).

- Groundwater was historically heavily used to support industrial development in **Birmingham, UK**. Groundwater abstraction reached a peak of 60 Ml/day in the 1950s which caused a water table drawdown of up to 30 m (Ellis, 2002). However, as industrial production declined and water use practices changed, the groundwater abstraction was reduced to 13 Ml/day in late 1990s and the water table returned to pre-industrial levels (though now groundwater abstraction is required to prevent basement flooding; see Section 3.2.3).
- 'Acceptable' groundwater mining occurs in several situations including Adrar, Algeria and **the Great Man-made River Project, Libya** (Case study 2).

Case study 2 – the Great Man-made River Project, Libya

Groundwater mining is not necessarily a problem. The Great Man-made River Project (GRMP) in Libya is one of the world's largest groundwater schemes; it abstracts fossil groundwater from various basins in the North West Sahara Aquifer System (NWSAS) and delivers it through large diameter (4 m) pipelines to supply irrigation, industrial and domestic demands in northern coastal Libya where the majority of the agricultural production is located.

It is estimated that the total water capacity of the NWSAS is 35,000 km^3 (which is made up of water accumulated during the last ice age between 38,000-14,000 years ago), however, with the current average precipitation of only 56 mm/yr, the current aquifer recharge is effectively zero.

GRMP Phase I wellfields in the Sarir and Tazerbo basins consists of a total of 254 boreholes drilled at 380-600 m depth, each able to deliver between 92-102 ℓ/s, and the scheme is estimated to reach total groundwater abstraction of 2248 million m^3/a (Hiscock, 2005). GRMP has a minimum design life of 50 years at the end of which the total abstraction is calculated to be 113 km^3, i.e. only 0.3% of the total groundwater resource (Hiscock, 2005). Therefore, if 2007 rates of abstraction are not increased and the water quality does not decrease with aquifer depth, thus reducing the total economically viable water volume, this water supply could last >1000 years. Additionally, modelled drawdowns for the Tazerbo well-field after 50 years of abstraction are 95 m (Hiscock, 2005).

Nevertheless, the water supply is considered to meet the ethical requirements of groundwater mining, namely that: 1) evidence is available that pumping can be maintained for a long period; 2) the negative impacts of development are smaller than the benefits; and 3) the users and decision-makers are aware that the resource will be eventually depleted (Price, 2002).

Sub-theme: Decentralised Supply

In addition to use of groundwater for bulk supply, groundwater is and can be used for decentralised supply in urban areas, e.g. by individuals for garden watering, swimming pools, and by industries for process water (also reflected in Figure 3-2). In cases where a water-intensive industry sits within the metropolitan municipality, use of groundwater may be more cost effective than use of municipal supply (i.e. factories reliant on high water volumes).

- With only 40% of the population having access to safe water, the unreliability of the municipal supply source in **Lagos, Nigeria**, has led to a prevalence of "off-grid" groundwater supplies to households in the city (Okojie, 2009).

Decentralised groundwater use has several advantages, listed in Figure 3-3. A significant advantage is that in many aquifer settings, several small abstractions across an aquifer are more effective at harnessing groundwater than a few bulk abstraction points. This is particularly true when the saturated thickness and hence available drawdown is limited.

- **Denmark** relies upon groundwater supplies (Case study 1), and groundwater is accessed for supply through a large network of small abstractions (decentralised approach), rather than large scale abstraction at a few wellfields per urban area.
- Given the potential benefit of reduced demand on the municipal reticulation system, the use of groundwater for non-potable purposes (i.e. garden irrigation) is beginning to receive recognition in South African MMs, including **City of Johannesburg**.
- This has been recommended for some time by the **City of Cape Town** in their water conservation and demand management strategies, and their water sensitive design measures. The current drought in Cape Town has forced a significant increase in the decentralised use of groundwater by industry, services such as hospitals and schools, individuals, and also by the tertiary services sector (banks, office blocks) to ensure that their offices can remain open should the municipal bulk supply source be shut down.

Decentralised supply has several risks associated with it, which have to be adequately managed for any of the benefits to be realised. The risks are also listed in Figure 3-3. In addition to those listed, where the municipality itself also wishes to use groundwater for bulk supply, and where decentralised supply is prevalent, a significant risk is the **competition for groundwater use**. The financing mechanisms are also complicated; whilst decentralised use reduces demand on the reticulated system, it also reduces municipal water revenue, and if a facility is "off-grid" there must be alternative mechanisms for charges for sewage (see governance theme). Lastly, a lack of decentralised groundwater abstraction's management may lead to saline seawater intrusion and ground subsidence.

PRIVATE URBAN IN-SITU GROUNDWATER USE
BENEFITS
• Much improved access and reduced cost for some groups of water-users (but not the poorest unless waterwell construction/operation costs are underwritten) • Highly appropriate for 'non-quality sensitive uses' (garden irrigation, laundry, cleaning, cooling systems, etc) • Does not cause serious resource depletion (except in confined aquifers) and recovers major water-mains leakage • Reduces pressure on municipal utility supplies, especially for demands of difficult locations or with temporal peaks
RISKS
• Interaction with in-situ sanitation can cause health hazards and make control of waterborne disease more difficult • Requires special caution if industrial pollution or serious natural contamination of groundwater is present • Inadequate waterwell completion can lead to transfer of contaminants from shallow to deeper aquifers • Intensive self-supply by more affluent urban dwellers can produce complex knock-on effects and seriously reduce utility revenue collection

Figure 3-3 Benefits and risks of private decentralised groundwater use[1] (from Foster & Tyson, 2015)

Sub-theme: Geothermal heat pumps

Groundwater is an important resource for heat and cooling, via **ground source heat pumps**. This technology reaches maximum benefit where there is a significant temperature variation between air and groundwater, for example during the British winter, groundwater is >10 degrees warmer than the air temperature. Ground source heat pumps are not well developed in South Africa, although they do have application potential, particularly as an alternative to air-conditioning for cooling during summer months.

Groundwater is also an important resource for **geothermal energy** internationally, however, is not well developed in South Africa.

3.2.2. Theme 2: Ecosystem support

Regardless of the level of use of urban groundwater (bulk or decentralised), active and appropriate management of urban groundwater is required to ensure groundwater's role in supporting ecological systems ("green infrastructure") is maintained. To some degree, in South African policy, this should be accommodated in resource quality objectives which influence license conditions (setting conditions for maintaining groundwater discharge to rivers, springs,

[1] Also termed "in-situ" groundwater use, referring to the use of groundwater accessed at an individual's property, or at a factory

wetlands). In addition, groundwater may drive wetlands which provide significant ecological or human benefit (i.e. recreational spaces). To protect these requires quantification and inclusion of their recharge areas in spatial planning.

- The recent "open space plan" for the **Lanseria sub-region of Johannesburg** incorporated the delineation of groundwater resources (and their recharge areas) that drive wetlands occurring in the open green spaces. Inclusion of these areas can lead towards their protection from development which risks reduce recharge.

3.2.3. Theme 3: Urban impacts on groundwater

Sub-theme: Groundwater quality

Groundwater in urban areas may be contaminated wherever there is a contaminant-releasing source and a pathway for their movement towards the groundwater body. There is a variety of potential sources including leaking sewer networks, petroleum storage tanks, industrial and commercial areas, waste sites, cemeteries, nitrate from fertilisers mobilised by garden watering, and inadequate sanitation in informal settlements (Table 3-1). The issue is exacerbated by the generally very slow groundwater movement: with a typical movement rate of 1 m/d in sandstone aquifers, contaminant leaks may persist (and spread further into the aquifer) for many years or even decades if no remediation actions are taken (which are often expensive and take a long time to implement). Furthermore, water may be deemed unfit for consumption by contamination of very small amounts of chemicals, e.g. benzene concentration in groundwater in South Africa is limited to 50 µg/L which is equivalent of 10 drops of benzene in a railroad tank car of water (Hohne, 2004, Shanahan, 2009). Aquifer pollution may also be caused by systematic management (or its lack of) practices, e.g. widespread discharge of wastewater to subsurface disposal systems or groundwater overexploitation leading to salt-water intrusion in coastal cities (Shanahan, 2009). Furthermore, aquifers under areas recently transitioned from agricultural to urban land use may be contaminated by legacy pollution from agricultural practices (e.g. excessive use of pesticides and fertilisers), as well as the groundwater quality may be poor due to naturally high mineral concentrations.

The risk and severity of groundwater pollution is also heavily dependent on the local hydrogeological setting, e.g. a deep water table may provide sufficient attenuation capacity for (some) of the pollutants to have degraded before it reaches the groundwater (Foster and Tyson, 2015). Furthermore, a confining layer (an aquitard) may prevent contaminant downwards movement and thus protect the underlying aquifer, however, the subsurface in urban areas has usually been heavily modified through excavations, tunnels and basements, as well as installation of pipes and boreholes, all of which contribute to altering the natural groundwater movement system and creating pathways for contaminant migration, e.g. old wells may create flow pathway from contaminated shallow aquifer directly to deep, yet uncontaminated aquifers.

Whilst policies must ensure contamination events from point sources are limited (e.g. correct lining at waste sites), and land use / town planning can go a long way to minimise diffuse pollution sources (e.g. adequate sanitation in informal settlements), monitoring and enforcement is required to identify contamination events, their sources and those responsible, and to remediate. Ideally, areas with poor groundwater quality can be remediated or at least isolated, whilst making use of the local resources (see sub-theme: Monitoring, adaptive management, licensing).

- A review of water quality for the **Cape Flats aquifer (Cape Town RSA)** documented contamination around waste sites (CSIR, 2015). However, the monitoring networks are generally insufficient to delineate the plumes. Monitoring across the aquifer is insufficient to understand the risk from other sources (particularly cemeteries), and the data from petrol stations is submitted from private companies to DWS, and not available publicly. Available data indicates contamination from leaky reticulation and sewage pipes (Case study 3).
- **Beaufort West (Western Cape, RSA)** uses groundwater as a key part of the municipal supply source. Contamination from leaking underground storage tanks at petrol stations was detected in the groundwater supply, requiring extensive pump and treat remediation measures to be established.

- Acid Mine Drainage (AMD) has been an issue in **The Witwatersrand Basin** near the City of Johannesburg as the polluted water threatens both surface and groundwater systems (Case study 4).

Component	Category	Risk factors
Regional considerations	–	Population density Land use and land cover Physical relief/slope Rainfall amount and intensity
Sources	Municipal and household level sources including domestic livestock and urban agriculture	*Surface sources:* Open defecation from humans and animals Surface waste sites and incineration sites Fertilisers and pesticides and waste use (solid/Liquid) Atmospheric deposition of combustion products *Sub-surface sources:* Pit latrines Septic tanks Soak-aways Waste pits Cemetery or other burial sites Open sewers/drains—most common type in SSA Reticulated sewers—very limit coverage *Other potential sources:* Market places, abattoir waste, both liquid and solid
	Hospital or treatment centre	*Surface and subsurface sources:* Liquid waste discharge to soak-aways/surface channels Solid medical waste disposal Latrines/septic tanks on site
	Industry e.g. mining	*Surface and subsurface sources:* Process plant effluent Solid waste disposal sites Storage tanks including petroleum products Site runoff and leaching from mine spoil
Pathways	Horizontal and vertical pathways in unsaturated and saturated zone	*Shallow sub horizontal pathways in tropical soil*: Tropical soils, e.g. Plithosol/Ferrasol horizons present Shallow depth to water table Thin soils and low organic matter content Natural rapid bypass from tree roots and burrows *Vertical and horizontal pathways in saturated zone:* Thin low-permeability zone above weathered basement Thickness and maturity of weathered basement zone Fracture size, length and density in the more competent bedrock below weathered basement
	Local/headwork pathways	Lack of dugwell headwall and/or lining Lack of well cover Use of bucket and rope—soil/animal/human contact Gap between apron and well lining Damaged well apron Propensity for surface flooding Gap between borehole riser/apron Damaged borehole apron Eroded or de-vegetated spring backfill

Table 3-1 Sources and pathways for urban groundwater contamination (adapted from Lapworth et al., 2017).

Case study 3 – Cape Town

The Cape Flats Aquifer (CFA) underlying much of the Greater Cape Town area (CCT) is unconfined and has a high water table, making it highly susceptible to groundwater pollution. Water management plans (CSIR, 2015; DWS, 2016a) have identified numerous potential contamination sources in the CFA:

- Point sources: 18 waste sites (i.e. landfills; generally unlined though located in low-permeability sites), 7 wastewater treatment works (WWTW), 16 cemeteries (decomposition of bodies creates micro-organism-rich leachate which is a hazard on scale comparable to or even larger than landfills and WWTWs; no legislation to limit the impacts, e.g. impermeable lining), industrial areas (Pinelands, Bellville and Cape Town International Airport), informal settlements (Khayelitsha and Gugulethu) and agricultural areas (Philippi Horticultural area);
- Diffuse sources: pollution from stormwater run-off if it is not treated before allowing to infiltrate and recharge the aquifer.

However, the leaky pipe infrastructure may also be a significant source. Water quality data from a selection of boreholes in the CCT area for which data is available (Figure 3-4) is shown below for both free chlorine (chemical added during water disinfection process and hence associated with leaky reticulation or sewer pipes given the same water is flushed) and Escherichia coli (bacteria associated with human and animal waste hence indicative (in the city setting) of leaky sewage network). Concentrations at many locations are elevated above that which would be expected in groundwater (essentially nil), with e-coli and free chlorine values above detection limits found in 15 and 11 sites (out of 18). Some sites show elevated free chlorine but did not detect e-coli, indicating leaky reticulation pipes (only). The distribution likely correlates to the quality and age of the reticulation and sewage infrastructure.

Some groundwater monitoring in the CFA is carried out by DWS who measure groundwater level at hourly or 3-monthly frequency at 21 boreholes, as well as bimonthly chemical analysis at 8 boreholes. The monitoring locations are an artefact of historical groundwater exploration carried out by DWS, and focus on the most productive parts of the aquifer, relatively close to the major abstraction in Philippi agricultural area. In addition, CCT carries out monitoring in the vicinity of waste sites (Figure 3-5), however, there is only limited/no monitoring at WWTWs and cemeteries. Overall, the monitoring scheme, especially of groundwater quality, only partially covers the entire aquifer, therefore providing only limited understanding of the overall system and distribution of any contamination.

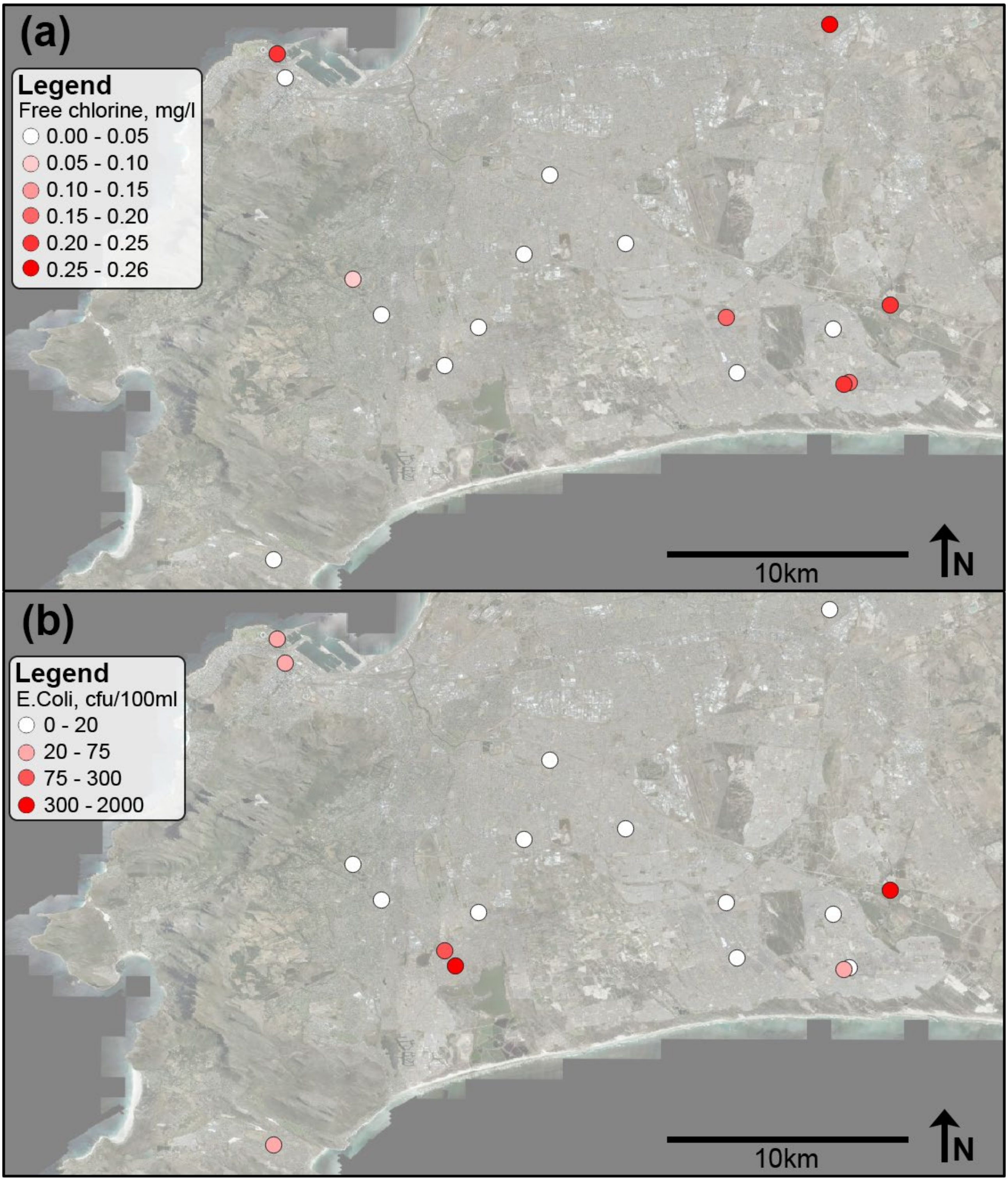


Figure 3-4 a) Free chlorine and b) E-Coli concentration distribution across Cape Town area indicative of recharge from leaky reticulation and contamination from sewage infrastructure (Delta-h, 2018a).

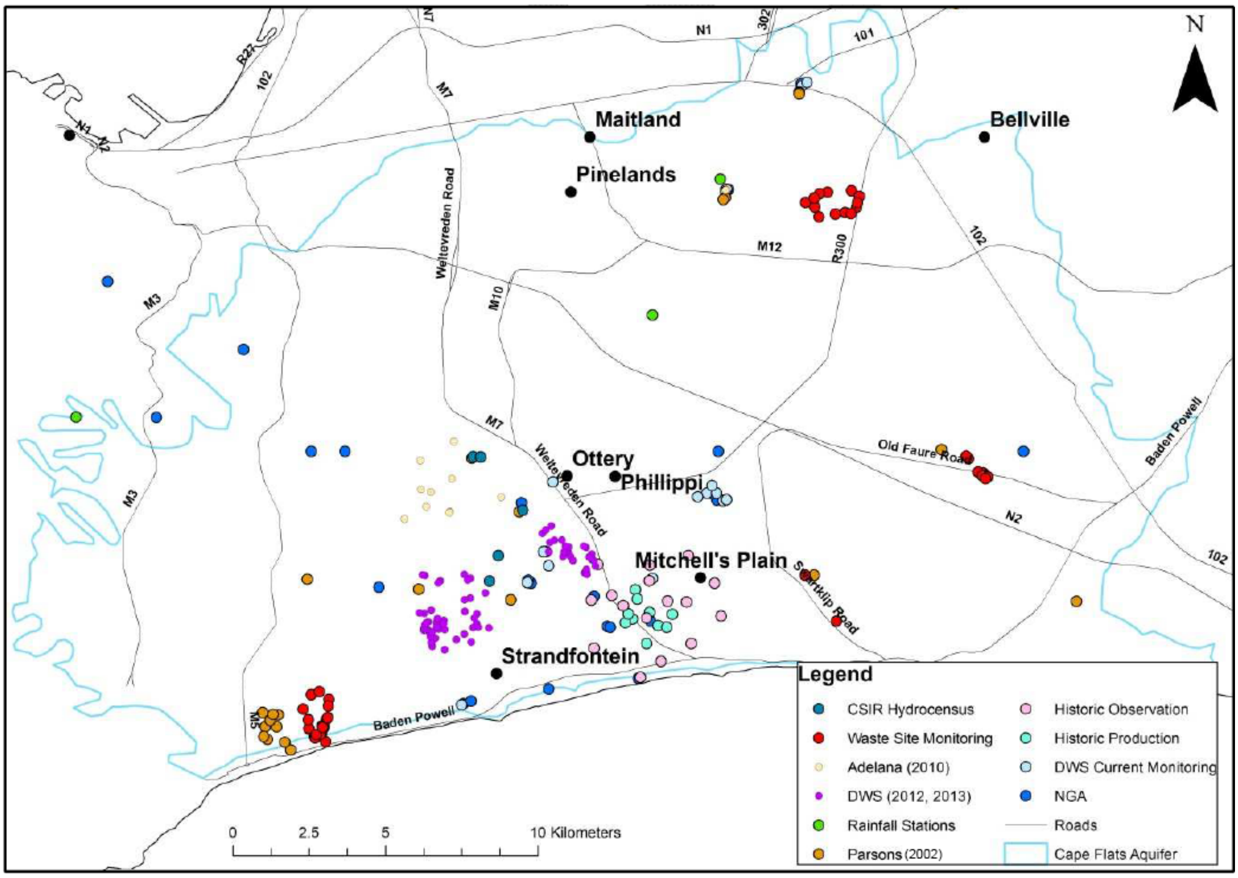


Figure 3-5 **Historic and current environmental monitoring points (from CSIR, 2015)**

Case study 4 – The Witwatersrand Basin, South Africa

The gold-bearing reefs of the Witwatersrand basin – a largely underground geological formation surfacing in the Witwatersrand region of Johannesburg – have been mined since 1887, but, as the resource was exhausted, the mines were beginning to close in the late 1950s. Each closure led to a cessation of the mine's dewatering scheme, which caused the voids to be filled up with water and created an increased pumping demand for the nearby still operational mines (though the water table still rose locally). In October 2008, the last operational mine – East Rand Propriety Mines Ltd., located at the far eastern end of the Witwatersrand mining belt in Boksburg – ceased its activity, and the groundwater table began to rise dramatically; in 2010 the water table was approximately 600 m below surface, and, with a rising rate of 15 m/month, the mine voids were expected to be completely filled by 2013 (McCarthy, 2010).

The rebounding water table caused the mine void space to be filled and for the groundwater to be contaminated by acid mine drainage (AMD). After being exposed to air and water, oxidation of metal sulphides (e.g. pyrite) generates acidity; the resulting groundwater is therefore characterised by low pH, high sulphate content and elevated heavy mineral concentrations and electrical conductivity (Holland and Witthüser, 2009). Long-term exposure to AMD-polluted water is associated with increased rates of cancer, skin lesions and decreased cognitive functions (Liefferink, 2015).

As the groundwater table rose, the AMD-polluted water began to flood urban basements and was discharged to the surface through seepage springs after which they joined the surface rivers and were rapidly transported downstream where they could enter the karstic Malmani group dolomite system (Transvaal Supergroup) through diffuse riverbed leakage, dolines and swallow holes (Holland and Witthüser, 2009). Concerns first arose in August 2002 when the first mine water started to decant south of COHWHS area near Krugersdorp (Holland and Witthüser, 2009). By 2012, the discharge was approximately 30 Mℓ/day, causing severe environmental damage to the Krugersdorp Nature Reserve (KNR) and posed a threat to the Sterkfontein caves within the Cradle of Humankind – a world heritage site located on top of a high-yielding aquifer considered to be a vital component of the expanding water supply demand in the Gauteng urban complexes (Holland and Witthüser, 2009) – and 11,491 downstream landowners and agricultural groundwater-dependant activities (GDARD, 2012; Liefferink, 2015).

The Department of Water and Sanitation (DWS) implemented a number of short-term and is developing long-term solutions. The short-term solutions were based on the neutralisation and removal of metals from AMD through pumping (and maintaining water table level to below 250 m depth) and treating the water in a number of treatment plants (Solomons, 2015). By 2015, the DWS had spent ~R2-billion in upgrading two existing plants – Gold One's Rand Uranium water treatment plant in Randfontein and Ergo's pumping and treatment facilities at the South-West Vertical shaft – and constructing an AMD treatment plant in Grootvlei mine No. 3 shaft (which became operational in 2016), and bringing the total volume of annually treated AMD to about 170 Mℓ/d (Solomons, 2015). It is unknown for how long the pumping would have to continue – likely between several decades and centuries –, though gradually, as all the dissolved material is flushed out, the water quality will improve, the treatments costs will decrease and the water might be of sufficiently high quality to be used for drinking or non-potable uses (e.g. irrigation), hence making the pumping operation profitable (McCarthy, 2010).

However, the treatment was unable to deal with the high sulphate content and the resulting 'treated' water had sulphate concentrations ranging between 2,395 and 3,012 mg/l, which is over a magnitude higher than the World Health Organisation's standard for sulphate in drinking water of 200 mg/l (Liefferink, 2015). This issue is addressed in the DWS long-term strategy of building desalination plants to remove salt loads from river systems and return the water to drinking-quality standard. DWS estimates that it would cost approximately R10-billion to build the plants and between R0.012-0.018 to treat a litre of water (Solomons, 2015).

Sub-theme: Groundwater recharge

Soil compaction and the sealing of permeable surfaces (e.g. roofs and roads) in urban areas prevents infiltration and diverts the precipitation towards stormwater drains, thus causing a reduction in recharge rates. However, the recharge may also be increased if the city introduces into its system large amounts of water that would not be available under natural conditions, i.e. water import from outside the urban borders to meet the growing water supply demand. Between 5-60% (Garcia-Fresca and Sharp, 2005) of all urban water system inputs (e.g. rainfall and imported water) are lost to groundwater recharge through leakages in the water mains pipe network, as well as from losses in sewer and storm drain systems, garden and park irrigation, stormwater detention ponds and artificial recharge, as well as by localised recharge through impervious cover, e.g. fractures (Figure 3-6) (Lerner, 2002; Sharp, 2010). Overall, the general trend observed in nearly all metropolitan areas is for the overall groundwater recharge to increase by up to several magnitudes compared to pre-urbanisation recharge volumes (Figure 3-7) (Sharp, 2010). The increased recharge is most notable in arid areas with naturally low local water supply, as well as in cities with poorly-maintained water and storm infrastructure network.

- The karstic **Edwards Aquifer, Austin, Texas (USA)** is a water source for 2 million people. Recharge from leaking water distribution and sewer network, and irrigation, has been quantified as 5% of the total recharge in the urban area (Passarello et al., 2012).
- In **Lima, Peru** the imported water amounts to 1650 mm/year, compared to only 10 mm/year of precipitation, which, coupled with an old and ineffective water mains system with leakage of around 60%, has led to the groundwater recharge rate increasing from approximately 5 to 750 mm/year (Foster, 1996).

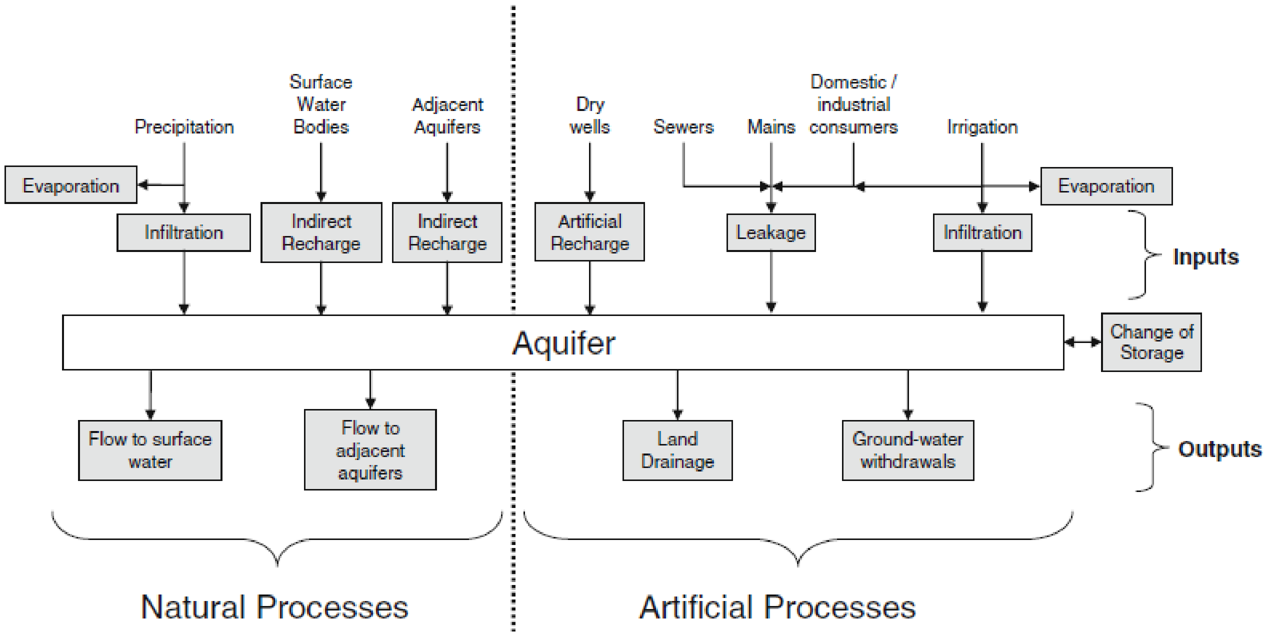


Figure 3-6 **The urban aquifer water balance (from Shanahan, 2009).**

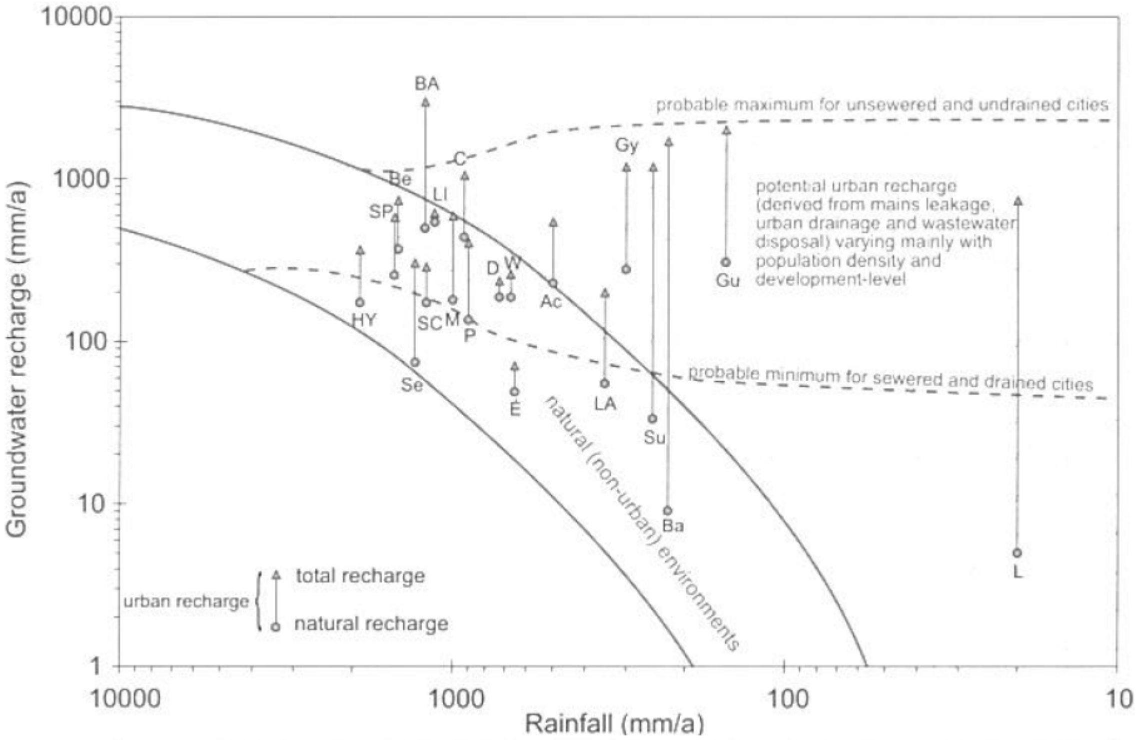


Figure 3-7 **Groundwater recharge change in cities around the world (from Garcia-Fresca and Sharp, 2005).**

Sub-theme: Subsidence

Whilst groundwater is often abstracted to maintain geotechnical stability in basement structures, in some circumstances, the degree of urban abstraction has caused significant subsidence and hence the abstraction itself causes a geotechnical risk. There are several examples of this internationally, and nationally:

- Abstraction from (and infiltration of water into) dolomitic aquifers in the Gauteng region (RSA), has caused sinkholes to form. The City of Johannesburg has specific dolomite risk by-laws which enable the city to control abstraction from dolomite terrains (Section 2.3.1).
- Oslo, Norway, has a shallow groundwater table and extensive abstraction occurs to maintain dry conditions in basements, and for construction. Subsidence of 2-3 cm per year has been measured. The municipality is actively managing this risk, and is currently developing a "sub-surface master plan" in an attempt to manage potentially competing uses of the subsurface, as illustrated in Figure 3-8 (i.e. carparks requiring dry conditions versus groundwater as a "role player" occupying the sub-surface) (Eriksson, 2017).

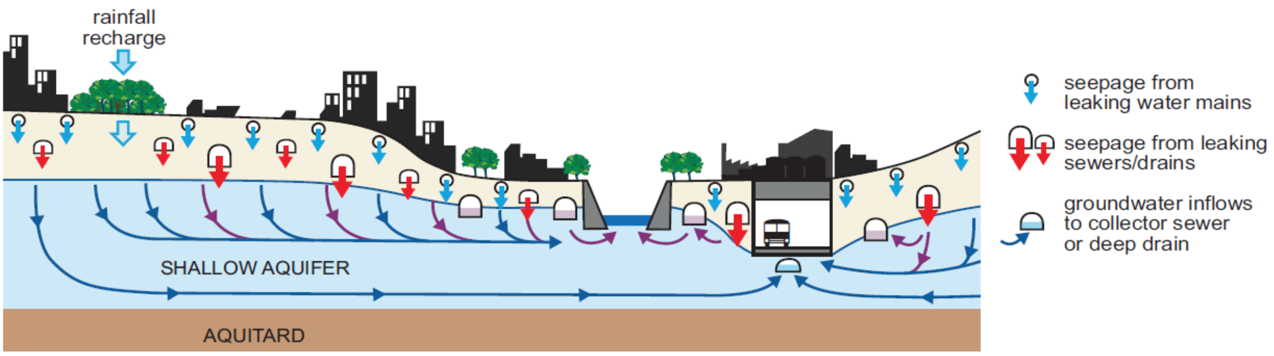


Figure 3-8 **Interactions between urban subsurface infrastructure and shallow groundwater flow (from Foster & Tyson, 2015)**

3.2.4. Theme 4: Groundwater management

Sub-theme: Monitoring and licensing

Use of groundwater in an urban setting for bulk supply, and management of the risks of decentralised supply, both rely on adequate monitoring, adaptive management, and ultimately relate to licensing approaches (amongst other policy control mechanisms such as by-laws). Bulk groundwater supply for urban use will undoubtedly involve abstraction of relatively high groundwater yields. Given impacts cannot be known in high confidence prior to abstraction (although they can be estimated in analytical or numerical models), **adaptive management** approaches – i.e. approach based on continuous monitoring of groundwater levels and quality, and periodically updated numerical models – are integral to the bulk use of groundwater.

- Adaptive management is a key part of the licence applications for groundwater abstraction for the **City of Cape Town**, as the yields are high, and impacts are thus far unknown (and have not been estimated).

Groundwater in urban settings is vulnerable to contamination, however, with **appropriate monitoring and management**, areas with poor groundwater quality can be remediated or at least isolated, whilst making use of the local resources. This relies on a suitably dense resource monitoring network, and the sharing and centralisation of data (which can be a requirement of licenses).

Competition for supply is a risk, but with **appropriate resource quantification methods and related licensing**, this can be averted. In South Africa a licence application generally incudes within it an estimate of the groundwater availability and relating this to the Reserve, both of which are generally based on water balance approaches (that equate groundwater availability to some portion of recharge minus use). The source of abstracted water (storage, reduced discharge, enhanced recharge or capture of surface water), the response time, and the impacts of abstraction including those on neighbouring abstractions are rarely estimated (Seyler et al., 2016b). In heavily used aquifers or aquifers with sensitive receptors, application of water balance approaches for groundwater quantification are inadequate. This situation results in uncertainty over groundwater yields, miscommunication over impacts, and inappropriate aquifer management. The situation also ultimately contributes to the current water use licensing situation.

- The DWS currently has a ~300-day turnaround time for the awarding of groundwater licenses (DWS, 2017). The delay in licenses in South Africa is a critical hurdle for urban groundwater supply, at a time when **Cape Town** urgently needs to rely on its groundwater resources to enable business continuity. The severity of the drought in Cape Town was only clear after the low rainfall in winter (June-September) 2017. Between October 2017 and February 2018 several businesses have developed groundwater supplies, and submitted licence applications to DWS. The majority of these are outstanding, and with a 300-day turnaround time, there is no indication that they will be awarded before the municipal supply is potentially shut down.
- Groundwater licensing decisions in the **United Kingdom** are managed by the Environment Agency with the support of regional numerical groundwater models (Case study 5).

Case study 5 – the United Kingdom

As per the European Union's Water Framework Directive's regulations, the UK has developed and implemented catchment-scale management plans to ensure 'good' water body quality status by 2027 (Whiteman et al., 2012). The United Kingdom's Environment Agency (EA) is working towards this goal by developing regional groundwater models covering all of the major aquifer systems. During an abstraction licence application process, the impact of the proposed abstraction conditions is assessed using the relevant model and the results are used to inform the most appropriate licence conditions. These models are also available for consultants for generation of more accurate smaller scale models which take into account the regional groundwater flow context (EA, 2001). Furthermore, to make the data more accessible to a wider audience and encourage its use, the National Groundwater Modelling System (NGMS) was created – a standardised map-based database holding groundwater models and supporting documentation (Whiteman et al., 2012).

Even though each regional modelling contract took over two years to complete and cost between £200-500k (R3.6-9.1 million), considerable effort was required to train people in its use and adapt operational decision-making processes to include NGMS into regular and safe use, the advantages brought by these models were worth the cost and have proven to be invaluable in groundwater management (EA, 2001; Whiteman et al., 2012). The main benefit is derived from the synthesis of the available data which improves the conceptual and quantitative understanding of the study area and allows evaluation of various future scenarios and risk assessments, which ultimately allows for a much more effective and less contentious knowledge-based abstraction licence decision-making process. Furthermore, the greater certainty provided by the models allows for the abstraction licence review period to be extended.

Sub-theme: National and municipal governance

The roles and responsibilities of DWS and water services authorities (i.e. the MMs and their sub-contracted water boards) are complex when it comes to **bulk water provision**. Pengelly et al. (2017) reflect that the DWS is responsible for bulk water provision in cases where resources are shared across catchment boundaries, e.g. management of the Western Cape Water Supply System supplying Cape Town (and wider area) because it straddles major catchment divide and supplies several municipalities. Also, DWS historically funded and developed the majority of bulk water resources infrastructure (dams, boreholes) supplying towns across the country. However, DWS in recent years has been keen to point out their role is the regulator and custodian of water resources, and that it is the role of the water services authority to plan and build (albeit perhaps with DWS funding) water resources infrastructure. Whilst this is in line with relevant policies, it is common for local and metropolitan municipalities to look to DWS for future water resources provision, also associated with the challenges in **funding the capital requirements for bulk infrastructure** (Pengelly et al., 2017). The complexity over roles and responsibilities and the access to funding may contribute to the lack of update on groundwater for bulk water provision by the MMs.

- Riemann et al. (2011) aligned the requirements for successful bulk groundwater abstraction (i.e. resource protection, monitoring), with the roles and responsibilities of the various role players (DWS, departments at municipalities) (Table 3-2). The document serves as a thorough guideline for MMs utilising groundwater.

	DWA / DEA	CMA	LM / DM	WSA	WSP	WUA	Water user / Polluter
Aquifer protection							
Land-use planning		X		X		X	
Waste management	Reg.		X				
Effluent quality management	Reg.				X		
Groundwater remediation	Reg.						X
Groundwater monitoring		X		(X)		X	X
Aquifer utilisation							
Groundwater assessment				X			
Licensing	X			(X)			
Well-field planning and design				X	(X)		
Well-field operation and maintenance					X		X
Groundwater monitoring				X	X		X
Reg. = Regulator	**X = Main responsibility**			**(X) = Input, partial responsibility**			

Table 3-2 Governmental organisation groundwater management responsibilities management (Riemann, 2012).

Related to the discussion on appropriate licensing (Section 3.2.1), the **water resources classification system** (WRCS) is designed to cater for the protection of all water resources (i.e. including groundwater). Resource quality objectives are determined and should inform license conditions. However, there are significant challenges with the WRCS as a whole, and with the application of a largely surface water derived system to groundwater resources (Riemann et al., 2017). Whilst governance is not the central focus of this project (Section 1.2), the shortcomings of the WRCS (and the related application of water balance methods, and lack of modelling or groundwater resource quantification of key aquifers for licensing) is certainly a governance challenge that contributes to poor groundwater management.

For MMs to adequately protect their groundwater resources requires the **incorporation of groundwater resources in spatial and development planning**. Recharge areas need to be delineated, and land use controlled in these areas to prevent contamination and maintain recharge rates (Le Maitre et al., 2017). However, given aquifer travel times, more important than recharge areas is the need for the capture zone of any urban water supply borehole to be delineated and formally protected in the spatial development frameworks of MMs. The protection mechanisms are more complex when the MM targets groundwater resources beyond the boundaries of the MM. The extent to which this is currently implemented in South Africa is summarised in Table 2-32.

- Nearly 30% of the Dinaric karst outcrop in **Croatia** is incorporated into sanitary protection zones and delineated in spatial development plans (Biondić et al., 2017).

Sub-theme: Dewatering

Underground structures in urban areas are **dewatered** to maintain dry conditions and geotechnical stability in basements (via sumps), and also other underground structures where dry conditions are required (tunnels). These structures influence groundwater flow (Figure 3-8). An opportunity exists to divert this abstracted water for beneficial use, rather than disposal.

- With shallow water levels in **Cape Town** (not only on the Cape Flats aquifer, but also in the fractured Malmesbury Shale aquifer), several large office buildings have basement car parks with sumps that essentially abstract groundwater. The beneficial use of this water has dramatically increased with the current drought, and several offices have developed systems to use this water for flushing toilets within the buildings (e.g. Woolworths HQ in the CBD, WCG Department of Environmental Affairs in the City Centre on Dorp Street).

- Groundwater seeps into the tunnel sections of the **Gautrain, Johannesburg**, and the potential for beneficial use of this water will be assessed as a case study in this project (Section 5.3)
- In **London, UK**, groundwater levels were significantly lower in the past, and significant development took place whilst groundwater levels were low, and hence without the necessary protection for potentially wet underground conditions. As groundwater use has declined in recent years, rising groundwater levels risk causing structural damage.

Sub-theme: Groundwater and Water Sensitive Design

Water Sensitive Design (WSD) is an umbrella term for approaches that aim to manage all parts of the urban water cycle (from water supply to wastewater treatment and stormwater management) in a way that mimics natural hydrological regimes, protects the natural environment, and reduces negative impacts of flooding and pollution (Figure 3-9). WSD particularly aims to overcome the highly contradictory nature of water in urban areas by making better use of the local urban water resources, through interventions such as rainwater harvesting, **stormwater retention** and re-use. **Managed aquifer recharge** (MAR), and decentralised groundwater use are both often considered to be WSD measures. However, there is a general need to improve the integration of groundwater consideration within WSD, as WSD measures are often recommended without consideration of the impact on or interaction with groundwater (i.e. permeable paving where groundwater levels are very shallow).

- Managed aquifer recharge has been successfully implemented in **Windhoek, Namibia** (Murray et al., 2018).
- The water square in **Tiel, the Netherlands**, serves a multi-functional purpose: it is an urban park for skateboarding and basketball. During high rainfall events, stormwater is diverted to the square which transforms to a sequence of water storage basins (Figure 3-10). The water is then diverted for aquifer infiltration, preventing floods.

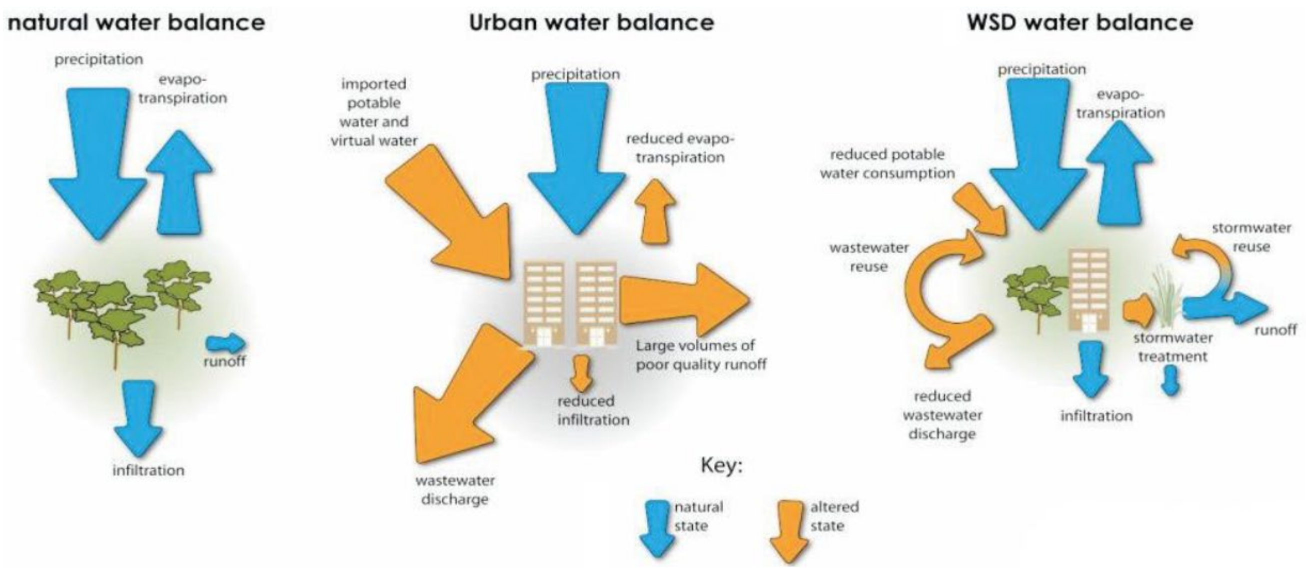


Figure 3-9 Comparison of natural, urban and WSD water balances (from Hoban & Wong, 2006).

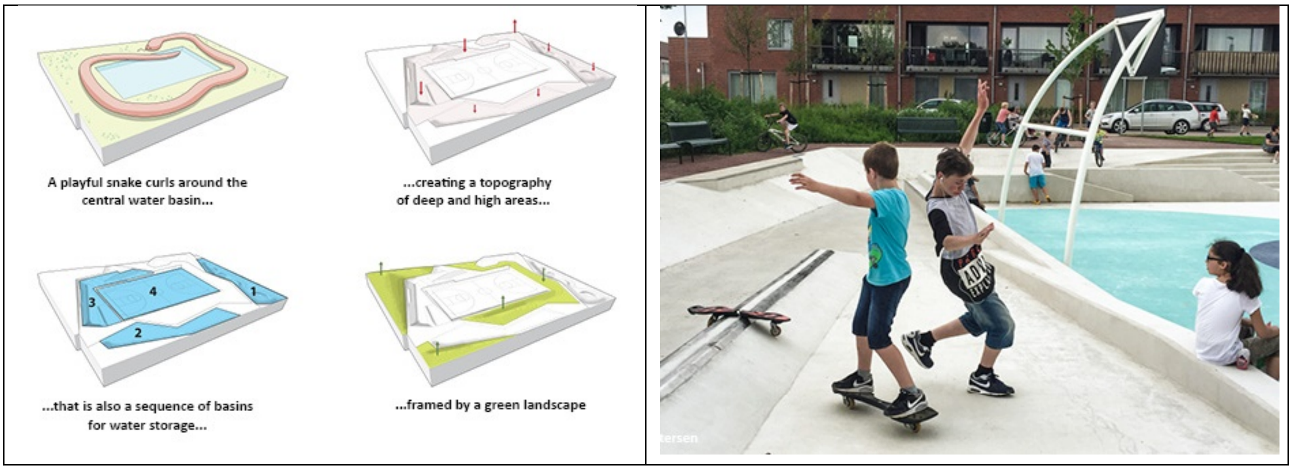


Figure 3-10 The Water Square, Tiel (NL); an example of urban stormwater retention for later aquifer infiltration (De Urbanisten, 2014).

4. GAP ANALYSIS

The urban groundwater themes and sub-themes (listed in section 3.2) were presented at an urban groundwater "think tank", on 20 February 2018, at the WRC in Pretoria. Invitees included the reference group members, staff from metropolitan municipalities involved in groundwater management (i.e. from water and sanitation or infrastructure planning department, from spatial planning, or from the environmental department), major water boards, the DWS, and other stakeholders. Representatives from all of the (eight) metropolitan municipalities were invited, and 6 metropolitan municipalities attended. Each urban groundwater theme was discussed, including case studies of best practice, leading to a discussion of the most pressing urban groundwater challenges at the MMs. These challenges are summarised below:

Municipal by laws were discussed in several contexts (in terms of registration of boreholes, permission to access properties with private groundwater use, and in terms of revenue for off grid groundwater users still contributing to wastewater related to lack of metering of wastewater). Existing by-laws were found to be lacking, and lacking in implementation. By-laws are required that go further than just registration of boreholes, towards active management and planning, to support decentralised supply.

Decentralised groundwater use (or private groundwater use within the metropolitan municipality area) was discussed in detail. The points raised illustrate a division of opinion over the appropriateness of private users exploiting groundwater at least for domestic use within the area under jurisdiction of a WSA. Private use is clearly considered a burden where the WSA also wants to exploit groundwater (competition for supply), and carries challenges for the revenue of metros (loss of income, structuring charges for wastewater), and is not actually legal (schedule 1 use does not apply within the area of a WSA). Yet, at the same time, the drought in Cape Town has forced private users to exploit groundwater resources for domestic supply – which can have real benefit in terms of lowering demand on the reticulation network.

The discussions highlighted that work is still needed in sharing clear **groundwater messages**. Some attendees questioned the worth of groundwater development for urban supply, when groundwater yields are small compared to surface water.

Combining the key remaining challenges highlighted at the think tank, with insights from the status quo assessment (section 2), a comparison has been made between the current status of urban groundwater development and management in South Africa with an ideal status, as demonstrated by the best practice examples given in Section 3. This comparison is summarised in Table 4-1, per urban groundwater theme.

The project aimed to provide a suite of "high-level technical solutions, strategies and tools" that will lead towards improvements in urban groundwater development and management. The approach to these tools and strategies has been adapted as the project progressed based on feedback from the reference group members and the dialogue sessions, and they include:

- Position papers detailing high-level solutions and best practice approaches to urban groundwater management. Certain papers include data gathered during this project, some provide examples from previous work, and some are more opinion-based. They are intended as stand-alone papers so contain some repeats from previous chapters. The selection of urban groundwater themes for which papers were developed was based on the themes with the most critical gaps (between current status in SA and best practice, Table 4-1).
- An urban groundwater plan detailing the way forward for supporting advancements in urban groundwater development and management (section 6).

Table 4-1 Summary of gaps between urban groundwater development and management themes in South Africa, and international best practice

Urban Groundwater theme	Urban Groundwater subtheme (see section 3.2 for description)	Gaps: Status in SA MMs compared to best practice
Human uses	Bulk supply	Poorly developed: five (of eight) metropolitan municipalities currently use groundwater resources; and groundwater makes up only a small percent of the total supply, reaching 13.1% in Tshwane.
	Decentralised supply	Use of groundwater for decentralised supply is increasing, however governance to manage this use is lacking, and strong misconception and uncertainty exists over impact of decentralised use.
	Geothermal energy, ground source heat pumps	Not well developed in SA.
Support for ecological functioning	Support for ecological functioning	Lacking; some isolated examples in SA, e.g. the identification of groundwater dependent ecosystems, and exclusion zones for borehole drilling near rivers and wetlands.
Urban impacts on groundwater	Groundwater quality	Relatively widespread in SA's metros; related to inadequate monitoring.
	Impacts on recharge	Varying recognition in SA; some recognition as part of WSD measures.
	Abstraction induced subsidence	Some best practice examples from Gauteng (such as dolomite by-laws), however some gaps in management remain.
Groundwater management	Monitoring, adaptive management, licensing	Lacking: • insufficient registration and monitoring of private groundwater use; • insufficient regional resource monitoring networks for resource protection (contamination), and related to this insufficient collation of central storage of private datasets; • ineffective groundwater resource quantification and management methods (lack of centralised models) and related licensing inefficiencies.
	National and municipal governance	Governance – related challenges hinder urban groundwater use and management in SA; specifically related to ambiguity over roles and responsibilities and funding mechanisms.
	Appropriate water resources classification and licensing mechanisms	Lacking in SA compared to international best practice; lack of modelling or groundwater resource quantification of key aquifers for licensing.
	Inclusion of groundwater in spatial & development planning	Some progress however lacking compared to international best practice.
	Beneficial use of groundwater dewatered for underground structures	Increasing in application, driven by resource constraints. Uncertainty over legislative requirements.
	Water sensitive design	Greater integration of groundwater in consideration of WSD measures is required

5. POSITION PAPERS TO SUPPORT URBAN GROUNDWATER DEVELOPMENT AND MANAGEMENT

Position paper 1: roundwater and Urban Resilience

5.1. GROUNDWATER USE AND URBAN RESILIENCE

5.1.1. Overview

Alternative water sources are required to meet the future water demand in all of the South African metropolitan municipalities, such as groundwater use, use of treated effluent, and desalination, alongside increasing efficiency and implementing water conservation and demand management measures. The additional pressure of climate change and increasing drought frequency in a water-scarce country requires diversification of supply to increase resilience. These pressures also increase the importance of groundwater for urban supply, given some aquifers have a slow response time and large storage capacity hence a capability to buffer droughts.

However, the use of groundwater for bulk supply remains lacking in urban areas of South Africa. Five of the 8 metropolitan municipalities do not use groundwater, and groundwater makes up only an insignificant percent of the supply (2%) in the remaining 3 metropolitan municipalities (Le Maitre et al., 2017). Although some metropolitan areas plan on groundwater development as part of future reconciliation plans (i.e. Nelson Mandela Metropolitan Municipality using the Table Mountain Group aquifer in the Uitenhage basin, and the City of Cape Town using the Cape Flats and the Table Mountain Group Aquifer), groundwater is likely to still only make up a small (~10%) percentage, of their total available resources.

The reasons for this lack of uptake of groundwater for bulk supply are wide ranging; and many are related to the way in which water supply infrastructure is funded and implemented within municipal planning systems. These dictate, to some degree, that new water supply interventions are initiated only when they are needed based on projected supply and demand and the time taken to construct. In effect, to date, the various metros have not required alternative sources to be actioned: according to traditional planning. Water supply interventions from other sources remain a future recommendation, required for implementation at some date in future. However, Cape Town's 2016-2018 drought (and specifically the 2017-2018 summer) has shown that it is worth planning for the unexpected.

Another reason contributing to the lag in the uptake of groundwater for bulk supply is that there still remains a mistrust of groundwater, even though the main causes of failing groundwater schemes relate to operations and maintenance failures, rather than resources failure (Braune et al., 2014, Cobbing, 2013, Cobbing et al., 2015). Furthermore, there remains a perception that groundwater cannot provide sufficient yields for it to be a meaningful water supply source in urban areas.

This paper intends to address this latter misperception, and the successful reliance on groundwater as a supply source to a great number of towns and to the agricultural sector is outlined. Whilst groundwater is a dispersed resource compared to surface water, which is concentrated via runoff to rivers and dams, the yields can still make a significant contribution to urban resilience. Using the establishment of groundwater supply to priority health care facilities in Cape Town as an example, the paper also demonstrates that via decentralised supply even lower yielding aquifers can be developed for enhanced urban resilience. This message is aimed at the metropolitan municipalities, and water users within them (industry, services, other government departments such as departments of education and health).

5.1.2. Groundwater Resources for Bulk Supply

5.1.2.1. *Success at town level*

Groundwater resources account for >50% of the supply source in thirty six percent (36%) of settlements in South Africa (Le Maitre et al., 2018, therein based on the second phase of the All Towns projects; DWS, 2014). These settlements are considered "sole source" groundwater settlements (DWA, 2011b). The proportion of sole source settlements has apparently increased to 36%, from 22% reported based on the first phase of the All Towns project (Braune et al., 2014, therein based on DWS, 2010). However, as highlighted by the lower use of groundwater by metropolitan municipalities, the uptake in larger towns is less; only 2 of the 26 areas of key economic importance are sole source (8%) (Le Maitre et al., 2018). Where groundwater is used, it is dominantly making up 100% of supply, and only 25% of settlements have more than one supply source, demonstrating a lack of implementation of conjunctive use, which is a key to resilience (Figure **5-1**).

The spatial distribution of settlements using groundwater (only), surface water (only) and some portion of both, is shown in Figure **5-2**, with the distribution of sole supply settlements (>50% groundwater) is shown in Figure **5-3**. The distribution of groundwater dependent towns correlates primarily with the locations of rural settlement, (i.e. Limpopo, North West Province), and secondarily with the location of productive aquifers (Le Maitre et al., 2018).

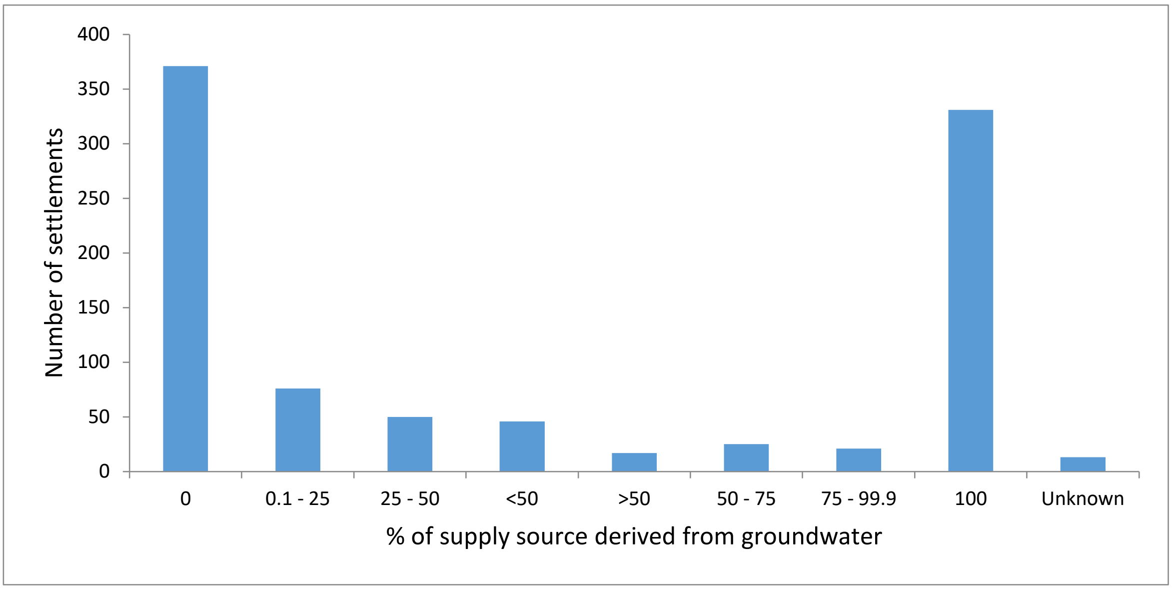


Figure 5-1 Histogram of the percent of settlement supply sources derived from groundwater, based on the second phase of the All Towns data (DWS, 2016c). <50 refers to 46 settlements with 0-50% supplied from groundwater, and >50 refers to 17 settlements with 50-100% from groundwater; however exact yield is not known

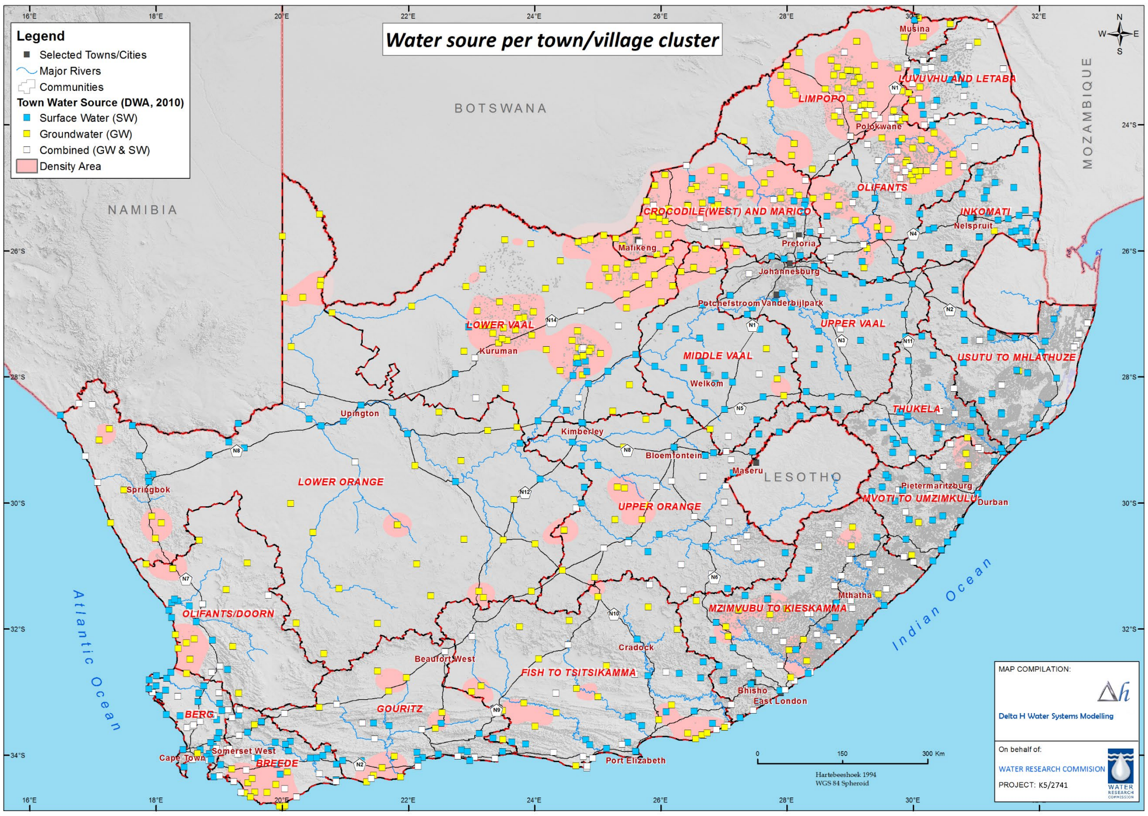


Figure 5-2 Map showing the water source of each settlement (groundwater, surface water, or combined), based on the first phase of the All Towns project (DWA, 2012e).

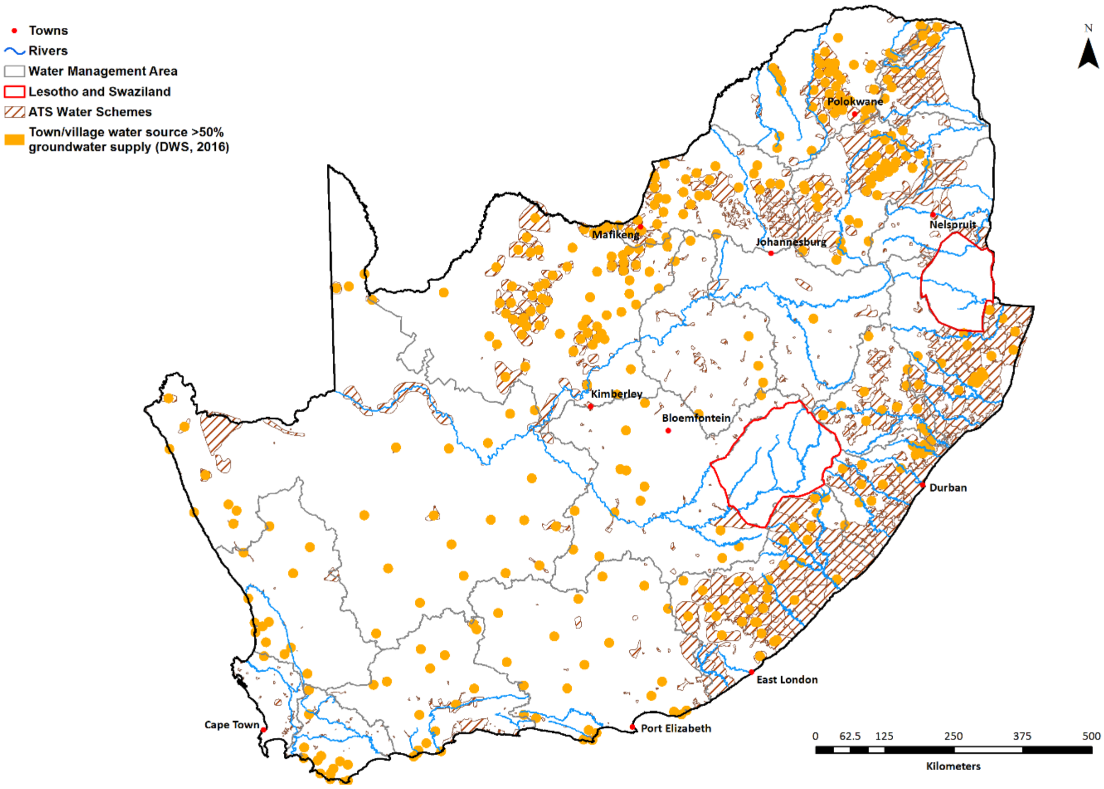


Figure 5-3 Location of sole source towns in South Africa (36% of all settlements), where groundwater makes up >50% of the supply source, based on the second phase of the All Towns project (DWA, 2016) and reproduced from Le Maitre et al., 2018

5.1.2.2. *Success at agricultural level*

The dominant user of groundwater is the agricultural sector, making up 59% of all groundwater use compared to 13% for domestic supply and 13% for mining purposes (Braune et al., 2014). The yields abstracted for agricultural purposes at aquifer scale greatly exceed any municipal or domestic supply wellfields. Perhaps in part because of the DWS's relative focus on water supply for domestic purposes, the agricultural sector has largely carried out this groundwater development with comparatively little interest or involvement from the hydrogeological profession; conference presentations detailing groundwater resource availability or abstraction impact focus on abstraction from domestic supply wellfields, or from the mining and industrial sector. In only a relatively few cases has the agricultural sector developed a wellfield centrally to supply farmers, such as the case for example the Koo Valley Water Users Association which owns a wellfield supplying farmers. In a growing number of cases the agricultural sector is acknowledging the shared nature of groundwater resources, for example:

- agricultural users of the Steenkoppies Aquifer were galvanised to form the Steenkoppies Aquifer Management Association following challenges to their water use from downstream users (Pietersen et al., 2011). Sadly due to a lack of continued impetus the organisation has since disbanded (Cobbing et al., 2016)
- the Titus River Irrigation Board in the Ceres basin (Western Cape) represents farmers irrigating predominantly from groundwater. They jointly manged project assessing the sustainability of the collective groundwater use in the area, facilitated by WWF and funded by Woolworths (Delta-h ,2018b)

The irrigation demand of predominantly fruit crops in catchment H10B (Ceres basin, Western Cape) is almost solely met from groundwater, with total registered abstraction of ~9 million m^3/a (DWS, 2017c). The registered abstraction is shown in Figure 5-4. Although the summer groundwater levels decline significantly due to the abstraction impact, the abstraction appears to be maintainable, as evidenced by the complete recovery of groundwater levels each winter (Delta-h, 2018b). The abstracted water is being derived from aquifer storage, which translates to lower discharge from the aquifers to surface waters; and the subsequent winter recharge is sufficient to replenish storage. It is challenging to quantify the impact of groundwater abstraction on reducing in natural groundwater discharge to surface waters, due to the lack of flow gauges in the area. However, the present ecological category for rivers in H10B is "C" reflecting that the ecology is "moderately modified from the Reference Condition, loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged" (DWS, 2017c, pg. 19); demonstrating that the ecological impact of any potential reduction in groundwater contribution to baseflow is (so far) not significant.

Irrigation demand in the neighbouring Hex Valley, known for grape produce, is met from a combination of surface and groundwater (Figure 5-5). The total registered groundwater abstraction in the valley is over 17 million m^3/a (DWS, 2017c). Similarly to H10B, there is a lack of suitable monitoring datasets from which to quantify the reduction in groundwater's contribution to baseflow due to abstraction. However, again, the present ecological category for the Hex River is "C" (DWS, 2017c, pg. 19); demonstrating again that the ecological impact of any potential reduction in groundwater contribution to baseflow is (so far) not significant.

Agricultural abstraction is generally distributed across the resource (i.e. a few boreholes on each farm), rather than centralised, which is likely a key to its success as the impacts are distributed. The examples above demonstrate that decentralised abstraction can lead to significant yields being abstracted, with apparently acceptable impact.

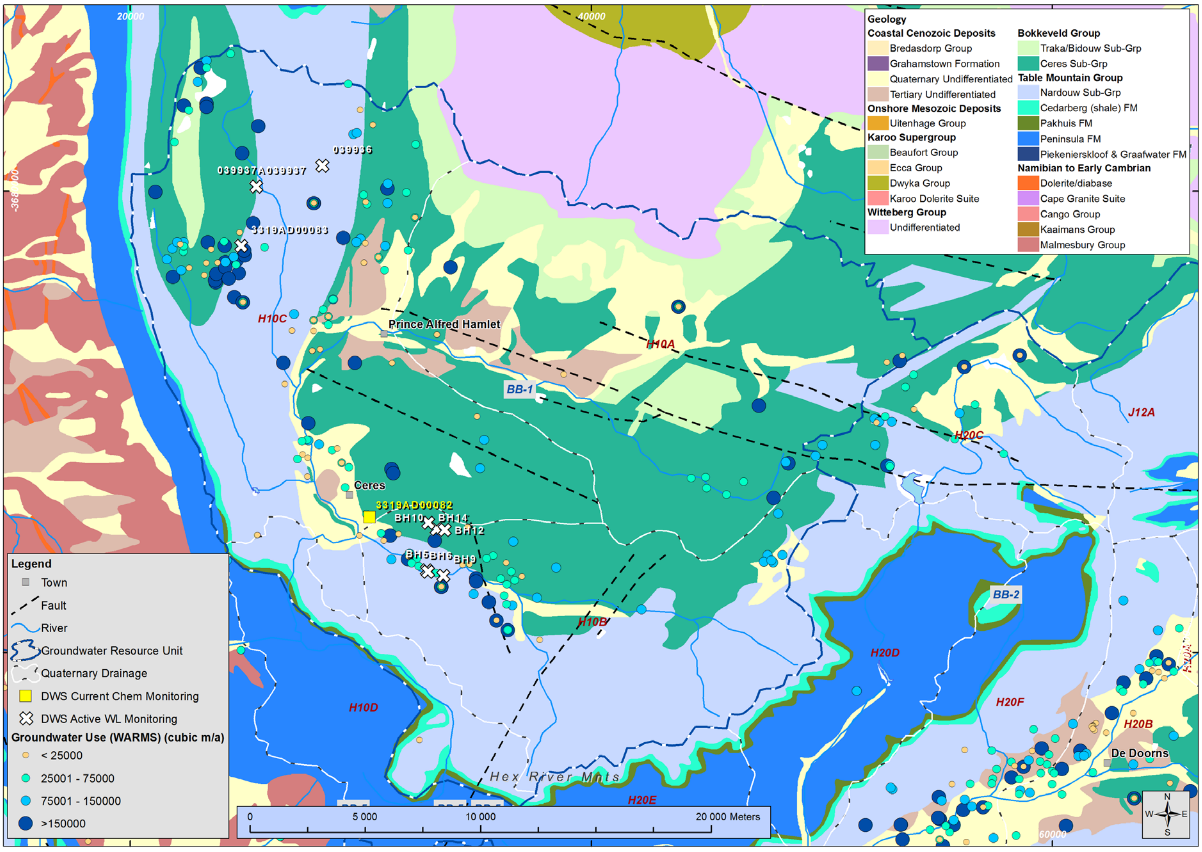


Figure 5-4 Registered groundwater use in H10B, in the Ceres basin (from DWS, 2017b)

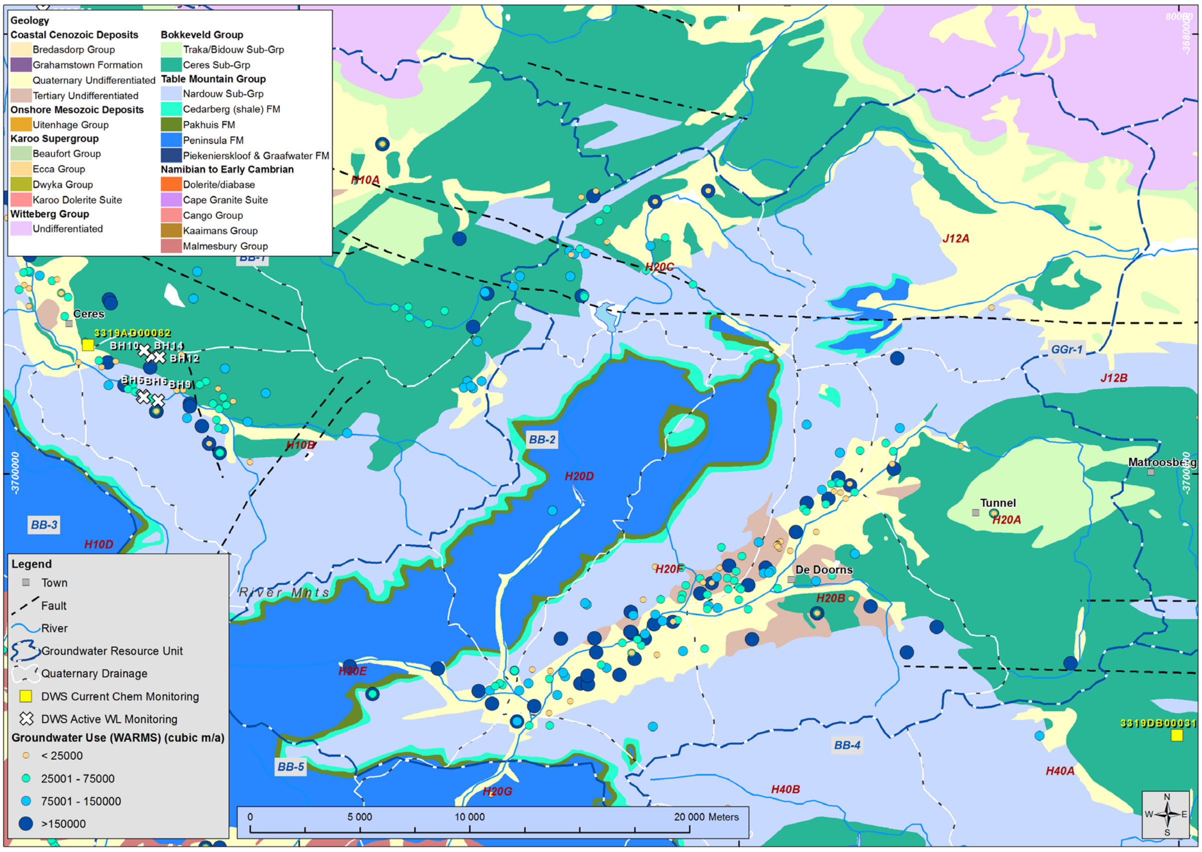


Figure 5-5 Registered groundwater use in the Hex River Valley, around the town of De Doorns (from DWS, 2017b)

5.1.3. Decentralised Groundwater Supply for Urban Resilience

5.1.3.1. *WCG Water Business Continuity Planning Programme – the plan*

The use of groundwater for non-potable purposes (i.e. garden irrigation) is beginning to receive recognition in South African MMs, and has been recommended for some time by the City of Cape Town in their water conservation and demand management strategies, and their water sensitive design measures (section 3.2.1). The current drought in Cape Town led to a significant increase in the decentralised use of groundwater, and not only for non-potable sources. Significant numbers of users from industry, the services sector such as hospitals and schools, domestic individuals, and also from the tertiary services sector (banks, office blocks) initiated groundwater development whilst there was a real possibility of supply interruptions due to shortages, developing "off grid" supplies. Whilst in many cases the boreholes and associated pump infrastructure were installed under what was considered an emergency, in order for the infrastructure to be worthwhile the investment, the majority of these users will utilise their alternative groundwater supply permanently to realise the return on investment.

The Western Cape Government is one such user within the City of Cape Town that embarked on the development of "off grid" water supply. Once it became clear that the 2017 winter rainy season had done relatively little to replenish dam levels in the supply system feeding Cape Town, the Western Cape Government begun planning to maintain supply at priority Department of Health facilities. The "Water Business Continuity Planning Programme" was established, and a hydrogeologist appointed directly as advisor to WCG to manage the programme. The programme assigned a priority status (A, B, C) to 87 facilities in the Western Cape, and set the ambitious aim of establishing groundwater supply at all facilities before "day zero", should it arrive. For the priority A facilities this meant a time frame of ~4 months for drilling testing and commissioning based on the expected outlook at the time. Under the programme six groundwater companies, three drilling companies, three pump test contractors (each with several rigs), and five engineering companies were initially appointed to the WCG in October 2017, with each contractor being assigned a groundwater company to which they were accountable, and each hydrogeologist and engineer forming a team. The brief to hydrogeologists was to drill and test as many boreholes as needed on site to provide for the site water demand, and backup should one borehole pump breakdown, starting with "priority A sites", then B and then C.

The 87 facilities included hospitals, community health centres (clinics), community development centres, and three WCG offices, with a total demand of 5762 kl/day, required more than 166 boreholes to be drilled (Table 5-1). Facilities within the City of Cape Town Metropolitan area made up over 77% of this total demand and are shown in Figure 5-6.

Table 5-1 Details of WCG Business Continuity Plan showing number of facilities, their water demand, and number of boreholes to be drilled

	Total	Phase 1	Phase 2	Phase 3
	All sites (WC)			
Number of sites	87	30	32	25
Number of boreholes expected to be required	>166	>66	>50	>50
Estimated Demand (kl/d)	5762	4124	1242	396
	CCT Metro sites			
Number of sites	54	14	22	18
Number of boreholes expected to be required	>102	>39	>43	>20
Estimated Demand (kl/d)	4463	3233	979	252

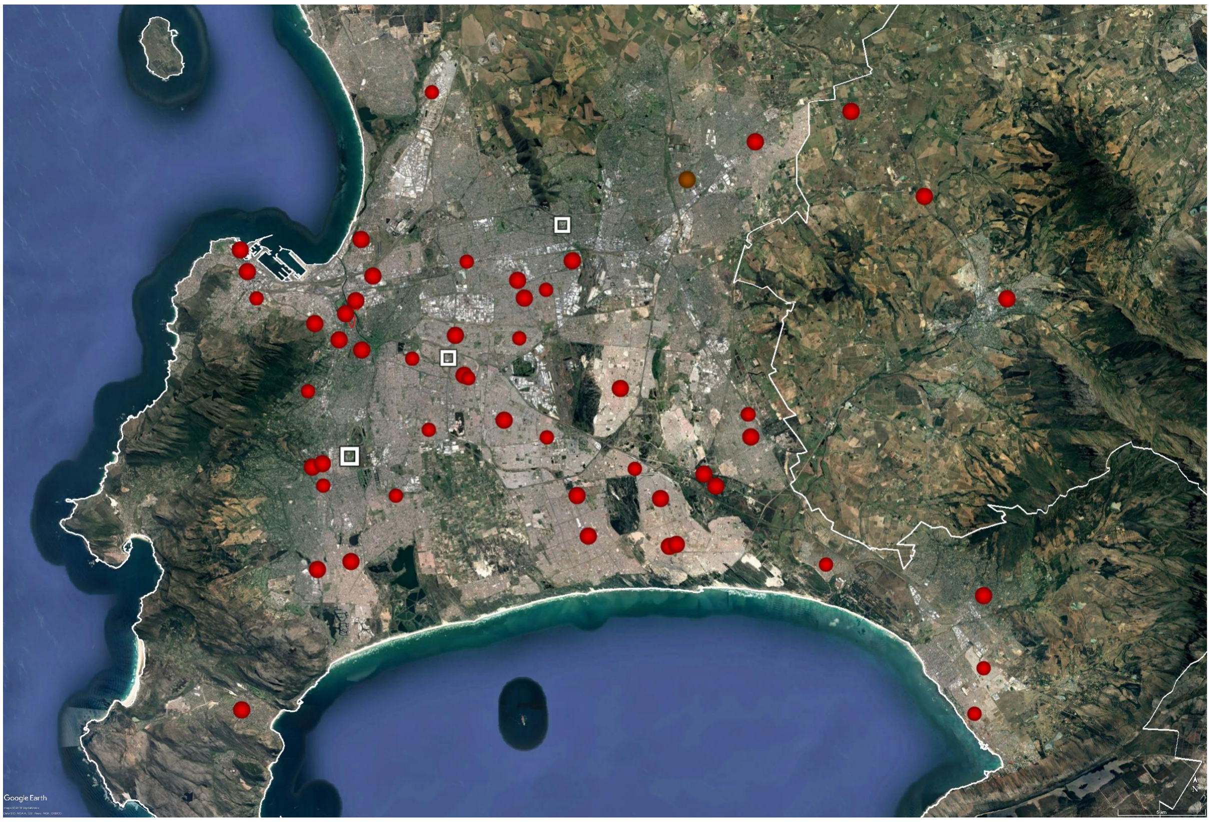


Figure 5-6 Location of sites included in the WCG Business Continuity Plan for the development of groundwater supply within the southern part of the Cape Town Metropolitan Municipality (outlined in white) with health facilities in red, offices in white.

5.1.3.2. *WCG Water Business Continuity Planning Programme – results*

Results are documented for 17 of the 55 Cape Town sites, for which data is currently available. Boreholes were sited based on hydrogeological considerations, and also proximity to incoming mains, in order to maximise the ease of supplying the groundwater to the facility. All drilling and testing of the first phase was complete by January 2018 as planned. All drilling and testing of the second and third phase was completed by March and May 2018 respectively.

Of the 17 sites, **all** were successful in meeting the facility demand from groundwater resources onsite, with the combined yield of the boreholes drilled onsite able to provide between 1 and 10 times the demand (Table 5-2). Ten of the 17 sites are situated on the Cape Flats and target the Cape Flats primary aquifer (but not necessarily within the most productive part), and as such good results can be expected. However, seven sites were located in areas underlain by the basement rocks of the Malmesbury Formation and Cape Granite Suite, both categorised as intergranular and fractured in the 1:500 000 hydrogeological map series, with expected yields either 0.0-0.1 ℓ/s or 0.1-0.5 ℓ/s. One of these (Stikland Hospital) is in a region where the Tygerberg Formation of the Malmesbury Shale is heavily fractured and so the good results are known to be possible for the area. Boreholes at two other sites underlain by the Tygerberg Formation of the Malmesbury Group shale also succeeded in intersecting significant fractures and achieved good yields (>1 ℓ/s per borehole). The remaining four sites (one in the Malmesbury Group and three in the Cape Granite Suite) are low yielding, with borehole yields around 0.1 ℓ/s common. Nevertheless, the low demand at these sites could still able to be met by the yield achieved.

Whilst the drilling and testing of the boreholes was completed within the timelines outlined above, the engineering design and construction phase of the project has progressed much more slowly than hoped. Presently, 1 year after initiation of the project, 4 of the 17 sites have recently been commissioned and run from groundwater permanently. An additional two will follow shortly. Regarding the remainder, whilst the designs are complete, the decisions over whether the remainder will be commissioned are outstanding. With day zero not materialising, the incentive is reduced. Also, although the local groundwater resources are sufficient for supply, in many cases the groundwater quality requires extensive treatment, particularly true for the sites targeting basement aquifers. At one site in the basement with low yield, the installation is unlikely to proceed because of the treatment cost.

Table 5-2 Details of WCG Business Continuity Plan showing number of facilities, their water demand, and number of boreholes to be drilled. CFA = Cape Flats Aquifer; CGS = Cape Granite Suite; CMD = Cape Medical Depot; CDC = community development centre; CHC = community health centre; SSC = shared service centre (Delta-h, 2018a).

Site	Demand (actual) (kl/d)	Boreholes existing	Boreholes drilled	Aquifer	Combined borehole yield[2] (kl/d)	Borehole yield / Site demand
Total from subset of Cape Town sites (17 of 55)	1246.8	13	33	n/a	3540.7	2.8
Somerset Hospital	216.0	0	4	Malmesbury Fm	432.0	2.0
Stikland Hospital	129.6	3	2	Malmesbury Fm	691.2	5.3
Horizon Youth	43.2	0	2	Malmesbury Fm	216.0	5.0
Alfred Street CMD	11.2	0	2	Malmesbury Fm	15.6	1.4
Metro South	51.8	0	4	CGS	69.1	1.3
False Bay Hospital	19.9	2	2	CGS	25.9	1.3
Lady Michaelis CDC	6.0	0	1	CGS	8.6	1.4
Lotus River CDC	8.6	0	1	CFA & CGS	86.4	10.0
Lentegeur Hospital	388.8	7	2	CFA	518.4	1.3
Mitchells Plain CHC	43.2	0	2	CFA	432.0	10.0
Khayelitsha CHC	25.9	0	2	CFA	172.8	6.7
Khayelitsha Hospital	121.0	1	1	CFA	432.0	3.6
Michael Mapongwana CDC	25.9	0	2	CFA	25.9	1.0
Gugulethu CHC	25.9	0	2	CFA	129.6	5.0
Vangate SSC	103.7	0	2	CFA	172.8	1.7
Grassy Park CDC	8.6	0	1	CFA	25.9	3.0
Hanover Park CHC	17.3	0	1	CFA	86.4	5.0

5.1.3.3. *WCG Water Business Continuity Planning Programme – lessons*

The WCG BCP project demonstrates that groundwater availability was not the limiting factor for groundwater supply at the site scale. Within the timeframe of ~7 months, the demand could be met at the majority of the sites from the boreholes drilled and tested. The demand provided for from groundwater in Cape Town (4463 kl/d or 1.6 million m^3/a) is equivalent to the small desalination works established at the waterfront during the drought, and equivalent to 1% of the total metropolitan supply during the drought. The division of labour under the central oversight of one highly experienced advisory hydrogeologist was a key to the rapid and successful roll out of the project. Given many sites were not on productive aquifers, this result could likely be replicated at other metropolitan municipalities.

[2] Impact of borehole interference estimated

However, groundwater quality may require potentially prohibitive treatment costs, and the time lag for the engineering design and construction means that groundwater supply may not be online on time in an emergency situation.

5.1.4. Interventions for decentralised supply

At the onset of the drought, off-grid water supplies were not catered for in terms of the City of Cape Town by-laws and were not favoured. Resistance came from concern for impact on revenue of water sales, revenue from waste effluent charges (as these are related to a portion of water supplied), and concern for cross contamination of the reticulation network via the introduction of alternative sources (section 4). The latter can be managed with the installation of a non-return-valve prior to the connection with alternative source. The CCT, however, recognised that several users were installing regardless of permissions and during the drought adjusted the by-laws and provided guidelines to cater for off grid supplies (CCT, 2018a and CCT, 2018b). The new by-laws cater for the installation of "alternative water" systems (i.e. groundwater, grey water), and requires these to be installed by certified plumbers and inspected. It is therefore recommended that:

- The use of groundwater for non-potable uses (i.e. garden irrigation) be promoted by all metropolitan municipalities.
- All metropolitan municipalities promote the use of alternative water sources for new developments, thereby encouraging the use of groundwater for dual reticulation for example
- Guidelines for alternative water systems be produced by all metropolitan municipalities, following the example set by CCT

Other criticism of off-grid groundwater supply centres on it being a challenge to manage and regulate the resource particularly in relation to competition for supply and the cumulative impact of several small users. The impact of all current and planned groundwater use can be accurately estimated (if data on current and future groundwater use is available), so this is not a technical challenge. The criticism of decentralised groundwater use therefore relates to governance issues, rather than technical challenges, which are worth addressing given decentralised use distributes drawdown and is the most optimal use of an aquifer particularly with limited saturated thickness.

There are deficiencies in the process by which our major aquifers are managed and licences are awarded, which means that the cumulative impact of groundwater use cannot easily or routinely be taken into account. Each individual licence application must consider all other users that may be impacted, and demonstrate the potential impact on neighbours. The DWS therefore transfers the responsibility for resource management to the applicant. Each applicant may take a different approach for this, and water balance type approaches (comparing total use to recharge over some area) are standard. The applicant is likely to consider the area relatively local to the abstraction, or at most the quaternary catchment, rather than carry out a resource-wide assessment. Whilst a new applicant can request a copy of the WARMS datasets from DWS in order to consider existing users, the time taken for licensing means that any new application will not be able to take into account other recent applicants who would be licensed before them but who are not yet awarded their licence and reflected in WARMS. This was a particular challenge during early 2018 when within 6 months, around 300 water use licenses were submitted to DWS regional office, for use of groundwater in the greater Cape Town region (pers comm W. Dreyer). The DWS is therefore left with WULAs which cannot hope to accurately reflect the impact of their abstraction on the resource; and furthermore, the DWS has no tools at their disposal to make this judgement.

This lack of consideration of cumulative impact of abstraction, and lack of tools to assess this, is in part related a more fundamental problem. There are severe deficiencies in centralised data collection and storage which hamper any attempt at groundwater resource management:

- The extent of current registered legal use and actual use is not known: there are inaccuracies in WARMS database; the Validation and Verification of water use is incomplete or not available outside of DWS.

- There is not a complete record of groundwater use; whilst most MMs require the registration of boreholes and wellpoints, there is little information on the degree of uptake / number of unregistered users, and the yields used. Although each domestic use will be small, it must be taken into account when considering the impact on the whole resource.
- Related to the lack of registration of boreholes, there is no requirement for drillers to declare boreholes drilled and they are not regulated.
- The primary groundwater data source resides in the private sector. Consultants drill boreholes, prepare reports, and undertake significant monitoring. Some of this data is reported to DWS, however it does not get entered (by DWS or the consultant) to any central database to make it available for anyone attempting to assess aquifer-wide conditions. Regional studies rely on data from the National Groundwater Archive (NGA), which generally ceased to be populated in 2004. Whilst the NGA is capable of being used for upload of data, it is not a straight forward process and not being used as such.

The challenges with decentralised groundwater supply therefore highlight the need to implement the following recommendations:

- It is recommended that all heavily used aquifers are managed with calibrated numerical models that are developed and managed centrally (by the DWS, or under contract to DWS, or by another party with delegated authority for water resources management from DWS), such that the allocable groundwater resource under various recharge scenarios could be well quantified, and the cumulative impact of each licence application would be estimated prior to awarding a licence (similar to the UK example, case study 3, section 3.2.1). This recommendation is echoed in Seyler et al., 2016b and in DWS, 2018.
- The registration of boreholes drilled is required, along with the requirement for drillers to submit data from any borehole drilled (location, log, water strikes, blow yields). These recommendations echo those in DWA, 2010d, DWS, 2016d, and in Braune et al., 2014.
- It is recommended that the sharing of all groundwater data be made compulsory, and a centralised easy to use database be constructed (or the NGA adapted) for this purpose. Again, these recommendations echo those in Braune et al., 2014; DWA, 2010d, DWS, 2016d, and also in Seyler et al., 2016b and DWS, 2018.

Position paper 2: Beneficial use of groundwater dewatered from underground structures

We gratefully acknowledge those who have contributed data to this paper:

- Les Hall, Woolworths
- Lance Hoffman, Redefine Properties
- Claire Pengelley, GreenCape
- Gavin Code and Roger Parsons of WCG Business Continuity Project
- Chelina Brodie of the Gautrain Management Agency

5.2. Beneficial use of Basement (Ground)water

5.2.1. Introduction

Urban areas have high water demand due to the concentration of population, industry and business. With supply schemes already constrained in some MMs, and becoming constrained in other areas, individuals, businesses, industries and municipalities are increasingly aware that measures that reduce demand are critical. For example, the use of groundwater from private wellpoints and boreholes – rather than potable water from the municipal supply scheme – is promoted in several MMs for garden watering. In line with this is rising acknowledgement that wasteful practices should be avoided, and water re-used where possible.

During the last few months of 2017 and early 2018, failure of the municipal water supply system was considered a real possibility for the City of Cape Town (and presented by the provincial government and the city as such) if water demand did not dramatically decrease. A significant number of hospitals, schools, businesses, industries and households elected to develop alternative water supply during this time rather than face the risk of supply interruption and associated impacts on operations. In the majority of cases this meant installing a wellpoint or borehole, and connecting it with the existing supply system onsite, with a non-return valve such that the introduced water does not contaminate the municipal supplies. Attention also naturally turned to reducing all wasteful water activities. Related to this, several groups (water users, CCT, provincial government, NPOs, researchers) turned to promoting the beneficial use of groundwater abstracted in basements and discharged to stormwater drainage. The GreenCape Sector Development Agency ran a seminar on the use of basement water on 14th February 2018 with the purpose to promote use of basement water with businesses, as a means to become resilient from water supply constraints and to support and guide businesses who may want to pursue the option.

Whilst beneficial use of water that is abstracted in urban areas for dewatering purposes is not particularly innovative, prior to the current drought in Cape Town the practice was probably only practiced by a handful of 'forward-thinking' newer buildings around Cape Town. The crisis spurred investment in alternative sources, and reduction of wasteful activities. Taking the lessons learnt from Cape Town, several sites with basements in Tshwane were investigated to determine the potential for beneficial use of the abstracted water. Whilst Tshwane is not (currently) experiencing the same kind of water supply constraints as Cape Town is, the future outlook suggests that the Vaal Water Supply System (VWSS) will eventually face constraints, and the City of Tshwane has been asked by DWS to implement WC/WDM measures (section 2.3.3).

This position paper outlines case studies of basement water use from Cape Town and Tshwane investigations, with the aim of promoting the beneficial use of basement water by sharing information with potential users and regulators.

5.2.2. Source of basement water

In areas with deep groundwater levels, shallow basements may not require dewatering measures, only drains to ensure rain water does not accumulate. However, underground structures and basements extending below the groundwater table require measures to ensure dry conditions, i.e. dewatering (also referred as groundwater control measures). A typical dewatering system for a basement is shown in Figure 5-7. The design of the low permeability cut-off wall controls the movement of the diverted water.

The water entering basements may also include stormwater derived from rainfall event runoff (i.e. the physical collection of rainfall on the roadway into an underground parking area). Above the water table, water may accumulate in the unsaturated zone on less permeable layers (forming perched aquifers) and percolate into the basement. Even without the presence of perched aquifers, water within the unsaturated zone moves, and may seep towards the basement. The water entering basements may therefore be a mixture of groundwater (in cases where basement extends below groundwater table), perched groundwater, stormwater, and shallow seepage water from the unsaturated zone. The source of basement water relates to the licensing necessary for its use (section 5.2.5).

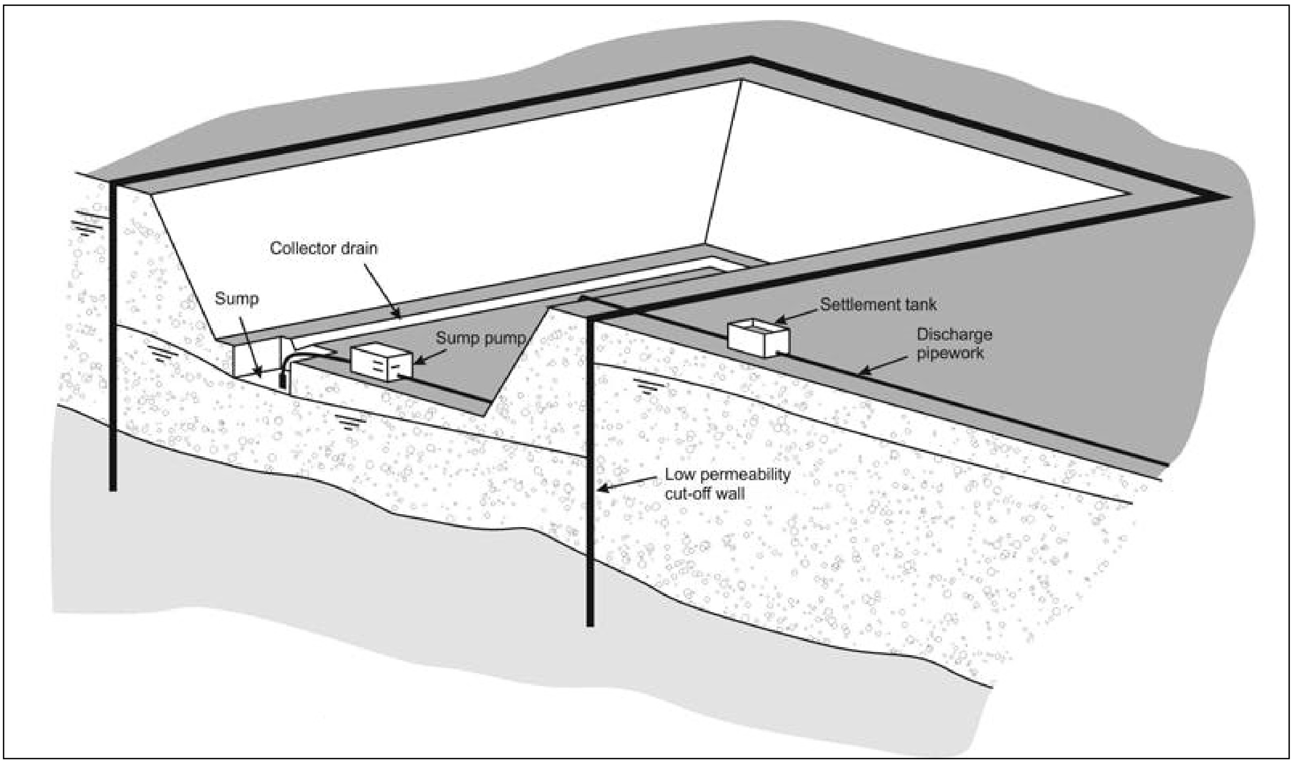


Figure 5-7 Typical groundwater control in basements (Groundwater Engineering, 2015)

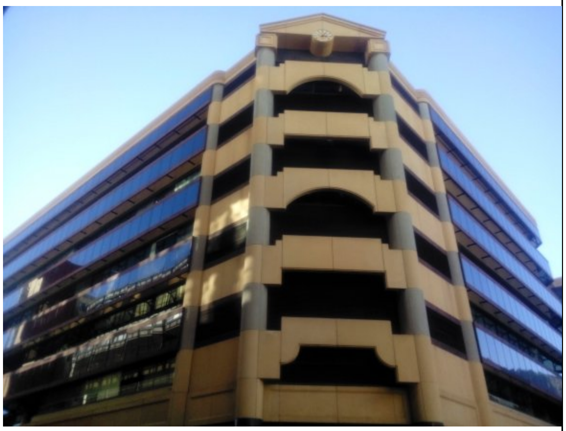
5.2.3. Cape Town

5.2.3.1. *Demonstration cases*

Woolworths head office campus, Corporation Street, Cape Town's CDB

The head office campus includes several separate buildings with various functions (offices, shops, hairdresser, car wash). The campus makes use of a water-cooled air-conditioning unit, which runs permanently.

Water seeps into the various sumps in building's basements, and prior to 2010 this water was discharged to the city's stormwater system. It made business sense for Woolworths to invest in the use of this water for beneficial means, a step which is in line with their commitment to sustainable practices.



The first phase was commissioned in October 2010 and supplies treated water for non-potable purposes including cooling, sanitation, use in ornamental fountains, and car washing. This was extended to supply all buildings in the campus in 2015.

The water quality requires treatment and a system was installed comprising:

1. Collection of water from all sumps to a central collection tank;
2. Ozone circulation system for bacterial removal;
3. 2 sand filters, a carbon filter, and high-pressure reverse osmosis ;
4. Final chlorination to prevent bacteriological growth in distribution.

The scheme has a yield of 90 kl/d, and a storage of 155 kl. The yield is relatively high for shallow seepage water, equivalent to 1 ℓ/s. Since commissioning, the scheme has provided on average 39 kl/d, reducing the potable water consumption onsite by 70%. Woolworths currently intend to extend the scheme to supply all potable water.

The Towers Standard Bank building, Cape Town's CDB

The Towers Standard Bank building in Cape Town's CDB was recently refurbished due to its age and lack of onsite parking. Various green initiatives were considered as part of the refurbishment including energy efficiency and water use. The building is located in an area of foreshore-reclaimed land. A significant amount of water was being pumped out of the basement to stormwater drainage network, and the feasibility of using the water was investigated.

Based on water quality results, a treatment system was setup with a filtration plant sufficient to treat the water for non-potable purposes. As part of the refurbishment, dual reticulation was plumbed to the ablution blocks, delivering basement water for flushing purposes, and for air-conditioning.

The capital investment for the basement water system was estimated at R1.3 million, which will be recovered in a 3-year period.

Western Cape Government's Cape Medical Depot, Alfred Street, De Waterkant

The Cape Medical Depot (CMD), in Cape Town's Waterkant area of the CDB, was included in the Western Cape Government's (WCG) Business Continuity Project, which involved the establishment of alternative supplies of water to priority WCG facilities during the drought. This facility provides a stable storage environment (refrigeration) for medical supplies and also runs a laboratory for medicine quality control.

The site is inland of the V&A Waterfront reclaimed land and is utilised by three independently operating entities with shared reticulation: South African Police Service (SAPS), Cape Provincial Library Service, and Alfred Street CMD. The site is almost entirely made up of buildings, making drilling boreholes for groundwater supply a challenge.

The site has a (total) water demand of 14 kl/d, and basement parking extends under part of the site. Dry conditions are maintained in the basement by two connected sumps (sump "ACs2" shown) which divert collected water to stormwater.

The yield of these sumps was estimated to be 9 kl/d. Lab results showed excellent water quality (within SANS2015 drinking water quality with the exclusion of colour, turbidity, and bacteria).

A borehole was drilled onsite to supplement water from the sump. Infrastructure is currently being established to collect sump water, treat it, and use it within the building, supported with borehole water to meet the shortfall.

5.2.3.2. *Up-scaling benefits for the City*

The business case for the beneficial use of basement water is demonstrated in the cases listed, with the return on investment from as little as three years. Reducing demand on the reticulated network also obviously has benefits for constrained water supply systems. Without data on the total number of basements across the City and their groundwater yield, quantifying the potential water demand savings available to the City of Cape Town – should all basement water be diverted for beneficial use rather than disposed of – is challenging. Whilst typical groundwater yields could be estimated based on a few measured case studies, an audit of all underground basements would be required.

The GreenCape Sector Development Agency ran a seminar on the use of basement water on 14th February 2018 which was attended by businesses interested in the use of basement water. Many of these businesses were in the services sector, or property developers who owned large buildings occupied by services industries or residential buildings. Out of around 30 attendees, 17 reported that their buildings did have basement water available, and a further three recorded that their buildings had surplus compared to their demand (Figure 5-8), though no basement yields were recorded. Seven properties reported having basement water available in the central CBD area. Based on a preliminary assessment of satellite imagery of large buildings assumed to have basements, the seven reported may reflect between 5 to 20% of the total number of buildings with basements in the CBD. If one such large building consumes around 8-14 kl/d (based on the demonstration cases), the total yield available from basements in the CBD may be up to 2 Ml/d. Reducing the demand on the reticulation by 2 Ml/d would be significant; this is the same yield as the first water supply intervention commissioned during the drought (March 2018) – a desalination plant at waterfront producing 2 Ml/d.

Promoting the use of basement water in Cape Town is based on the assumption that its abstraction (and other planned future abstractions) can be sustained by the local groundwater resources. However, the water is being abstracted regardless, by virtue of the presence of the basement. The underground structures essentially act as French drains, skimming the top off the aquifer, and locally reducing the water table. An assessment of abstraction scenarios for the Cape Flats aquifer has demonstrated that local small-scale abstraction is more effective in harvesting groundwater than larger point source abstraction, because the saturated thickness of the aquifer limits the yield available at individual boreholes (Seyler et al., 2016). The yield abstracted from basements may be reduced should the regional groundwater table be reduced in future, due to large-scale abstraction and / or climate change reducing recharge. Nevertheless, whilst it is being abstracted to maintain dry conditions, the case for its utilisation rather than disposal is clear.

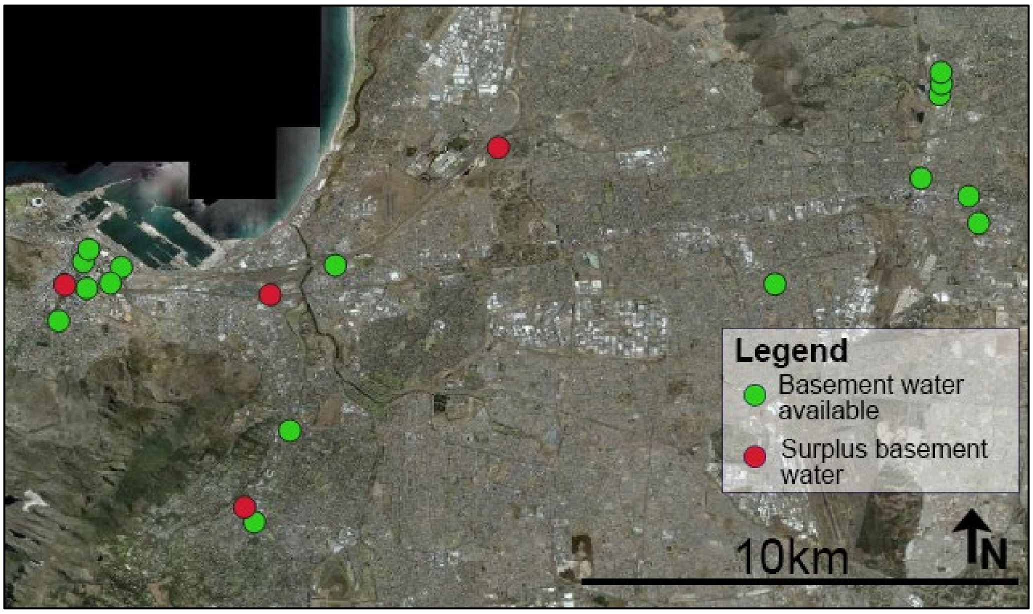


Figure 5-8 Map of Greater Cape Town area showing the locations of selected businesses with basement water available, based on user reported information.

5.2.4. City of Tshwane

5.2.4.1. *Demonstration cases*

State Theatre, Pretorius Street, Tshwane's CDB	
Located in the heart of Tshwane city centre, the State Theatre consists of five arenas, a large public square and a number of restaurants. There are three basement levels (13.4 m depth), and the groundwater ingress is managed by collecting the seepage in three sump pits and discharging for disposal into the municipal stormwater drainage system. The possibility of supplementing the heating, ventilating and air conditioning system (HVAC) with groundwater to reduce water consumption from the council was investigated.	
	The total water demand of State Theatre is 136 kl/d, of which 60-75% is used for the air-conditioning cooling system. The yield of the sumps was estimated to be 133 kl/d, which could potentially cover almost 98% of the State Theatre's total water demand. Groundwater quality results showed excellent water quality (within SANS2015 drinking water quality with the exception of turbidity) and it can be used in HVAC system with minimal filtration requirements.
The total cost of HVAC system's modification to utilise basement water was estimated at R1.5 million, and, with an estimated annual saving of R0.54 million per year, the capital would be recovered in a 3-year period.	

Reserve Bank, 370 Helen Joseph Street, Tshwane's CDB

The South African Reserve Bank (SARB) is the central bank of the Republic of South Africa. SARB has 38 floors and four basement levels (13.4 m depth). Groundwater seepage is collected in two sumps; some of it is used for garden irrigation, while the rest is discharged into the municipal stormwater system.

SARB currently uses potable water from the municipal reticulation network for domestic, mostly non-potable uses – car-wash, fountains, toilet flushing and air condition system – hence could benefit financially from integrating basement water into its water systems.

The total water demand of the building is 112 kl/d, which can be fully met by the estimated yield of the sumps (155 kl/d). Groundwater quality results showed excellent water quality (within SANS2015 drinking water quality), so only minimal filtration treatment is necessary.

SARB is currently considering the option of using the basement water for its supply.

Tshwane House, Madiba Street, Tshwane's CDB

Tshwane House is the new headquarters for the CoT MM, and was one of the first Government buildings to target a 5-Star Green Star SA certification within a public-private partnership (PPP).

The building has three basement levels (9 m depth) situated on Madiba street and two basement levels on the Johannes Ramokhoase Street. The seepage groundwater is collected in two sumps and discharged into the municipal stormwater drainage system.

Tshwane House uses potable water for drinking, fountains and air condition system, as well as collected (and filtered) rainwater for toilet flushing. The total water demand is approximately 45 kl/d, which could be met by the estimated sump yield of 52 kl/d.

Groundwater quality results showed excellent water quality (within SANS2015 drinking water quality with the exception of turbidity and bacteria, so filtering and bacterial disinfection would be required).

Tshwane House is currently considering using its basement water supply for toilet flushing and fountains.

Demar Building, 371 Francis Baard Street, Tshwane's CDB

Demar Building is a residential building with three basement levels (8.3 m depth), and the basement water is collected into a single sump and discharged into the stormwater drainage system.

The Demar Building currently uses potable water for domestic uses (e.g. drinking, cleaning flushing toilets), garden irrigation and air condition cooling system.

The water demand of the building is 45 kl/d, while the total yield of the sumps is estimated to be 15 kl/d. The groundwater quality is good and within SANS2015 standards (except for faecal coliform bacteria).

While basement water cannot meet the entire water demand, it can be used to augment the water supply (though some filtering and bacterial treatment would be required).

Centre Walk, 267 Helen Joseph Street, Tshwane's CBD

Centre Walk is a shopping centre with two basement levels (9 m depth). Basement water is collected into a single sump and discharged into the municipal stormwater drainage system.

The building use potable water for domestic use (e.g. drinking, cleaning, and toilet flushing), garden irrigation and air condition cooling system.

The total water demand of the building is 14 kl/d, which can be partially met by basement water (approximately 4.3 kl/d).

Groundwater quality results showed excellent water quality and is within SANS2015 drinking water quality standards (with the exception of faecal coliform bacteria).

5.2.4.2. *Up-scaling benefits for the City*

Though in some areas of City of Tshwane the groundwater level may be as deep as 50 mbgl because of groundwater abstraction, in general the average groundwater level is relatively close to the surface (3-4 mbgl). A hydrocensus by Bengeza (2018) in the TMM's CBD investigated 20 sites, 15 of which were found to have basements with groundwater seepage. Of these identified properties, five were investigated in detail as case studies and were used to extrapolate a rough estimate of the overall basement yield in the CBD. The city's CBD was divided into blocks, and each block was assigned a basement water yield value based on the most proximal case study site's measured value – resulting in a maximum total yield of approximately 2.3 Ml/d. In comparison, if the average basement yield (72 kl/d) calculated from the five case studies is applied to the 15 identified sites with basement seepage, an estimated minimum yield of 1.1 Ml/d is found.

Though highly uncertain, these values offer an indication of the total potential water demand savings available to the TMM from diverting basement water for beneficial use, however, as with the CCT study (section 5.2.3.2), quantification is difficult without a complete audit. Nevertheless, this range of 1.1-2.3 Ml/d indicates that basement water comprises a non-negligible fraction of the total TMM's annual water demand (up to 0.74%), which is comparable order of magnitude to 12.6% of TMM's Rietvlei Dam's annual yield. Therefore, if implemented on a regional scale across all of TMM, basement water utilisation could alleviate some of the City's water demand in a sustainable manner and reduce reliance on surface water.

5.2.5. Legal definition of basement water and necessary permissions

5.2.5.1. *National government permission*

The DWS Cape Town regional office experienced a significant increase in requests for guidance of basement water use during the 2017-2018 drought. In order to promote the use of basement water with businesses, as part of the February 2018 seminar on the use of basement water hosted by GreenCape, the necessary permissions for the beneficial use of basement water were investigated. The information reported here is based on the analysis of the national legislation, investigations GreenCape conducted with DWS, and on the insights given by the reported demonstration cases.

There are various uses of basement water to consider, each of which would require a different set of permissions: use for non-potable verses potable supply, and use in the same building (by the same owner / business that is abstracting from the basement) compared to provision or sale of surplus basement water to another user. The relevant legislation includes the National Water Act (NWA), the Water Services Act and the Water and Sanitation by-laws of the city the basement is located.

Whether the water is to be used for potable or non-potable purposes, the basement acts as a drain capturing the local groundwater, which is then pumped out to maintain dry conditions. The basement therefore abstracts groundwater, an activity covered by Section (21)a of NWA – abstracting water from a water resource. The type of registration or licence required for water abstraction then depends on the type of intended use and the abstracted yield. Schedule 1 of the NWA allows water to be taken from a water resource (Section 21(a)) without registration if the use is for "reasonable domestic use" only, including small garden irrigation. If the use is not only domestic purposes (and use by a business is not considered domestic), then either a General Authorisation (GA) or a Water Use Licence is required for water abstraction. The distinction between the two is related only to the abstracted yield, and the GA limit is set per the given quaternary catchment. In the Greater Cape Town area (catchments G22A to G22E) the GA limit for section 21(a), taking water from a water resource, is 400 m^3/ha/year. For a large building with an area of 0.1 km^2 (approximately the area of the Alfred Street demonstration case with 9 kl/d abstraction), abstractions of over 4 kl/d would require to be registered with the GA. The GA limit for 21(a) reduces to 150 m^3/ha/year to the north of Cape Town (Milnerton, Bloubergstrand, Atlantis, G21A to G21F) (DWS, 2016b).

However, basement water is a mix of groundwater (where the basement is below water table), shallow seepage water, and runoff (section 5.2.2). In communications with DWS, it became clear that basement water is not considered (by DWS) as groundwater, therefore not a "water resource" and hence Section 21(a) does not apply. An alternative legal classification of basement water is under section 21(j) of the National Water Act:

> "removing, discharging or disposing of **water found underground** if it is necessary for the efficient continuation of an activity or for the safety of people" (NWA, 1998, Section (21)j).

Water found underground is legally defined in the Government Gazette as "water that enters mine workings, basements, tunnels, or other construction through seepage or runoff and does not refer to water found in an aquifer" (DWA, 2013c, p26). Basement water clearly poses a problem as its source will be mixed, hence falling between section 21(a) and 21(j). Removal, discharge and disposal of water found underground is not listed under Schedule 1 (i.e. it is not permissible without registration / license), hence any activity triggering 21(j) will require registration under the GA applicable to 21(j). The GA limit for section 21(j), provided the person removing water legally owns it or has legal access to the land on which section 21(j) occurs, is the removal of "up to 100 cubic metres of water found underground on any given day, if the removing of water:

- does not impact on a water resource or on any other person's water use, property, or land;
- is not detrimental to the health and safety of the public in the vicinity of the activity; and
- does not detrimentally impact on the stability or health of the surrounding ecological functioning of any hydrologically lined water resources." (DWA, 2013c, p26)

The previous discussion refers to the actual activity of removal of basement water to maintain dry conditions. The subsequent re-use of this water is permitted under the GA, which states that the removed water must be discharged to a water resource, or disposed of, or re-used. The GA limit for 21(j) of 100 m^3/d (100 Kl/d) is likely to be sufficient for the removal of water from basements around Cape Town. Furthermore, the GA states that the user must meter the quantity of water removed, and that the quality of raw water abstracted must also be monitored, but in accordance with the requirements for its use.

Whilst the above legal definition(s) of water entering basements make intuitive sense, the DWS has advised on the following, and some contradictory and confusing issues continue to emerge:

- The latest guidelines for alternative water installations from CCT (CCT, 2018) list that approval is required from DWS (in terms of Schedule 1, a GA, or licence) for use of basement water as per groundwater and surface water. The guidelines do not specify how DWS would define basement water and therefore whether the approval is required in terms of section 21(a), or as 21(j) (described below).
- Some personnel have advised that section 21(j) is considered by DWS to only apply in mining situations and not in basements, largely because of an assumption that section 21(j) refers to water that contains waste, which is not applicable to basement water (an opinion shared by the Directorate of Compliance Monitoring, and reflected in the grouping of (21)j under wastewater in the online guidance for licensing: http://www.dwa.gov.za/Projects/WARMS/).
- Other personnel at DWS have advised that basement water should be considered wastewater, and falls under section 21(j) (an opinion shared by the Berg-Olifants catchment management agency). Therefore, non-potable use or disposal of this water is permissible, within the GA limits applicable to section 21(j), and acknowledging the requirement in the NWA for its disposal to not impact on a water resource / health or the environment.
- Practically speaking, those at DWS within the regional office licencing department have begun to advise that basement water can be used without any permission or regulation from DWS, which is feasible if basement water is classified as grey water or stormwater, instead of a water resource or water containing waste.

As the purpose of the NWA and the associated water use licenses is to regulate water use for the protection and fair use of water resources, then it is perhaps appropriate that basement water be considered grey water and exempt from licensing; assuming small / localised impact of its removal. However, the lack of records for all locations and yields of groundwater abstraction (be it from a wellpoint, borehole or a basement), poses a problem for aquifer management as an accurate picture of current groundwater use and therefore the available yield is impossible to attain. The advantage of implementing the need for basement water abstraction (regardless of its eventual use) to be registered with DWS, is that the GA requires the metering of the quantity of water removed. Enforcement of this requirement even once registered is a further challenge.

5.2.5.2. *Local government permission*

- City of Cape Town

Regardless of the definition of basement water as per the NWA, use of any water other than that supplied by CCT for non-potable and potable purposes triggers the requirement for several permissions as stated by the CCT's municipal by-laws, for both the use itself and the installation. Permission is specifically required for the connection of the alternative water supply to the distribution system: "no person may connect a water supply obtained from any source other than the water supply system of the City to any water distribution system without the prior written approval of the Director, and in accordance with any conditions determined by him or her" (CCT, 2010, section 56(2)). As an example, the permission from the CCT for the Woolworths basement water system is shown in Figure 5-9, which refers to the system as a "greywater facility".

The Water Services Authority (in this case, the CCT), has a mandate to provide all potable water in the area of jurisdiction. Therefore, should the water abstracted in a basement be used for potable purposes, several additional permissions are required. In the case of the CCT, the 2010 by-laws state that "no person may use or permit to be used any water obtained from a source other than the water supply system of the City for domestic purposes" (CCT, 2010, section 56(1)). This condition is under amendment to "no person may use or permit to be used any water obtained from a source other than the water supply system of the City for domestic purposes without the prior written approval of the Director, and in accordance with any conditions determined by him or her" (CCT, 2017c, section 56(2)). To supply potable water from treated basement water, for example in the case of a landlord of a large residential block, the Water Services Act Water Services Act, 1997 (Act 108 of 1997) also requires for the landlord to enter a contract with the CCT to become a Water Services Intermediary. The contract would detail the specifications for water quality, the requirements for monitoring of water quality, and would likely exempt the CCT from liability if sub-standard water was provided leading to health implications. Likewise, any "transfer" of water abstracted from basements for another use, in the case that surplus water is available, would also require registration as a water services intermediary, whether the water is to be used for potable or non-potable purposes.

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10 May 2012

WOOLWORTHS HEAD OFFICE AND CAMPUS BUILDINGS

RE: PERMISSION FOR THE COMMISSION OF A GREYWATER SYSTEM AND ITS USE FOR COMMERCIAL/INDUSTRIAL PURPOSES

Sir/Madam

This letter serves to inform you that you are hereby permitted to commission your grey water facility for industrial purposes. The City of Cape Town is satisfied that the required installations are in accordance with its Water by-law, 2010. You must submit your meter readings to Mr David Bester every month for accurate billing of your sewerage charge. You are further required to comply with the City of Cape Town's Water by-law,2010 PG 6847;LA22920 in its entirety.

(for) Director – Water & Sanitation

Figure 5-9 Copy of permission obtained in 2012 from City of Cape Town, in terms of the Water by-law (2010), for Woolworths to utilise basement water (considered greywater) for non-potable industrial purposes onsite

- City of Tshwane

Similarly as for City of Cape Town, TMM's water supply by-laws (TMM, 2003) prohibit the use of water of water from a source other than the water supply system (except for a rainwater tank not connected to a water installation) for either potable or non-potable use without a written consent of a City-appointed engineer and adherence to the imposed regulations regarding the water's use. To gain permission, the water user must provide satisfactory evidence that the water (with or without treatment) complies with the requirements of SANS 241, or that the use of the water will not pose a danger to health.

Furthermore, according to the by-law, a borehole is "a hole sunk into the earth for the purpose of locating, abstracting or using subterranean water [..]" (TMM, 2003, p5), which indicates that basement water, i.e. water collected using abstraction in sump pits, should be required to also comply with all by-laws applicable to boreholes: MM may request notification of planned and existing boreholes, require owners/occupiers to conduct an Environmental Impact Assessment and obtain a permission (and comply with its conditions) from the MM to use the borehole for potable supply, as well as, if the water is discharged into the City's sewerage system, provide and maintain a meter measuring the total quantity of water discharged.

However, it appears that currently in the City of Tshwane the use of basement water is not regulated and/or enforced: of the five investigated sites, none had a permit (or claimed a need for one) to discharge basement water into the stormwater system and none were taking measurements of the discharged water's quantity and quality. Considering the high discharge rates from some of them (e.g. South African Reserve bank with 155 kl/d and State Theatre with 133 kl/d) and the high risk of urban groundwater contamination, the lack of regulation may lead to a shortcoming in the City's ability to manage the groundwater and stormwater systems, and create a health hazard.

5.2.6. Recommendations

This paper makes it clear that there is a business case for the individual building to divert basement water for beneficial use rather than disposal. It is recommended that the WRC send this position paper to the green building council of South Africa and property groups, in order to promote the use of basement water, specifically in any new or re-development sites where there is an opportunity to install dual reticulation systems (i.e. potable water for drinking, and non-potable for flushing).

This paper also makes it clear that there is a benefit to the MM to promote the use of basement water, either for potable or non-potable purposes, in terms of alleviating strain on the bulk supply system. In order to promote implementation, it is recommended that all water services by-laws be amended to discourage the discharge of potentially useable water into the stormwater system.

It is recommended that DWS consider basement water as largely runoff, seepage water, thus applying section 21(j) of the NWA, which requires those removing water from basements to maintain dry conditions, to apply for General Authorisation. The registration process then allows data to be harnessed on the quantity of water removed from basements, which has bearing on urban groundwater resources management. Alternatively, municipality by-laws could be amended to specifically include basement water and enforce registration of the abstracted yield.

5.3. Beneficial use of Tunnel Ingress Water

5.3.1. Gautrain tunnel

With growing population and industry water demand, MMs are seeking to expand their water supply schemes by either upgrading surface water transfer schemes, promoting WCWDM techniques or by exploring alternate water sources, such as desalination plants, groundwater or harvesting stormwater. This position papers aims to illustrate the potential value and economic feasibility of utilising groundwater that would otherwise be discharged without any beneficial use, e.g. ingress water in the Gautrain tunnel as part of its dewatering process.

The Gautrain is an approximately 80 km long train line opened in 2012 connecting the City of Johannesburg, the City of Tshwane and Ekurhuleni. Approximately 16 km of the train line between Sandton and Park Stations is located underground, surrounded mainly by Basement Complex's granite / gneiss and Pretoria Group's fractured aquifer (Figure 5-10).

As part of the dewatering scheme to maintain dry conditions within the tunnel, water ingressing into the tunnel is channelled through a collection drain towards a sump where it is then pumped to the surface, passed through an oil separator removing oil and grease and then discharged. An Integrated Water Use License (IWUL) permitting groundwater discharge of up to 8500 m^3/day was granted in 2007 by DWS.

The daily discharged volume is highly dependent on the season and rainfall recharging the groundwater. The maximum daily discharge limit is rarely reached, and in 2007 varied between approximately 4750-5900 m^3/d with an average of 5200 m^3/d (BCC, 2017). The tunnel water is discharged to the surface through five discharge points (shafts E2, E3, E4, and Sandton and Sandspruit Pump Station (Figure 5-10 and Figure 5-11). Discharge at points E3 and E4 is unknown as it is not measured due to continuously low discharge rates (and are thus considered negligible), while, based on average discharge values between 2013-2017, around 68% of the total water is discharged from E2, 17% from Sandton and 15% from Sandpruit Pumping Station (BCC, 2017). Of these, only the Sandpruit Pumping Station discharges directly to surface water (river), and the remainder discharge to stormwater systems.

It is worth noting that the surrounding groundwater flow system can be assumed to still be in a transient state in response to the dewatering process lowering the regional groundwater table, so over time the total yields will likely continue decreasing until a steady state system (i.e. dewatering losses balanced by capture) is achieved. The final yields and time scales until steady state is achieved are unknown and may take decades to centuries.

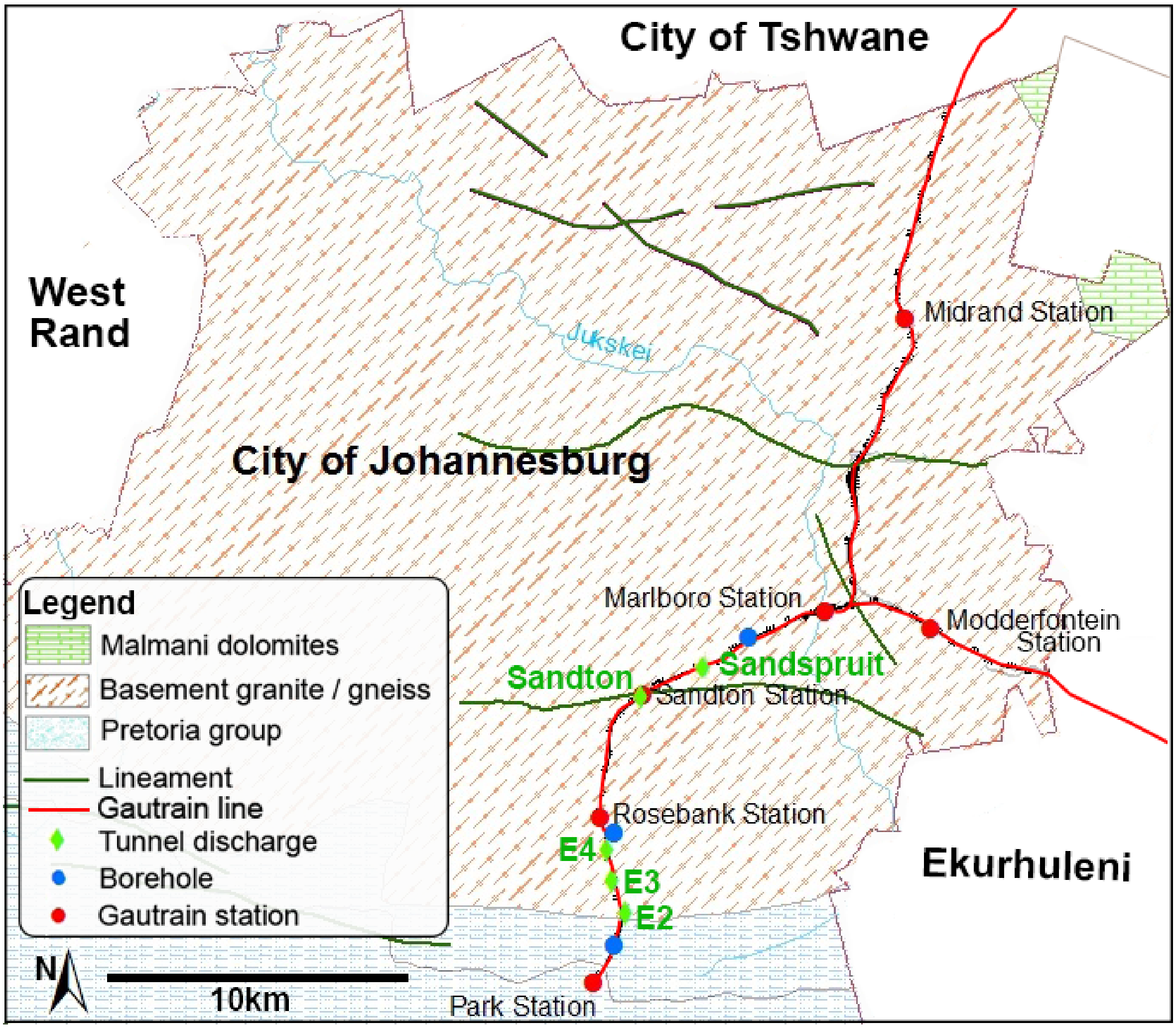

Figure 5-10 Gautrain line, geology and tunnel ingress water discharge points within the City of Johannesburg municipality (adapted from Mahlahlane, 2018).

Figure 5-11 Sandspruit discharge point (BCC, 2017).

5.3.2. pportunities

The potential benefits and opportunities of the ingress water has not been fully recognised. The current average discharge of 5200 m^3/d equates to a total annual discharge of 1.90 million m^3/a. While it is only 0.3% of CoJ's annual water demand, it remains a potentially significant amount considering that CoJ is a water insecure city with 98% of the water already allocated and faces projected water shortages by 2019 (CoJ, 2017). As is often the case, the largest overall cost-effective benefit can be achieved through the combined benefits of multiple smaller-scale projects rather than a single large one.

The groundwater discharged from the Gautrain tunnel is generally of excellent to good quality (with some instances of elevated salt concentrations in Sandton, which would require only minimal treatment (mixing with purified water)) and is suitable for all uses, including human consumption. Therefore, this water source presents multiple opportunities regarding it use, including:

1. Incorporation into Johannesburg Water's (CoJ WSA) bulk water supply scheme;
2. Used as decentralised supply for local communities to reduce pressure upon the municipal water supply system;
3. Aquatic, groundwater-dependant ecosystem augmentation to alleviate some of the potential negative effects of the regional water table's lowering;
4. Bottling of water to generate revenue.

Each strategy presents its own set of benefits and challenges regarding its implementation: both in terms of the financial costs (initial construction and long-term maintenance) and legislative requirements (i.e. licensing) for water use.

Position paper 3: Water Sensitive Design and roundwater

5.4. WATER SENSITIVE DESIGN AND GROUNDWATER

5.4.1. Introduction

Water Sensitive Design (WSD) is a holistic urban planning and design approach that integrates the entire urban water cycle into land use and development process with the aim of improving water quality and quantity, biodiversity, as well as adding economic, environmental and amenity value to cities (Section 3.2.4). WSD incorporates all forms of urban water – potable water, stormwater, wastewater and groundwater –, with groundwater generally receiving the least consideration because of its 'out of sight, out of mind' nature. However, groundwater is a crucial part of the urban water system and is closely interlinked with the other WSD framework elements, e.g. providing baseflow to surface water bodies like rivers and wetlands, storage for stormwater and treated wastewater's later re-use. Furthermore, WSD must consider the impacts on the groundwater system lest to avoid degradation of groundwater quality, formation of sinkhole or increase risk of groundwater flooding from WSD recharge-inducing measures.

5.4.2. WSD measures overview

WSD includes an extensive array of interlinked tools and techniques:

- *Stormwater harvesting*

WSD's stormwater harvesting is largely based on Sustainable Urban Drainage Systems (SUDS), i.e. a series of management practices, control measures and technologies designed to reduce stormwater runoff, attenuate peak flow and improve water quality, often through interconnected treatment chains (Table 5-1).

SUDS have generally been rather limited in scope and have placed focus solely on stormwater management with minimal mention of exploiting the collected stormwater as a water supply. Furthermore, it generally makes no mention of the potential impacts on groundwater quality and recharge quantity, despite the fact that many of its elements are based on stormwater infiltration into the underlying soil and that there may be strong groundwater-surface water interaction at, e.g. wetlands and retention ponds.

WSD principles expands upon the basic SUDS principles by also considering the possibility of using the collected stormwater as a local water source for either potable (with treatment) or non-potable use. Such schemes may provide water cheaper than the supplied potable water and substantially reduce municipal potable water demand (e.g. potentially up to 20% in the Liesbeek River Catchment, Cape Town (Carden et al., 2017)). Stormwater harvesting schemes may also be directly linked with groundwater by using underground storage as a means of storing stormwater for later re-use (see Managed Aquifer Recharge below).

Table 5-3 SUDS measures of stormwater management.

Control area	Type	Description
Source	Green roofs	Vegetation-covered roofs capable of absorbing light to moderate rainfalls (80-90 percentile storms (Armitage et al., 2012)). Provides pollution control and is most suitable for densely populated areas with limited space.
	Rainwater harvesting	Stormwater is channelled from roofs, stored in tanks and utilised (with minimal treatment) for secondary water uses such as toilet flushing and garden irrigation.
	Soakaways	Underground storage areas filled with permeable aggregate that gradually allows the collected stormwater to infiltrate into the underlying soil.
	Permeable pavements	Pavements constructed in a manner that promotes stormwater runoff infiltration into the underlying soil.
Local	Filter strips	Maintained grassed areas of land used to intercept stormwater and attenuate flood peaks.
	Swales	Shallow grass-lined drainage channels used to reduce stormwater runoff volumes and peaks flows, as well as to filter out larger particles and remove dissolved pollutants through infiltration and bio-infiltration.
	Infiltration trenches	Excavated trenches filled with highly permeable aggregate and separated from the surrounding soil by a weakly permeable geotextile; the trenches remove some contaminants (sediments, metals, bacteria and organic matter) and the treated water slowly infiltrates into the underlying soil.
	Bio-retention areas	Landscaped depressions designed to capture and treat stormwater runoff.
	Sand filters	Pollutant-removing sedimentation chambers linked with underground infiltration chambers.
Regional	Detention basins	Ordinarily dry grass-lined ground depression designed to capture stormwater runoff, attenuate peak flows and remove pollutants from water. Some of the captured water infiltrates into the ground, while most of it is discharged at an outlet.
	Retention ponds	Basins with permanent pools of water that capture and gradually release stormwater runoff while providing high pollutant removal capacity.
	Constructed wetlands	Shallow marshy areas partially or completely covered with aquatic vegetation, which are highly effective at pollutant removal and have the added benefits of increasing biodiversity and amenity.

- *Greywater harvesting*

Greywater is untreated household and office building wastewater, i.e. effluent from baths, showers, sinks and laundry, but not toilets (which requires more intensive treatment). Greywater is used to locally supplement water for non-potable uses, e.g. toilet flushing and garden irrigation. Though more limited in volume than stormwater harvesting, greywater re-use has the advantage of being a more reliable water source, i.e. the potential discharge rates are constant throughout the year and it does not require long-term underground storage. Wastewater from industrial uses may also be used for this purpose, however, it would require more intensive treatment prior to its discharge into the environment.

- *WCWDM*

A key part of WSD is improving water use efficiency through Water Conservation and Water Demand Management (WCWDM) programs, thus effectively reducing water demand. For example, installing water efficient devices in domestic properties in the Liesbeek Catchment, Cape Town could reduce indoor water use by nearly 50% (Carden et al., 2017). Further demand reduction can be made by using water source most suitable for its use ('fit-for-purpose') e.g. using potable water only for drinking and cooking purposes, while retaining harvested greywater for all other non-potable uses, thus reducing potable water demand from the bulk supply. Lastly, using local water sources (i.e. decentralised supply) subsequently reduces water losses from leaky bulk water transfer infrastructure.

- *Managed Aquifer Recharge (MAR)*

Managed Aquifer Recharge (MAR) is a technique whereupon stormwater, rainwater, greywater or treated wastewater is used to recharge an aquifer for the purpose of environmental benefit (e.g. providing baseflow or reducing risk of saline intrusion) or storage and later recovery (Dillion et al., 2009). Depending on the purpose, water may be stored in the aquifer either through natural infiltration or subsurface injection (Figure 5-5), and because the storage is not exposed to the atmosphere, there are no evaporation losses (though some water may still be lost from transpiration, if the water table is shallow). In addition to providing an additional source of water, MAR has a range of other potential benefits, including flood and peak flow mitigation, improving coastal water quality by reducing urban discharges, and enhancing local groundwater abstraction potential (Dillon et al., 2009).

The main aquifer characteristics controlling the viability of underground storage are the aquifer storativity (the volume of water that can be stored) and the hydraulic conductivity (the rate at which water may recharge the aquifer from the infiltration pond leakage, or be abstracted) (Murray et al., 2007). Therefore, the most suitable aquifer for MAR is one with high storativity and high hydraulic conductivity, e.g. coarse unconsolidated sand. Furthermore, local geology controls whether MAR creates a risk of sinkhole formation or aquifer collapse after its dewatering phase (Carden et al., 2017).

MAR stormwater and wastewater re-use schemes could provide a bulk water supply for the City of Cape Town in the range of 18-40 Mm^3/a (5-11% of the average potable demand) (Carden et al., 2017); currently the most notable MAR scheme is in the Atlantis aquifer in the Western Cape which has been the primary water supply source for the town of Atlantis since the 1980s (Murray et al., 2007).

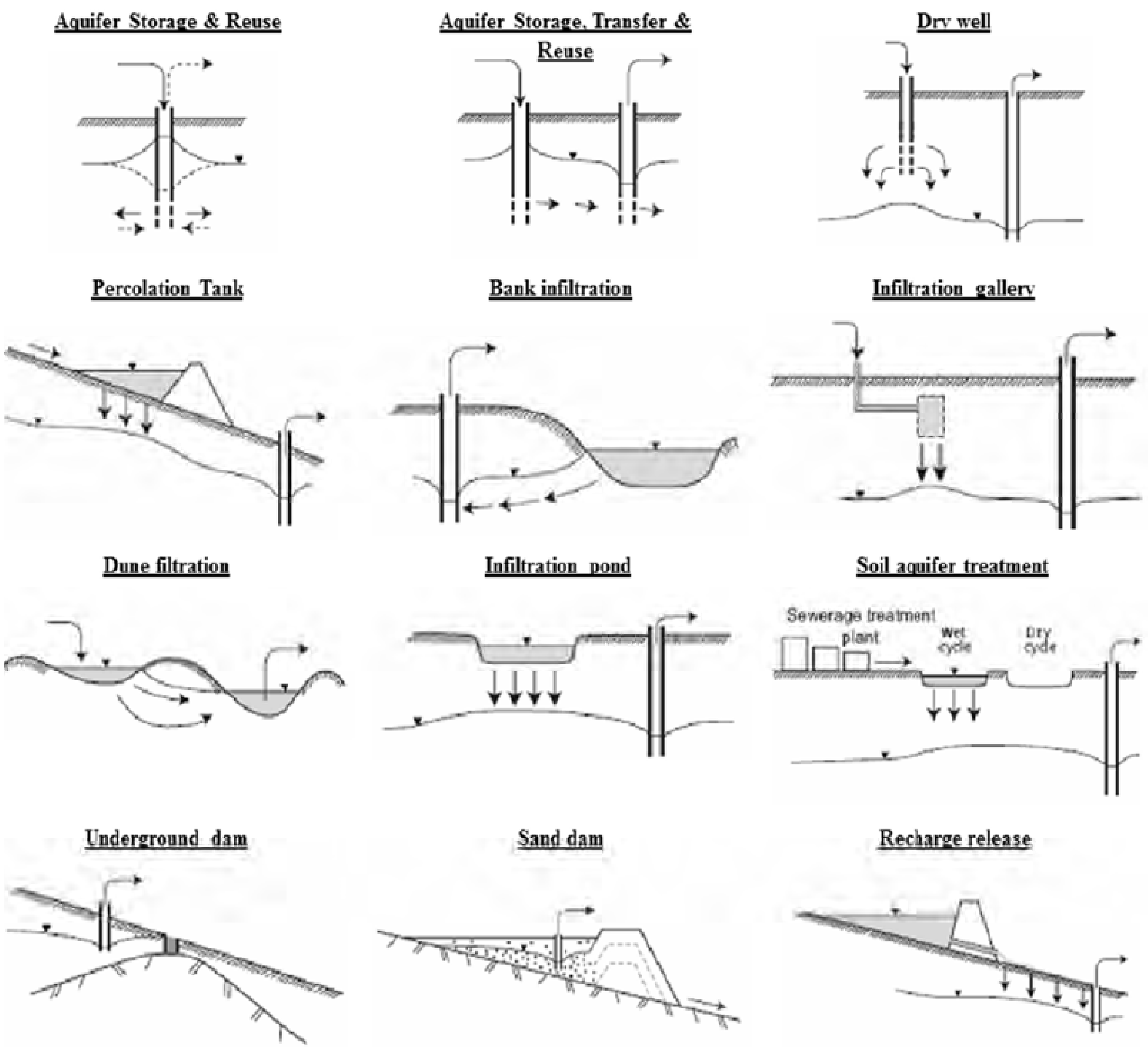

Figure 5-12 Types of Managed Aquifer Recharge (from Hoban & Wong, 2006).

5.4.3. WSD impacts on groundwater quality and recharge quantity

Whether through water conservation measures or stormwater control, all WSD measures have an impact on the urban water cycle which either directly or indirectly also affect the spatiotemporal groundwater recharge patterns and the overall groundwater quality and viability as a water source.

The most direct impact comes from MAR through periodical artificial aquifer recharge and abstraction schemes. The additional stored water may significantly enhance local groundwater abstraction potential and groundwater abstraction elements can be used to control the severity of groundwater flooding during the rainfall season (CSIR, 2015). However, with poor management strategies, the induced artificial recharge may have detrimental effects on nearby infrastructure (Armitage et al., 2014). For example, the locally elevated water table may alter natural groundwater flow patterns and induce basement flooding, increase risk of flooding (e.g. from smaller available storage in the unsaturated zone causing fully saturated conditions and overland flow to be reached faster), or cause soil collapse and land subsidence. Therefore, to limit such detrimental effects, the abstraction points need to be positioned strategically within close proximity to the recharge points to fully contain and exploit the artificially stored water.

A major benefit of MAR schemes is the generally higher quality of the abstracted groundwater compared to the original stormwater / wastewater because of aquifer attenuation, filtration and biodegradation processes, which act to remove pollutants. However, the purification efficiency is highly dependent on the water table depth and the injected water's quality. If the water table is close to the surface or the aquifer is highly permeable or fractured (e.g. karstic systems), the percolating surface water reaches groundwater with minimal delay and little to no attenuation. Therefore, it may introduce large amounts of pollutants commonly found in stormwater such as heavy metals (e.g. lead, copper, chromium and nickel) from vehicles and industrial processes, or organic compounds from either decaying organic matter or anthropogenic sources (e.g. petroleum hydrocarbons or vehicle exhaust emissions) (Armitage et al., 2014). Heavy metals and other particulate matter are generally removed through sediment filtration, while organic compounds are removed through volatilisation, sorption and degradation; all of these processes benefit from deeper water table (i.e. spending longer in the unsaturated zone). Where the water table is shallow, surface pre-treatment (e.g. wetlands) may be required to protect the groundwater quality.

On the other hand, if the aquifer's groundwater quality is already poor or is contaminated from, e.g. spills from petrol station fuel storage tanks, the abstracted groundwater's quality may be even worse than the original stormwater / wastewater. Therefore, to ensure the long-term viability of MAR schemes, it is critical to implement groundwater protection measures within the capture zone for all types of recharge – both natural and artificial.

Artificial groundwater recharge, especially of the subsurface injection type, introduces water of different chemical composition into the local groundwater system, which may cause various chemical and/or physical reactions. For example, if the natural groundwater is anaerobic (i.e. lacking oxygen), addition of oxygen-rich surface water may cause an increase in bacterial growth and iron / manganese oxidation, which may block pore space and lower overall aquifer storativity, hydraulic conductivity and well efficiency.

WSD measures such as WCWDM, greywater harvesting and local groundwater abstraction decrease demand upon the centralised bulk water supply and hence reduce the throughput of the reticulation / sewer system and the associated water leakage potential. Furthermore, in the case of greywater harvesting, transfer some water which might otherwise have gone into the sewers systems, to irrigate the garden and recharge the underlying aquifer. Overall, these measures have a largely indirect, non-linear and hard to quantify effect on the groundwater recharge spatial input patterns and timings, and further research is required.

Though generally not included in SUDS assessments, these stormwater management measures may often have a strong and direct effect on the groundwater recharge quantity and quality. In their efforts to alleviate stormwater flooding and peak flows, measures such as soakaways, permeable pavements, filter strips, swales, and especially detention basins and retention ponds strongly promote water infiltration into the soil (instead of transferring water to stormwater sewers or discharging to rivers / sea), which creates significant point sources of recharge (Sharp, 2010). Meanwhile, other SUDS types such as green roofs and rainwater harvesting reduce the groundwater recharge potential by transferring part of the stormwater to sewage system or atmospheric storage (i.e. evaporation). However, these losses are minor compared to increased recharge gained from the other measures, hence overall SUDS act to increase groundwater recharge.

Many SUDS elements, such as swales, detention basins and filter strips, act to purify the stormwater through sedimentary filtration and biofiltration, so the water recharging the groundwater is generally of better quality than the original surface water. However, as was discussed before, if the groundwater table is shallow, the pollutant attenuation may be highly limited and some SUDS elements, e.g. infiltration trenches, may instead act as highly permeable pathways allowing polluted stormwater transfer into the aquifer with minimal delay.

Furthermore, it is clear that the overall viability and efficiency of many SUDS elements depends on the local groundwater flow system, hence it should be considered in the planning using, e.g. aquifer vulnerability maps. For example, if the water table is very shallow, SUDS elements like soakaways and infiltration ponds will be fully saturated and unable to hold any more excess stormwater, or, if the water table is very deep, water inputs are low and no geotextile lining is used to slow down water's downward percolation, retention ponds and artificial wetlands may be losing more water than they are receiving and eventually drain.

5.4.4. Discussion

An advantage of WSD is the potential for reducing the urban demand upon the regional bulk Water Supply System (WSS) schemes and instead transition into decentralised WSS that would allow towns and settlements to operate using locally-sourced water supply. For example, it is estimated that in Cape Town the average yearly rainfall volume is approximately three times its potable water demand (Carden et al., 2017). Therefore, if all of this water could be harvested (and minimal natural water system flows maintained within safe ecological limits), the City could meet all of its foreseeable future water needs without having to import water from outside its boundaries.

WSD takes a step forward towards this goal by promoting stormwater collection and long-term storage, and by reducing the overall demand upon bulk potable water supply in the form of water-efficient devices and conservation measures, greywater re-use and rainwater harvesting. Since rainfalls are season-dependent and largely occur in winters when the water demand is at its lowest, the ability to store this water for the peak demand period (i.e. summer) is critical. While some of this water could potentially be stored in reservoirs, their construction is limited to certain areas with suitable topography and geology, and some of the stored water is inevitably lost through evaporation. Therefore, MAR is paramount in allowing the implementation of large-scale stormwater harvesting schemes. This would, however, require more research into its interaction with groundwater and development of more effective MAR groundwater management practices.

Much of research regarding the use of WSD and its interaction with groundwater has already been completed both internationally and in South Africa (e.g. Water by Design (2009) and Carden et al. (2017)). However, there has not yet been an in depth investigation of the space requirements needed by many of the WSD elements such as retention ponds or wetlands – in many densely populated urban settlements there is often not enough space for their implementation, therefore the potential for using WSD for aquifer recharge is also limited. Furthermore, so far the research on WSD usage has been focused in locations with sedimentary cover, and little to no attention has been given to the unique groundwater-related challenges and opportunities WSD faces in areas underlined by fractured basement or karstified limestone and dolomite aquifers.

For example, karstified aquifers are vulnerable to contamination predominantly due to the fast ingress (concentrated recharge) of surface water in dolines or swallow holes as well as the thin to absent soil cover (providing retention of potential pollutants). Similarly, there is a risk of sinkhole formation caused by localised water ingress or regional lowering of the water table. An analysis of sinkhole statistics on a 3700 ha karstic dolomite area by Buttrick (2018) showed that 99% of the analysed 650 sinkhole events occurred on water bearing infrastructure, with stormwater pipes being the "prime culprit" followed by bulk water and sewer lines (with equal numbers).

While the consideration of WSD concepts is for obvious reasons highly desirable, these well-established design principles need to be re-thought and adapted to dolomitic terrains if they do not want to put the very people and aquifers they aim to protect under risk. Thereby, specialist input is essential for stormwater management and MAR project development in karstic areas and must be managed carefully both in terms of quantity and quality. Special consideration needs to be given to aquifer vulnerability and stability by, for example, identifying suitable areas of infiltration, preferably of diffuse nature rather than localised points. Lastly, groundwater abstractions must consider compartment boundaries and maintainable yields (e.g. reduction in natural discharges).

5.4.5. Recommendations

WSD is a viable set of management principles and techniques promoting sustainable and holistic urban water resource management, which adds economic, environmental and amenity value to cities. However, there is a general need to improve the integration of groundwater consideration within WSD, as WSD measures are often recommended without consideration of the impact on or interaction with groundwater (i.e. permeable paving where groundwater levels are very shallow). Currently the most established and recognised role of groundwater in WSD is in MAR, but there are many more links critical to the long-term viability and efficiency of some WSD elements, such as high water table precluding the use of some SUDS because of the high groundwater contamination risk.

Overall, spatial planning decisions should incorporate the use of MAR and other WSD infiltration-inducing systems, provided the groundwater levels are deep, negative effects associated with heightened water table (e.g. groundwater flooding) are controlled by well-planned abstraction schemes, and the groundwater system in karstic aquifers is fully understood and safely managed.

Position paper 3: roundwater source protection zoning

5.5. GROUNDWATER SOURCE PROTECTION ZONING

5.5.1. Overview

Chapter 3 of the National Water Act provides the tools for a balance to be reached between use and protection of water resources, via resource directed measures (RDM) including the classification of water resources, the Reserve, the establishment of Resource Quality Objectives (RQOs), and via pollution prevention mechanisms (NWA, 1998, Parsons and Wentzel, 2007). In addition to the pollution prevention mechanisms, other "source-directed measures" are available to prevent or minimise the impact of pollution sources. These include water use licensing and the setting of conditions therein, which can be based on the RQOs established; the setting of minimum requirements for waste disposal; and standards for effluent disposal (Parsons and Wentzel, 2007). In addition, the National Environmental Management Act, 1998 (NEMA) "is a crucial instrument for preventing or minimising" various activities with potential high impact on groundwater quality (Braune et al., 2014, pg. 29).

Although these mechanisms are in place, section 3 highlighted that groundwater quality in urban areas is impacted by a variety of sources: leaking sewer networks, underground storage tanks at petrol stations, industrial areas (e.g. dry cleaners), waste sites, cemeteries, nitrate from fertilisers mobilised by garden watering, and inadequate sanitation in informal settlements. Data is presented demonstrating the impacts of mining activities in groundwater on Gauteng, and from leaking water reticulation networks in CCT (case study 3 and 4 section 3.2.3). The available mechanisms appear to have been ineffective in the control of pollution sources and in the overall protection of urban groundwater resources. Riemann et al. (2017) highlight that "the RDM methodology is not applicable to all water resources and mostly carried out at a scale that is insufficient for water resource protection" (pg. 33). In addition, where RQOs are established, albeit perhaps lacking in necessary detail, they are generally not implemented. In terms of source directed measures, much of what is provided for in legislation is ineffective for pollution deriving from non-point sources (nitrate from fertilisers mobilised by garden watering, and inadequate sanitation in informal settlements).

In the context of an urban area it is also perhaps unrealistic to expect it would be possible to protect the entire groundwater resource underlying the urban area. The RDM and the source directed measures require complementary policy for the protection of (ground)water *sources*. Braune et al., 2014, similarly highlight that there is a gap in the protection of "vulnerable groundwater sources supplying domestic water to communities" (pg. 30). It is not only domestic supply that deserves this protection; also groundwater that supports sensitive ecological functions requires protection (groundwater "supply" to ecology), and any user that is reliant on the source at a particular quality (whether it be for domestic or industrial use). In order to do so, the area of aquifer that contributes to the discharge point must be identified (source or "capture zone"), and protected in spatial plans via the control of landuse ("source protection zone").

The various zones that are commonly delineated include (Figure 5-13):

- "A zone immediately adjacent to the site of the well or borehole to prevent rapid ingress of contaminants or damage to the wellhead (often referred to as the **wellhead protection zone**).
- A zone based on the time expected to be needed for a reduction in pathogen presence to an acceptable level (often referred to as the **inner protection zone**).
- A zone based on the time expected to be needed for dilution and effective attenuation of slowly degrading substances to an acceptable level (often referred to as the **outer protection zone**). A further consideration in the delineation of this zone is sometimes also the time needed to identify and implement remedial intervention for persistent contaminants.

- A further, much larger zone sometimes covers the whole of the drinking-water catchment area of a particular abstraction where all water will eventually reach the abstraction point. This is designed to avoid long term degradation of quality" (Chave et al., 2006, pg. 466-467)

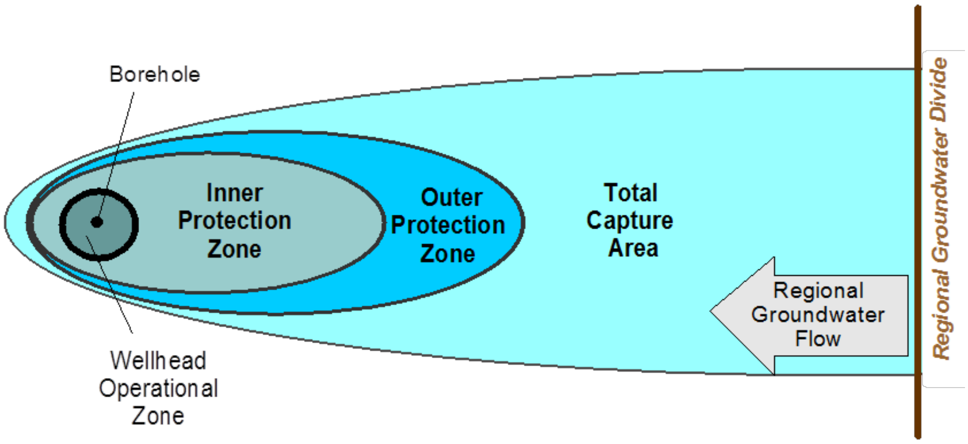

Figure 5-13 Commonly delineated groundwater source protection zones or areas (Chave et al., 2006)

Available approaches for the identification of capture zones range from simplified methods based on fixed distances, to more detailed methods based on numerical models, with the uncertainty reducing with the increased complexity is relatively standard:

- "Arbitrary fixed radius. Draws a circle of fixed radius around an abstraction point. Inexpensive and requires little expertise, but method of least certainty.
- Calculated fixed radius. Draws a circle of specified time of travel using a simple equation based on volume of water drawn to the well in a specified time. Requires data but can be completed quickly.
- Simplified variable shapes. Derived from hydrogeological and pumping figures similar to those at the wellhead, and orientates the shape according to groundwater flow patterns.
- Analytical methods. Uses equations to define groundwater flow and contaminant transport. Requires knowledge of hydrogeology, such as transmissivity, porosity, hydraulic gradients and thickness of the aquifer. The most widely used method.
- Hydrogeological mapping. Requires specialized expertise in geological and physical mapping and such techniques as (dye or particle) tracing. Best suited to smaller aquifers with near-surface flow boundaries.
- Computer assisted analytical and numerical flow and transport modelling. This may include estimates of log reductions in pathogen concentration. Requires data and expertise." (Chave et al., 2006, pg. 468)

Whether the Source Protection Zone (SPZ) that has been identified is successful in protecting the groundwater source depends on whether land use and therefore polluting activities can be controlled within them. This is generally achieved through the land use planning or pollution control legislation of the country, where the designation of the SPZ triggers specific requirements.

There is widespread implementation of SPZ internationally. Chave et al. (2006) provide a detailed analysis of the activities that are restricted in the inner and outer protection zones in Australia, Germany, the UK, Ireland and Indonesia. In Karst terrain, which is highly vulnerable to contamination, the SPZs need to consider sinkholes that may be significant distance from the abstraction site, and preferential flow lines. Nearly 30% of the Dinaric karst outcrop in Croatia is incorporated into sanitary protection zones and delineated in spatial development plans (Biondić et al., 2017). Nel et al. (2009) highlighted the benefits of implementing SPZs in South African, leading to the consideration of how to delineate SPZ in fractured rock terrain typical in South Africa and the development of guidelines to this effect (Nel et al., 2014).

However, the widespread implementation of SPZ identification and establishment in spatial planning is lacking in SA (as evidenced by Table 2-3). The following sections outline two examples where SPZs have been identified, and outlines recommendations for establishment of SPZs throughout urban areas:

- The first example demonstrates the derivation of the source zone contributing the groundwater discharge to surface water. The protection of this area achieves not only the protection of groundwater quality discharging to surface water, but can also ensure the landuse in the area does not reduce recharge, hence the rate of groundwater discharge is protected.
- A second example comes from the various attempts to identify SPZ for abstraction on the Cape Flats Aquifer, in Cape Town.

5.5.2. Lanseria Open Space Plan

5.5.2.1. *Requirements of the study*

According to the Spatial Planning and Land Use Management Act, open space includes "land set aside or to be set aside for the use by a community as a recreation area, irrespective of the ownership of such land" (RDLR, 2013). Open space plans are generally developed under the direction of metropolitan municipality's land planning department, and form one of the key inputs to the Spatial Development Frameworks. As well as providing important recreational services, these open spaces may provide critical recharge services, and groundwater sourced in the area may support ecological infrastructure (wetlands, etc.) within the urban area. Whilst the consideration of (ground)water resources in open space plans is not prescribed, the terms of reference for the Lanseria Open Space Plan recognised that open spaces are important for urban water security (including providing recharge) and for biodiversity, ecosystem goods and services and therefore need protection (CoJ, 2017c). The terms of reference required that the open space plan to be developed included the delineation of areas required for the protection of important hydrological processes and river health, including wetlands, springs, watercourses and recharge areas. To meet this requirement, a numerical model was established to define the source zones for the prioritised groundwater-dependent ecosystems. The following sections summarise the approach and results.

5.5.2.1. *Lanseria regional setting*

Historically, much of the Lanseria open space project area functioned as an important agricultural area for the growing city of Johannesburg, and the northern area is proclaimed as small holding farms. The majority of urban and residential development within the study area has occurred within the last 25 to 30 years, and in the centre-south of the area, which includes the development of Lanseria Airport, and the suburbs of Diepsloot, Cosmo City, Steyn City, Riversands, and Malibongwe Ridge. Nevertheless, the area contains a large portion (56%) of open space including vacant and underutilised land and fields (Newtown, 2018).

The study area falls in the A21C and A21E quaternary catchments of the Crocodile-West and Marico Water Management Area. The main drainage areas of the Jukskei and Klein Jukskei rivers include several ridges (Figure 5-14), some with associated seepage wetlands. The wetlands and riparian zones within the area were identified and categorised into five types (below), along with identification of the critical biodiversity areas and ecological sensitive areas. These overlap with most of the threatened species being found in close proximity to the Jukskei River (Newtown, 2018):

- Level One: Main rivers (Crocodile and Jukskei)
- Level two: Secondary Rivers (Klein Jukskei)
- Level three: Channelled valley bottom wetlands linking directly into level one and two
- Level four: The remaining Channelled and Unchannelled valley bottom wetlands and
- Level five: Seepage wetlands and depression wetlands.

The area is underlain by the Johannesburg Dome's mafic and ultramafic plutonic rocks (Figure 5-14). The Johannesburg Dome rocks can be classified as a fractured hard rock aquifer. According to the Hydrogeological Map (Map 2526, 1:500 000) the regional hydrogeology is characterized by an 'intergranular and fractured aquifer. The fractured aquifer, attributed to the presence of the Johannesburg Dome has a potential yield of 0.5 to 2.0 litres per second. A micro-fractured matrix in these aquifers provides the storage capacity with limited groundwater movements while secondary features such as fractures / faults and bedding planes enhance the groundwater flow. The intergranular aquifer is associated with the river alluvial and quaternary sand deposits. Therefore, the following aquifer systems can be distinguished for the area of interest:

- A shallow weathered aquifer
- An alluvial aquifer system replacing or overlying the weathered aquifer in the vicinity of river courses
- A deeper fractured aquifer system within the Johannesburg Dome.

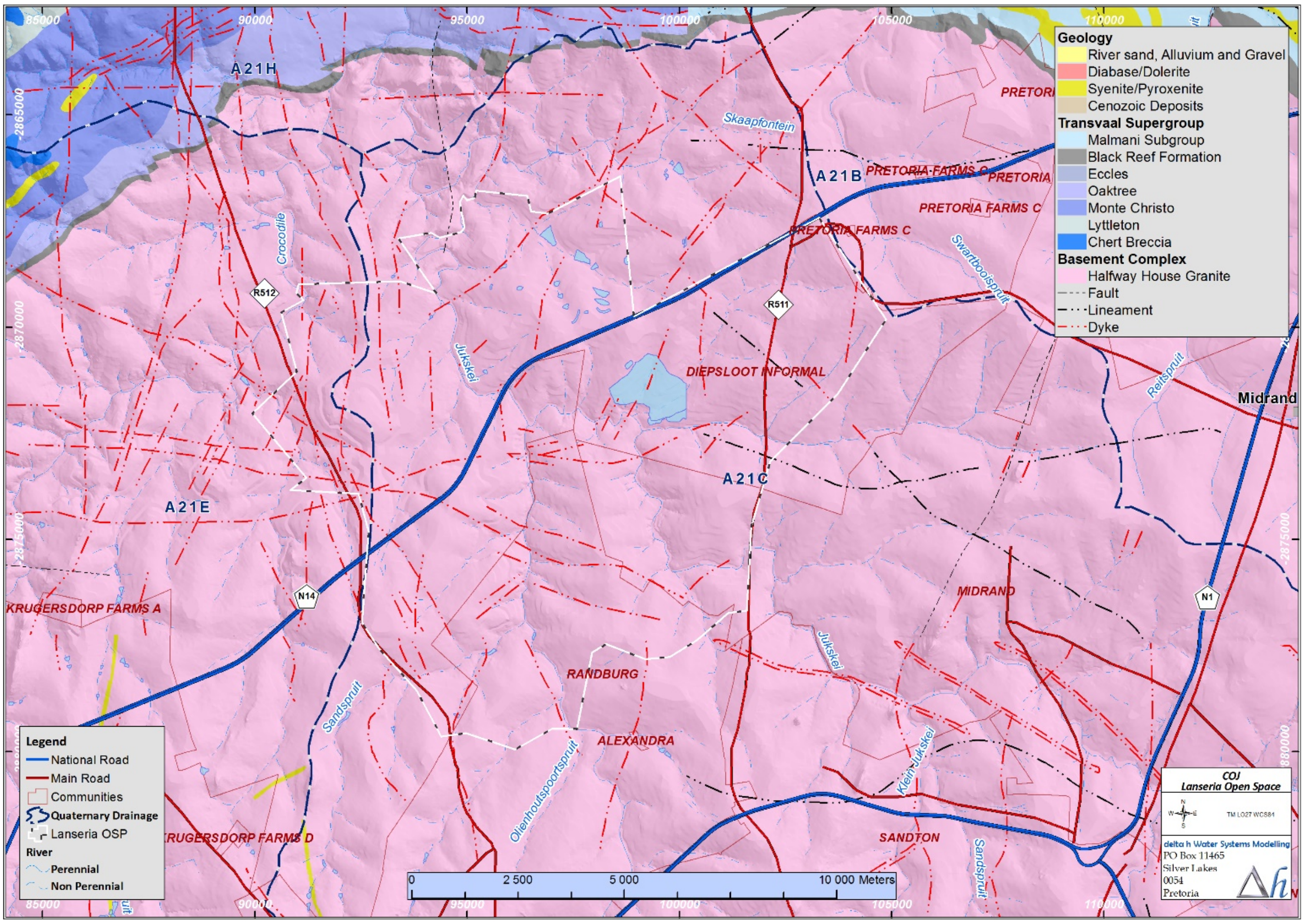

Figure 5-14: Regional geology of the study area (from Delta-h, 2017).

5.5.2.2. *Source zone identification with numerical model*

A finite element numerical groundwater flow model was established in the software SPRING (Delta-h, 2017). A river or 3rd type (Cauchy) boundary condition was assigned to the streams and river courses within the model domain whereby the leakage of groundwater into the river (or vice versa) depends on the prevailing gradient. Wetlands (level 3, 4 and 5) were incorporated as seepage elements within the model boundary condition. Therefore, should the calculated water table elevation exceed the surface elevation for these areas, water is removed from the system, reflecting outflows within these wetland areas via evapotranspiration or surface run-off.

The developed model was subsequently used to simulate the source zones of the different wetlands and water courses. This was achieved by assigning a constant concentration (100 %) boundary condition to the different water courses and calculating the advective-dispersive (dispersivity of 50 meters) transport against the groundwater gradient or flow field for up to 50 years (i.e. a water particle would theoretically require 50 years after recharge from surface to reach the water course). The resulting catchment areas are shown in (Figure 5-15). The delineated areas have been included as "green network elements" in the final open space plan, which were considered when listing the sensitivities to development and development restrictions in each area. The control of landuse activities in the zone protects the groundwater quality feeding the ecological habitats, and also protects the groundwater recharge maintaining discharge.

The study demonstrates best practice approach in spatial planning for the protection of groundwater sources "supplying" ecological infrastructure. It is recommended that this approach become common practice; that all open space plans and ultimately all spatial development frameworks include the delineation of groundwater source zones supplying sensitive or priority ecology.

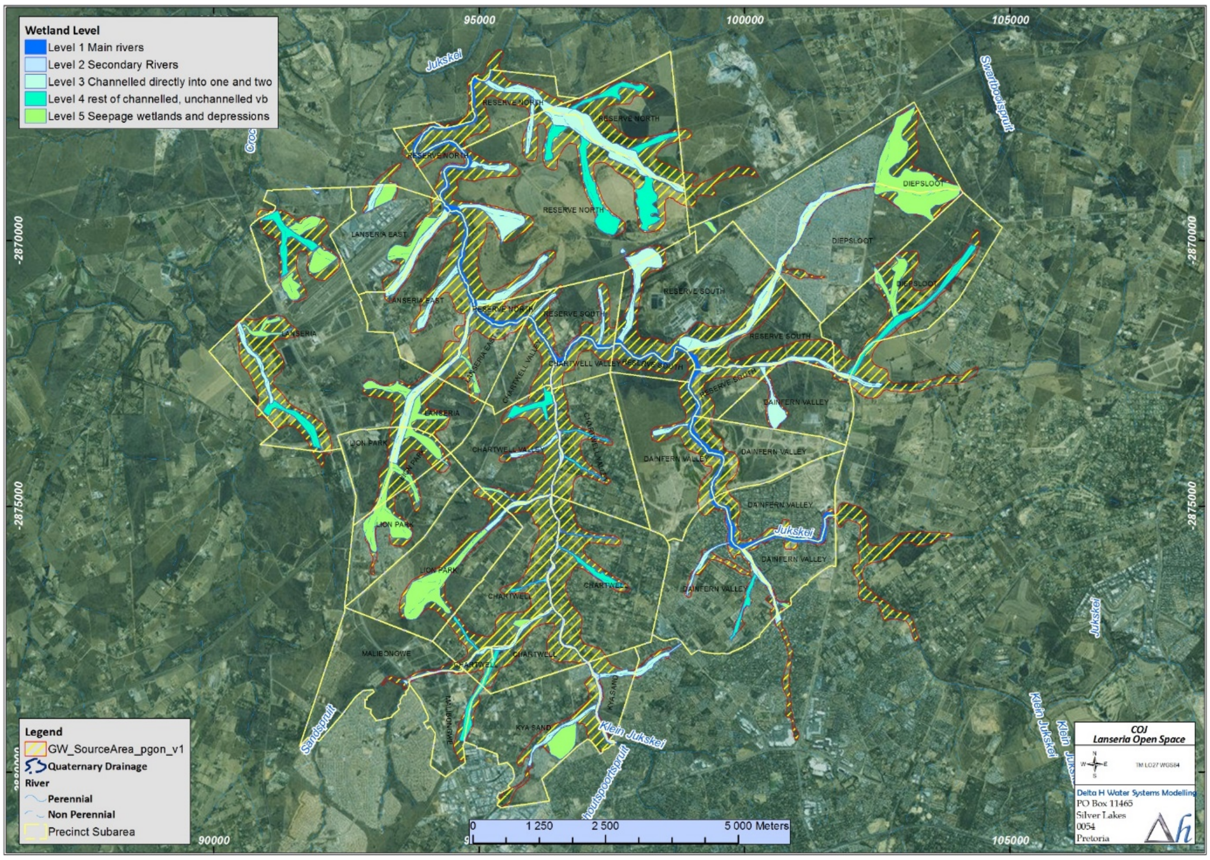

Figure 5-15 Groundwater source areas for surface water and wetland features in the Lanseria area (Delta-h, 2017).

5.5.3. SPZ for domestic abstraction in Cape Town

The theoretical background provided in overview for SPZs is readily implementable for a planned settlement where a groundwater source that is being planned prior to any urban development, once policy to do so is in place. This is clearly rarely the case, and there is a challenge in how to implement SPZs (declaring an SPZ and controlling the landuse), when the area is already developed. The City of Cape Town is a case in point, where the major Cape Flats aquifer underlying the city is overlain largely by developed land.

The common perception that the Cape Flats aquifer is contaminated was a contributing factor to the lack of its development for supply, and led to the recommendation that the aquifer not be used as a source of potable water until a long term remediation plan was implemented (DWS, 2014):

> "The potential use for bulk water supply must consider potential threats to water quality, impact on existing use, potential for saline intrusion, costs versus benefits and circumstantial social threats. The aquifer is situated between residential, industrial and informal land uses, which pose a threat to its water quality and it is thus deemed unfit for bulk water supply….. Due to the contamination of the Cape Flats Aquifer, it is not recommended that groundwater be used as a source of potable water." (DWS, 2014, op. cit. pg. i, & pg. 37)

However, results from the identification of SPZ for hypothetical abstraction sites on the Cape Flats aquifer demonstrate the benefit of SPZs in cases where there are groundwater quality concerns. Seyler et al. (2016a) developed a numerical model of the Cape Flats aquifer in order to assess various water sensitive design scenarios for the City, including bulk use of groundwater with and without MAR, decentralised groundwater use, and the impacts of landuse changes on recharge. Hypothetical abstraction sites were simulated, and the source zone to the hypothetical abstraction sites was delineated (using the same approach as for the Lanseria Open Space plan). The groundwater flow field was "reversed", a unit source concentration assigned to the abstraction boreholes, and the advective-dispersive transport simulated to delineate the time-of-travel based capture zones of the abstraction boreholes. The inner source zone was defined based on 50-day travel time, and the outer zone based on a 365-day travel time, following examples in Chave et al. (2006). The zones are shown in Figure 5-16, and demonstrate that the zones are relatively local to the boreholes. The protection zone is an area of land within which it could be more achievable to actively manage land uses, and prevent contamination, than addressing activities across the entire aquifer. The hypothetical abstraction sites were not selected with any consideration of landuse, yet in each case the 365 day outer protection zone did not encounter cemeteries, WWTW, waste sites, industries or petrol stations (Seyler et al., 2016b). The protection zones did include a major highway (which would require diversion of runoff water), and (part of) an informal settlement (which would require special on-site sanitation practices). The exercise nevertheless demonstrates that with this kind of modelling it would be feasible to select the optimal position for a borehole in an already built up area prior to drilling, where its outer protection zone does not encounter existing contamination sources (or these are at least minimised). This result led to the recommendation that the Cape Flats aquifer be used for bulk supply (regardless of contamination or not as is the case for surface water), in conjunction with the identification of zones of clean groundwater not affected by point pollution, and the implementation of bulk abstraction with protection zones (Seyler et al., 2016a).

Spurred by the drought, the City's approach to the use of the Cape Flats has shifted since DWS (2014), and exploration drilling for domestic supply commenced early 2018 on the Cape Flats. Over 100 (exploration and proposed production) boreholes have since been drilled (McGibbon, 2018). The exploration has led to more in depth understanding of the aquifer properties and "aquifer protection zones", and an "aquifer protection zone buffer" has been identified based on aquifer thickness and surface water catchment divides, reflecting the areas "believed to be key catchment areas for the most productive parts of the aquifer" (Hay et al., 2018, pg. 115). The boreholes to be use for production are yet to be identified and it is recommended that inner and outer protection zones be delineated, and formalised in terms of land use control.

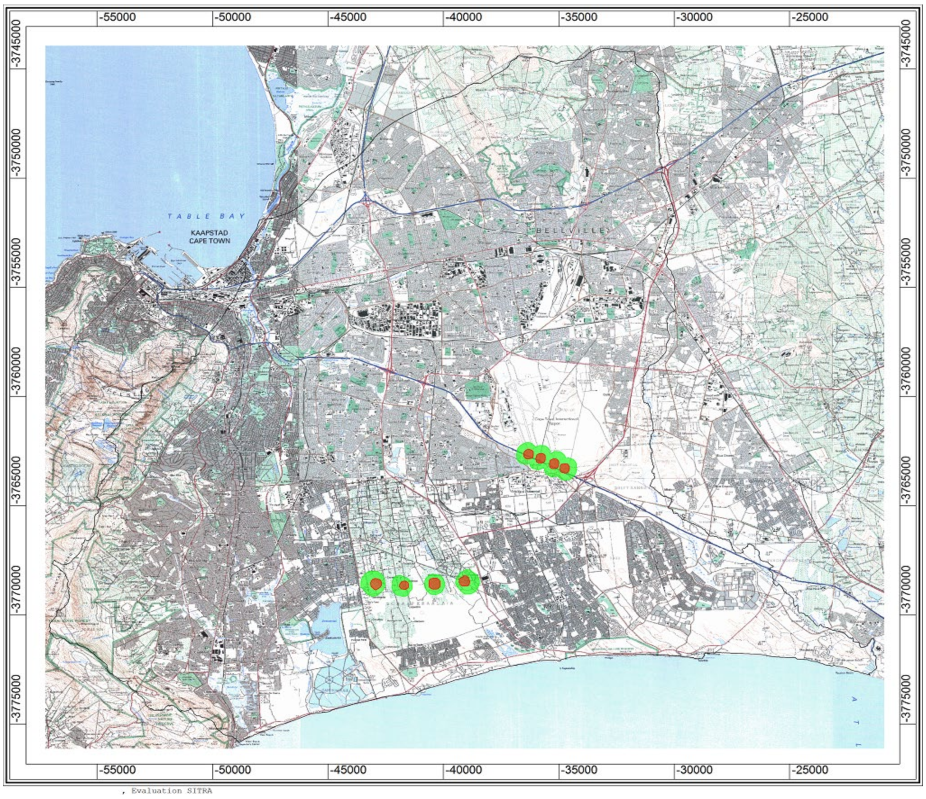

Figure 5-16 50-day (red) and 365-day (green) protection zones for abstraction of 10 million m³/a in total, from hypothetical boreholes (located at centre of red area) (Seyler et al., 2016a)

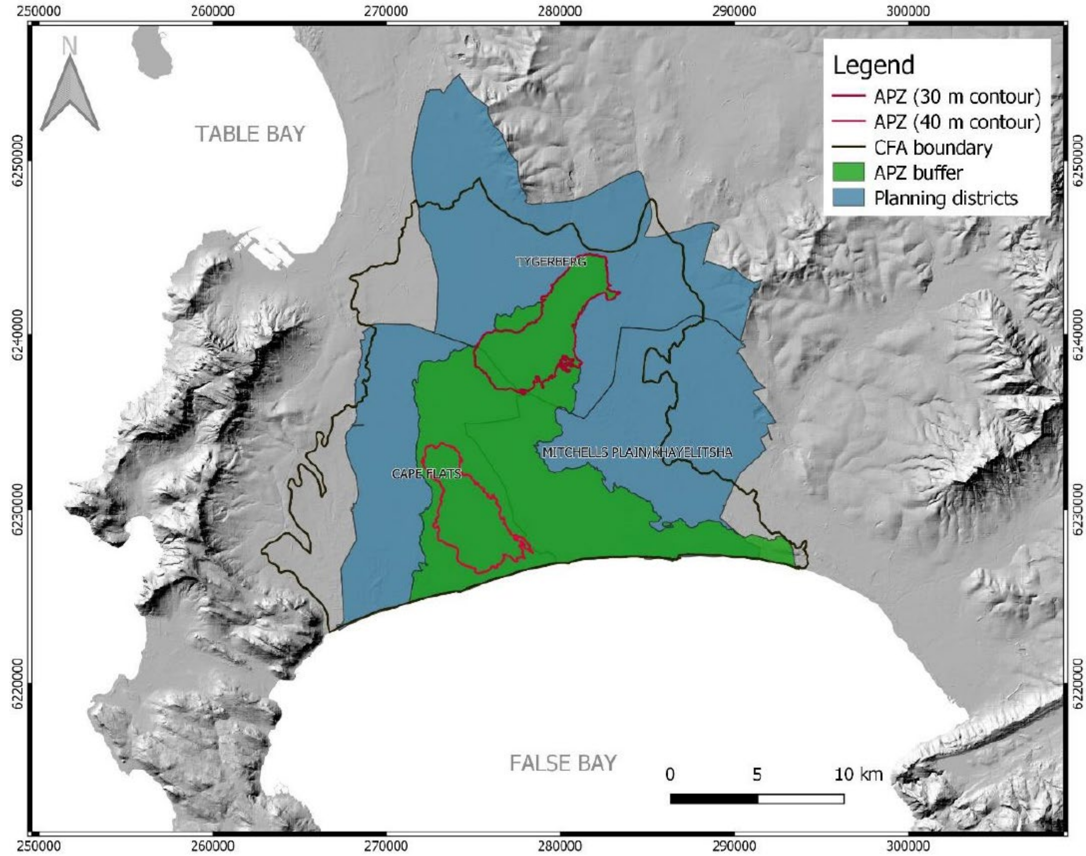

Figure 5-17 "Aquifer protection zones" (APZ) based on aquifer thickness contours; and the APZ buffer based additionally on the quinary water catchment divides (Hay et al., 2108)

5.5.4. Recommendations

The benefit of identifying and implementing SPZs to protect urban groundwater sources for domestic supply is clear. The approach can also be applied to identify groundwater sources contributing to groundwater dependent ecosystems, thus protecting the groundwater quality (and quantity) they receive. It is therefore recommended that:

1) In the case of domestic abstraction the following three steps are required:

- The relevant land management legislation be amended to incorporate SPZs, laying out what an SPZ is, and the land uses excluded within SPZs, and the process by which the areas are to be incorporated in SDFs.
- Simple policy is developed for the standardised identification of SPZs, to include:
    - a prioritisation procedure is required to identify which urban domestic abstraction points require formal protection, which can be simply derived from Chave et al., 2006, and from Parsons, 1995 (a prioritisation scheme for groundwater resources for protection is presented therein reflecting on the aquifers importance and vulnerability)
    - the definition of SPZ (inner outer and total zone)
    - listing the range of acceptable methods for the delineation of SPZs
- Subsequent to completion of the above two, SPZs should be identified by the metropolitan municipality or the WSA

2) In the case of private abstractions, mechanisms for implementation of SPZs are more complex, as there's no constitutional mandate of the state to provide clean water to industry (whereas there is for domestic uses). It is recommended that any private user who is reliant on groundwater at a specific quality for operations, identify the SPZ and the current land use within the area. If there is potential for pollution from existing activities in the area, the user can report these to DWS to promote the enforcement of RDM measures and source-control measures within the SPZ area; i.e. request prioritisation of this area for implementation of RQOs and for enforcement of licence conditions.

3) In the case of groundwater dependent green infrastructure in urban areas: It is recommended that all open space plans and ultimately all spatial development frameworks include the delineation of groundwater source zones supplying sensitive or priority ecology.

6. PLAN FOR IMPROVED URBAN GROUNDWATER DEVELOPMENT AND MANAGEMENT

6.1. Overview

The original terms of reference for this project referred to a "research strategy" for urban groundwater. Technical know-how is not the key gap in terms of realising appropriate development and management of urban groundwater resources (section 4). Thorough recommendations for improved groundwater development and management have been listed previously (DWS, 2010, Braune et al., 2014): rather than developing a new set of recommendations particularly applicable to urban groundwater, what is required now is practical action to drive these forward. Similar sentiment was presented seven years ago already, where research into the perspectives of South African water sector experts revealed that one of the highest ranking tools or measures available for implementing sustainable and adaptive groundwater management in South Africa was to 'implement existing groundwater legislation and regulations', with 'formulation of new groundwater legislation and regulations' being ranked of minor importance (Knüppe, 2011, p. 73). The WRC therefore requested a "tactical plan" be developed for improved urban groundwater development and management, which could help prioritise actions for implementation, and detailing how recommendations made here and in the National Groundwater Strategy are implemented (actions taken by who, when). The "tactical plan for improved urban groundwater development and management" shown in Figure 6-1 was therefore developed with the need for action at the forefront of mind, with a focus on using what is workable in current legislation, proposing new legislation or amendments to legislation where absolutely necessary, and listing actions that are readily possible with existing legislation. However, whilst current legislation is largely sufficient; new tools and approaches are recommended, some of which are already under development in concurrent studies.

A second urban groundwater "think tank" was held on 4th December 2018, at the WRC in Pretoria, during which a draft tactical plan was presented and discussed. The plan shown in Figure 6-1 is the result of discussions with and input from reference group members, staff from metropolitan municipalities involved in groundwater management (i.e. from water and sanitation or infrastructure planning department, from spatial planning, or from the environmental department), major water boards, the DWS, and other stakeholders. The activities recommended in the tactical plan are connected with arrows demonstrating how one leads to or relies on another (Figure 6-1).

6.2. Urban Groundwater Plan – outline

The plan shown in Figure 6-1 draws on recommendations made throughout this document. The recommended actions are largely motivated for in the previous sections of this report, and a short description of each action is provided below.

Amended Legislation

The following amendment to legislation is recommended:

- There is currently no legal mechanism for source protection zones, and it is recommended that land use management policy be amended at the national level to incorporate the allowance of SPZs, listing permitted land uses in each zone. It is likely that the Spatial Planning and Land Use Management Act (Act. Not 16 of 2013) of the Department of Rural Development and Land Reform is the appropriate legislation for SPZs (DRD&LR, 2013). Section 5.5 outlines that significant international experience can be drawn on in order to implement this requirement without too much effort.
- The by-laws of CCT (2010), for example, state that no person may negligently, purposefully or wastefully "inefficiently use water or allow inefficient use of water to persist" (Section 37e). It is recommended however that special mention is made of the use of basement water in all municipal by-laws. All metropolitan municipality by-laws should therefore be amended to prohibit the disposal of dewatered groundwater from basements to sewer and strongly discourage disposal to stormwater.

- Furthermore, the by-laws vary across the metropolitan municipalities on their protection of groundwater. It is recommended that these be standardised to ensure the best elements of each by-law is represented in all of them, for example providing the metropolitan municipalities with the ability to enter property to monitor boreholes.

Measures to reduce potable water demand in a development via rainwater grey water and black water harvesting are part of the rating system of the green building council of South Africa. The use (rather than disposal) of groundwater which is potentially dewatered at the site is not explicitly included in the ratings. The national standards for building construction incudes standards for water supply and drainage for buildings (SANS 10252), which documents for example the required terminal fittings and overflow pipes (amongst other items). The standards do not deal explicitly with the installation of an alternative source of water, such as use of groundwater dewatered in basements. In addition to the inclusion of basement water in municipal by-laws, it is recommended that the building standards and green building ratings also be amended to prohibit the disposal of dewatered groundwater from basements to sewer and strongly discourage disposal to stormwater, and to further encourage dual reticulation.

The need to enforce centralisation of groundwater data is widely recognised (described in section 5.1.4). Braune et al. (2014) state that "a process to centralise private data is seen as a very cost effective and rapid way of expanding national groundwater data archives. Regulations should be developed in this regard with the groundwater industry." (pg. 36). The National Water Act (DWS, 1998) provides the legal mechanism for the provision of "private" data to the state under Section 141, and for the sharing of that data with the public under section 140c. It is therefore recommended that a gazette be released which gives effect to the NWA section 141. The gazette should include the provision of:

- Information on the drilling of new boreholes including geology and borehole construction (from the driller or the consultant)
- Information on the pump testing of new boreholes including water quality (from the driller or the consultant)
- All routine monitoring data including abstraction yield, groundwater level, groundwater quality (from the user)

To enforce the sharing and centralisation of groundwater data requires a data repository, described below.

New policy

There is no provision for groundwater source protection in current South African legislation, hence the recommendation above that land use management legislation be amended. In addition, a new policy document is required to standardise the implementation of SPZs, to include:

- The definition of an SPZ (including the description of inner, outer, and total capture zone)
- The procedure for determining which sources have SPZs identified, i.e. a prioritisation procedure
- Acceptable identification methods
- The procedure for update of the SPZ

Braune et al. (2014) recommend "special groundwater regulation" in order to realise:

- Pro-active protection of the underground resource
- Maintenance of professional standards
- Securing data for a national groundwater information system

This requirement is not incorporated in the urban groundwater plan. The protection of underground resources is (intended to be) achieved by the WRCS (existing legislation), and by the identification of SPZs (new legislation). The maintenance of professional standards is something that is being currently taken up by the Groundwater Division, with the planned proclamation of a code of conduct. The requirement for continued professional development has also been introduced for SACNASP registered scientists. The securing of data for national systems is already accommodated in the NWA.

Technical activities

Implementing existing legislation, and the recommendations for new policy and amended legislation leads to the requirement to complete various technical activities:

- The identification of SPZ for all prioritised sources
- The establishment and gazetting of RQOs in all metropolitan municipalities
- The implementation of the validation and verification (V&V) process to support improved groundwater management

The implementation of existing WRCS legislation may be considered a short term gain (Riemann et al., 2017), compared to more preferable long-term intervention of amending legislation to better suit and protect groundwater resources. There are certainly shortcomings in the WRCS and RQO process, nevertheless, they do allow for legal limits on groundwater quality to be established, giving the DWS a tool to take the MM to task on disperse pollution sources (leaking waste pipes, un-serviced informal settlements, poor quality stormwater).

Supporting processes

Whilst it is not discussed in detail in this report, the listed legislation requires significant effort to enforce, from local and national government. The capacity of DWS for compliance monitoring must be significantly improved. Related to this, DWS-owned monitoring networks require reinitiating in some cases and thereafter expansion in order to monitor adherence across the aquifer scale to RQOs.

New Tools: Data Repository

Related to the recommendation that the sharing of groundwater data be mandated, a repository is required for groundwater data. Furthermore, the very notion of groundwater management must adapt to the reality of current use patterns: groundwater management has to involve the significant number of agricultural, domestic (individual and municipal), and industrial groundwater users within urban areas who share a resource. These users (and DWS and decision-makers) have little understanding of their current and potential future impact on their neighbours and vice versa, and of changing resource availability (i.e. climate change) on them. They have no mechanism to share and view data meaningfully, and take operation decisions accordingly. An additional hurdle preventing users becoming actively involved in groundwater management is widespread mis-understanding (even amongst 'professionals') of some fundamental principles of sustainable groundwater use. The groundwater community has failed to share clear information on the (perhaps largely acceptable) impacts of abstraction, and myths have proliferated. It is recommended that an online data repository be generated for the storing of all groundwater data, to incorporate data in the NGA, HYDSTRA, GRIPP and private users' data, in accordance with NWA Section 139. The data must be available for public download (in line with NWA Section 140c), and it is also recommended that the online tool be able to provide analytical and visualisation tools.

In terms of legislation, the DWS is mandated to collect groundwater data, and has various databases storing groundwater data (including NGA, HYDSTRA). The DWS is theoretically the appropriate owner of such a data repository, albeit with some overlap with the Council for Geoscience's mandate on geological data from borehole logs. It was recognised at the second think tank that the DWS does not have the capacity nor funds to establish and maintain such a database, and it would likely have to be endorsed by DWS but establish and maintained by an alternative entity.

New approaches
There are deficiencies in the process by which our major aquifers are managed and licences are awarded, which means that the cumulative impact of groundwater use cannot easily or routinely be taken into account (by applicants, by the DWS), nor the adherence to groundwater quality RQOs reported on (by DWS). Currently, DWS assesses groundwater availability periodically in water resources assessment studies (which do not always use latest data), and assesses groundwater condition through the publication of annual monitoring reports. However, these report only on the monitored groundwater levels and quality at the sparsely distributed DWS-owned monitoring boreholes and are limited in the consideration of aquifer-wide resource availability and impacts of abstraction. In part, these deficiencies relate to the lack of centralised groundwater data. The development of a centralised data repository enables new approaches to be implemented for groundwater management.

It is recommended that an aquifer modelling and assessment initiative be introduced, to include all major aquifers and major population centres, in which numerical models are developed using all data available (outlined in 5.1.4).

- The data acquired from the recommended online system for capturing electronic (and in turn from enforcing monitoring by private users) would be used as the basis for development and routine update of the numerical models.
- The model results would be able to demonstrate the adherence to (groundwater quantity related) RQOs.
- The impact of proposed abstraction can be assessed in the relevant model and associated licence conditions derived.
- The models should be available under licence for use by consultants where required (for example, for the creation of sub-regional models to address local/site scale issues or more complex proposed abstraction) preventing wasted effort (and funds) in multiple models being generated for the same aquifer over time by different consultants each with different and (incomplete) datasets (typically the case in South Africa).
- This approach also enables, critically, the cumulative effect of each licence application to be assessed.

The development of a centralised data repository would enable routine assessment of groundwater quality across aquifer scale, for assessment of adherence to groundwater quality related RQOs, and assessment of contamination threats.

Significant advancements in capacity would be required for the DWS to implement the above-listed new approaches. It was recommended at the think tank that rather than expect these new approaches to be housed in DWS, that the DWS delegates water resources management responsibility to the metropolitan municipality as the water services authority, (and thereon to the water board where applicable), or to the CMA. These options also have shortcomings (the metropolitan municipality would be policing their own abstraction) and there may not be one solution that fits the whole country, with the role being taken on by different entities in different areas. It was also highlighted that civil society has a role to play in driving the new approaches, and that the benefit of making the data repository downloadable to the public, is that this would stimulate significant research. Shortcomings of DWS could in essence be propped up by researchers assessing trends in the datasets.

Enablers and benefits
Implementing the recommended aquifer modelling and assessment initiative could theoretically lead to an improvement in the turnaround time for WULAs, as the models would house current data on resource availability and would be able to generate expected impact of abstraction. It is acknowledged that to get to this stage is a significant leap from the current situation and requires significantly improvements in capacity at DWS.

New supporting measures
Various measures are recommended that would act to support the measures outlined in the urban groundwater plan:

- It is recommended that efforts be made to maintain the professional standards in the groundwater industry including the development of a code of conduct (underway). In addition, training in SANS10299 is recommended as part of the newly implemented Continued Professional Development measures of SACNASP.
- It is recommended that in order to promote decentralised use of groundwater in the MM areas, that each MM develop guidelines for the installation of alternative water systems
- Related to the various recommendations made, there is a need to provide training or increase awareness in the hydrogeological profession and within the MMs regarding the implementation of new SPZ policy, and regarding the mainstreaming of groundwater into urban planning.

Outcome

Implementing all aspects of the plan would achieve:

- Increased human use of groundwater resources in acceptable manner and thereby greater water security
- Improved management and of groundwater resources
- Improved protection of groundwater sources (SPZ) and resources (RQO)
- Improved groundwater quality
- Improved health of groundwater supplied urban green infrastructure

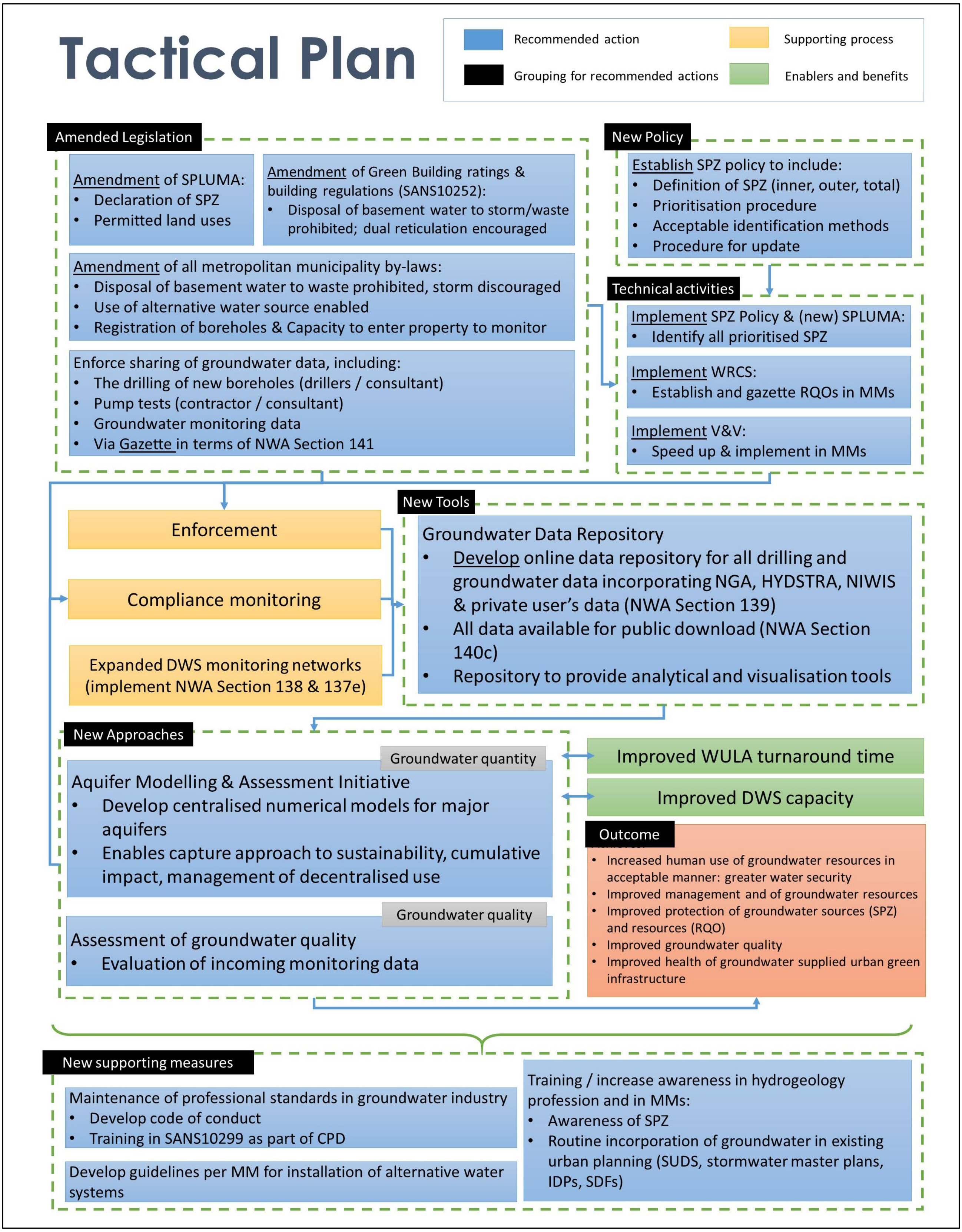

Figure 6-1 **Tactical plan for improved urban groundwater development and management**

6.3. Urban Groundwater Strategy – Implementation

Significant shifts are required in order to realise all aspects of the tactical plan for improved urban groundwater development and management. A wide range of recommendations are made in the National Groundwater Strategy (DWS, 2016d), and the tactical plan is intended to highlight what are the most important areas of required action in order to shift towards better (urban) groundwater management. The plan demonstrates how (urban) groundwater management is a cross cutting issue that requires the involvement of various spheres of government, various government departments, and role players. There is no single body that can be responsible for the full implementation, but as the interest and motivation to initiate this study came from the WRC, it is recommended that the WRC, through follow on studies, maintain oversight for each element of the plan.

Some work is already underway on at least parts of the recommendations made within the plan, illustrated in Figure 6-2. A project is underway with the WRC to develop model municipal by-laws, which should incorporate the recommendations made here. The need to enforce groundwater data sharing and for a central repository for this data is widely recognised and included in the recommendations made in the NGS. The Danish Embassy currently has an agreement to support and collaborate with the DWS in various areas of water security, and through this collaboration, the Danish Embassy is currently working with DWS and the WRC on enforcing data sharing and amending the NGA to enable easier upload facility. It is recommended that these interventions focus on implementing existing legislation, as data sharing can be enforced in terms of the NWA, Section 141. In addition the WRC has several projects looking at groundwater data storage, data visualisation tools, and groundwater data capturing from users via apps. The lessons from these projects must lead to an improved or re-invented NGA for online central data repository. In terms of supporting measures, the Groundwater Division of the Geological Society of South Africa is committed to maintaining professional standards in the groundwater industry, and is currently developing a code of conduct to regulate groundwater professionals.

There are no known current interventions in other areas of the tactical plan and it is recommended that the WRC initiate studies or liaison in these areas, including:

- Developing SPZ policy and amending SLUMA. Implementing SPZs in South Africa is also recommended in the NGS (DWS, 2016d), however there is no known current intervention addressing this recommendation. The amendment of SPLUMA for incorporation of SPZs and associated SPZ policy recommended here is an area that would benefit from immediate attention. Significant prior research has been conducted in SPZs and there is international policy and legislation to serve as example. This intervention does not therefore require significant research, but rather requires liaison, promotion and adoption at the appropriate level decision-making level.
- Liaison with the green building council, to prohibit the disposal of dewatered groundwater from basements to sewer and strongly discourage disposal to stormwater, and to further encourage dual reticulation.
- Contact training institutions to develop a training course in SANS 10299
- The recommendation for centralised (i.e. owned by neutral party such as DWS) numerical groundwater models to enable a capture approach to sustainability, the detection of cumulative impact, and management of decentralised use has been made elsewhere (DWAF, 2008b, Seyler et al., 2016b, DWS, 2018). Out of the recommendations made in the tactical plan, this is the most challenging to implement related to the lack of capacity at DWS, and a necessity for DWS to delegate powers if it is taken on by another party. It is recommended that the WRC take steps towards implementing the recommendation via initial consultation with the hydrogeology profession followed by liaison, promotion and adoption at the appropriate level decision-making level with DWS and relevant parties.
- Whilst several of the MMs participated in this study, some have indicated they would appreciate an urban groundwater session dedicated to their MM with wider staff representative than were able to attend the think tanks. It is therefore recommended that the WRC continue the Urban Groundwater think tanks to share and

promote these project insights in greater detail with the MMs and with the wider groundwater sector, addressing:

- training / increase awareness in hydrogeology profession and in MMs on the awareness of SPZ and on routine incorporation of groundwater in existing urban planning (SUDS, stormwater master plans, IDPs, SDFs)
- promotion of other project elements of the project such as promoting the use of basement water and the recommended amendment of by-laws, guidelines for installation of alternative water systems,

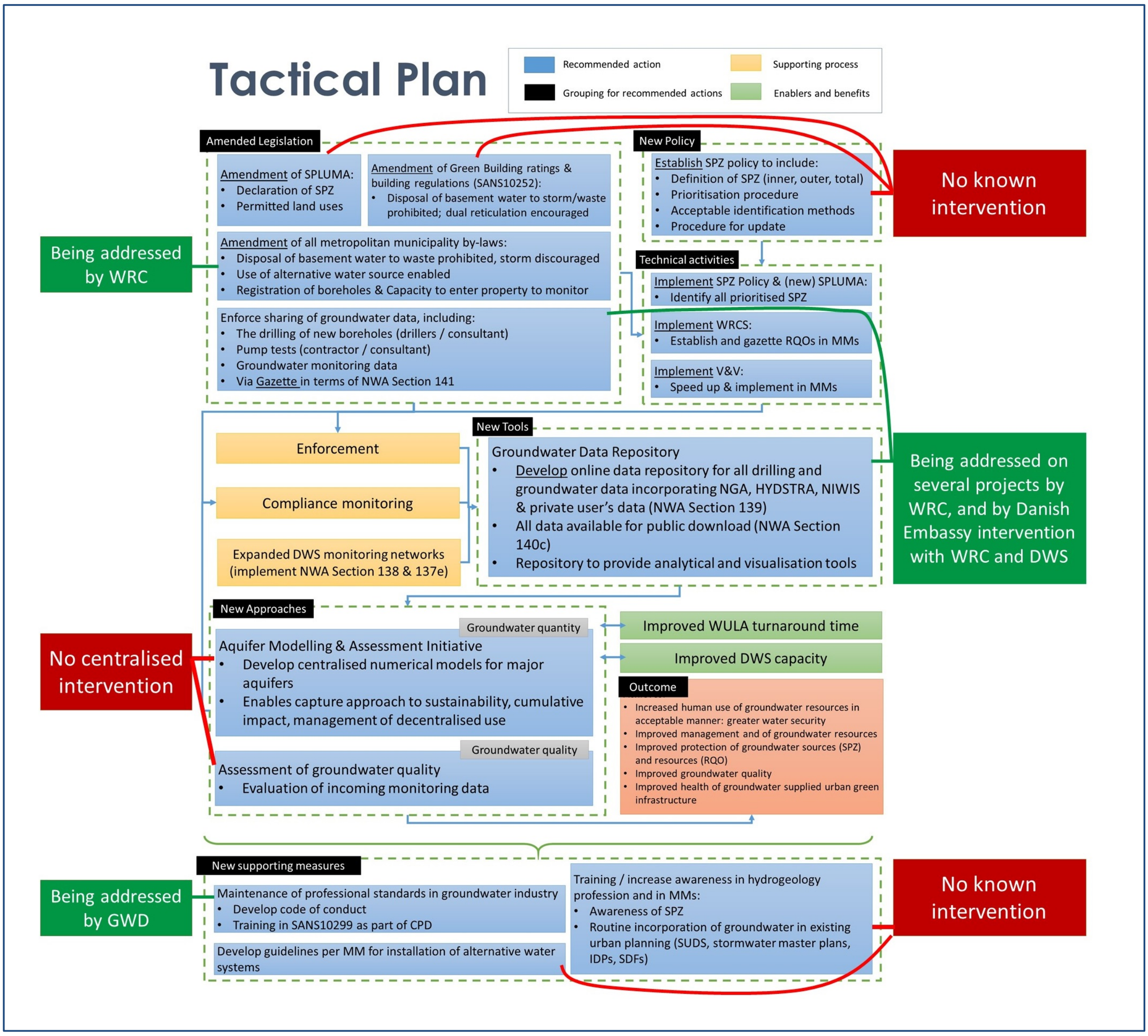

Figure 6-2 Tactical plan with existing interventions indicated

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