IDENTIFICATION, DELINEATION AND IMPORTANCE OF THE STRATEGIC WATER SOURCE AREAS OF SOUTH AFRICA, LESOTHO AND SWAZILAND FOR SURFACE WATER AND GROUNDWATER

D Le Maitre, H Seyler, M Holland, L Smith-Adao, A Maherry, J Nel & K Witthüser

WATER RESEARCH COMMISSION

TT 754/1/18

Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater

Report to the

WATER RESEARCH COMMISSION

Prepared by

David Le Maitre[1], Helen Seyler[2], Martin Holland[2], Lindie Smith-Adao[1], Jeanne Nel[1,3], Ashton Maherry[1] and Kai Witthüser[2]

[1]Natural Resources and the Environment, CSIR, Stellenbosch
[2]Delta H, Pretoria, South Africa
[3]Institute for Environmental Studies, Faculty of Science, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

WRC Report No. TT 754/1/18

July 2018

Obtainable from
Water Research Commission
Private Bag X03
GEZINA, 0031

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

The publication of this report emanates from a project entitled *Enhancement of the method to identify and delineate South Africa's Water Source Areas: Integrated Report* (WRC Project No. K5/2431)

ISBN 978-0-6392-0006-4
Printed in the Republic of South Africa

Citation:

Le Maitre, D.C., Seyler, H., Holland, M., Smith-Adao, L., Nel, J.L., Maherry, A. and Witthüser, K. (2018) Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for Surface Water and Groundwater. Report No. TT 743/1/18, Water Research Commission, Pretoria.

ACKNOWLEDGEMENTS

The research in this project was funded by the Water Research Commission (WRC), for whose assistance we are sincerely grateful. Additional funding was also made available by the Council for Scientific and Industrial Research (CSIR) and Worldwide Fund for Nature (WWF). Their support is gratefully acknowledged.

Participants from various affiliations and sectors are thanked for their enthusiastic participation in project workshops and meetings. Those involved shared their data, knowledge and experience freely without which this research would not have been possible. They represented the government, private sector and civil society. The project team would like to thank all participants.

The members of the WRC Reference Group are thanked for their time, guidance and valuable inputs:

Mr Wandile Nomquphu (Chairperson)	Water Research Commission (WRC)
Dr Dirk Roux	South African National Parks (SANParks)
Ms Christine Colvin	World Wide Fund for Nature – South Africa (WWF - SA)
Mr Samir Randera-Rees	World Wide Fund for Nature – South Africa (WWF - SA)
Mr Dean Muruven	World Wide Fund for Nature – South Africa (WWF - SA)
Dr Koos Vivier	Exigo-EOH
Dr Kornelius Riemann	Umvoto Africa CC
Mr Julian Conrad	Geohydrological and Spatial Solutions International (GEOSS)
Ms Amanda Driver	South African National Biodiversity Institute (SANBI)
Mr John Dini	South African National Biodiversity Institute (SANBI) (now with the WRC)
Dr Christo Marais	Department of Environmental Affairs (DEA)
Mr Andrew Wannenburgh	Department of Environmental Affairs (DEA)
Ms Nicolene Fourie	Department of Environmental Affairs (now with the CSIR)
Ms Lebogang Matlala	Department of Water and Sanitation (DWS)
Ms Ndileka Mohapi	Department of Water and Sanitation (DWS)
Mr Fanus Fourie	Department of Water and Sanitation (DWS)
Ms Isa Thompson	Independent (retired from the DWS)
Mr Niel van Wyk	Independent (retired from the DWS)

We thank Mr Dirk Versfeld for his participation in and advice to the team and for reviewing the final draft report, and Ms Magdel van der Merwe who provided assistance with the report formatting.

EXECUTIVE SUMMARY

Introduction and background

Water Source Areas (WSAs) have historically been defined using the criterion of the production of relatively large volumes of runoff which sustain lowland areas downstream. This report builds on a previous study by WWF-SA and CSIR which identified 21 Strategic WSAs (SWSAs) which covered 8% of South Africa and supplied 50% of the mean annual runoff. These SWSAs for surface water (SWSA-sw) were included in the 2013 National Water Resources Strategy as areas needing protection for water security. Groundwater was not included in the 2013 study although it is an important, and often the only, reliable water source in much of South Africa. This study, through extensive consultation with stakeholders, redefined what is meant by a WSA to include groundwater, has refined the Strategic Water Source Areas for surface water (SWSA-sw) and has identified a number of Strategic Water Source Areas for groundwater (SWSA-gw).

Strategic Water Source Areas (SWSAs) are now defined as areas of land that either: (a) supply a disproportionate (i.e. relatively large) quantity of mean annual surface water runoff in relation to their size and so are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b). They include transboundary Water Source Areas that extend into Lesotho and Swaziland.

Objectives and aims

This report summarises the findings of a 3-year Water Research Commission project (July 2015-December 2017) led by the Council for Scientific and Industrial Research (CSIR) and Delta-h Water Systems Modelling. Specifically, the project aimed to:

1. Review and refine the understanding of the hydrological processes that lead to the generation of runoff and groundwater recharge in South Africa's water source areas, and especially in groundwater systems.
2. Develop an integrated method to identify and delineate water source areas that include run-off generation and groundwater recharge (i.e. surface water and groundwater).
3. Link the water source areas and their associated water resources to key benefit flows.
4. Identify key pressures and recommend management and protection options water source areas.
5. Explore policy mechanisms for the uptake of the products.

The primary outputs from this project are this Integrated Report, a Management Framework and Implementation Guidelines for Planners and Managers report which provides information on policy, legislation and other measures relating to their protection and management, and a Knowledge Dissemination report which provides a summary of the importance of the SWSAs, the key findings and recommendations for general audience.

Approach

The project had both a research component and a stakeholder consultation and review component. The research component addressed the first four aims and the consultation focused on policy integration. Stakeholder groups were identified in addition to the reference group, and stakeholder workshops were organised with the dual aim of obtaining both their inputs and their support for the implementation of protection measures for the SWSAs. These workshops involved a broad range of people with knowledge and expertise in the fields of water research, water resource planning and management, and environmental conservation to discuss the findings of the research, obtain their comments and critiques, and to obtain agreement on the final set of SWSAs.

Stakeholder inputs were used to define which of these WSAs should be considered as important for national-level water security (i.e. SWSAs) and which are important but at a sub-national level (i.e. WSAs). The SWSA-sw were delineated with boundaries, two of the 2013 SWSA-sw were considered sub-national (Pondoland and Zululand Coast), and three new ones were added (Upper Vaal, Upper Usutu, Waterberg), bringing the total to 22. A further seven, small, sub-national WSAs for surface water were identified. The SWSA-gw study identified 37 areas that were important at the national level and a further 20 that are important at a sub-national level. This study has focussed on the national SWSA, but information on all sub-national WSAs is included in the appendixes. The benefits were assessed by estimating how much of the water SWSAs provide is supplied to urban areas, for domestic and industrial purposes, for irrigation, and to the economic activities that those centres sustain. The final step was to assess the pressures on and potential risks to these areas from changes in land cover, mining and alien plant invasions. The outputs of this work have already been included in the draft National Water Master Plan and in the draft National Spatial Strategic Development Framework.

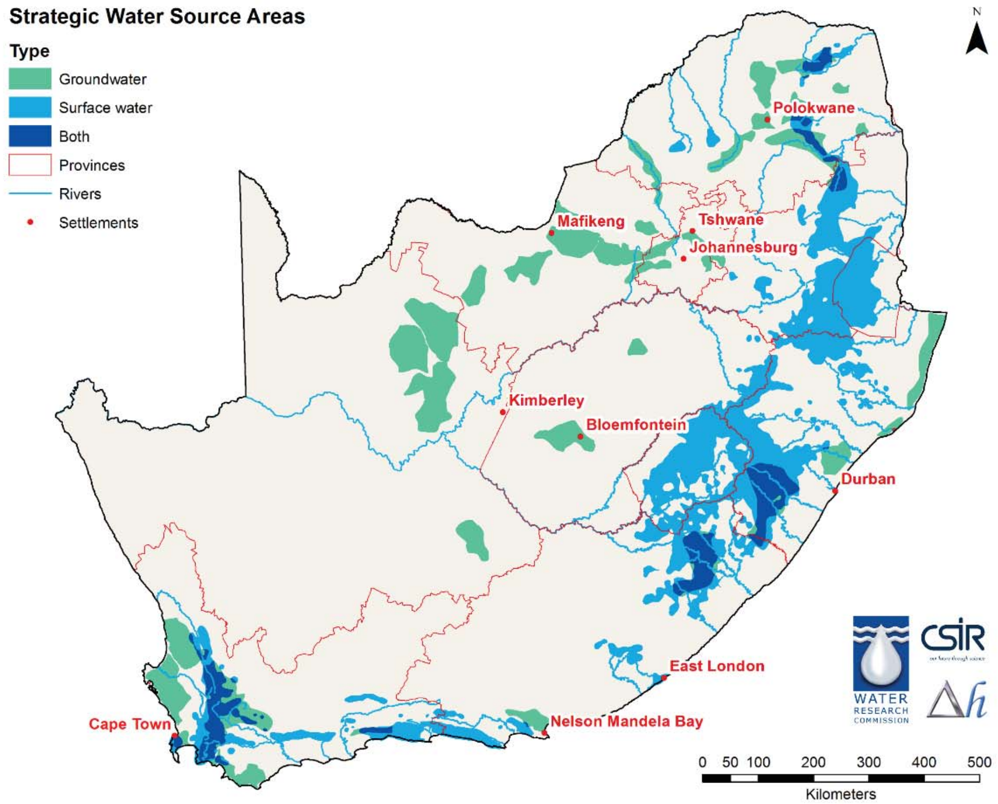
Overview

As described above, water source areas are places or areas, such as water catchments, which produce disproportionately greater volumes of water per unit area than other areas. This can be because of climatic conditions like high rainfall, or physical properties such as the ability of the soils and underlying weathered material and rocks to store water as groundwater. The water in wetlands, streams and rivers is known as surface water or runoff, and large volumes are typically generated in high rainfall areas over the period of a year. Water in saturated layers or zones below the land surface is known as groundwater and discharges or outflows of groundwater sustain springs and river flows in the dry season (known as baseflow). The SWSA-sw are all located in high rainfall areas where baseflow is at least 11-25 mm/a, evidence of a strong link between groundwater and surface water in the SWSA-sw. The aquifers are sustaining baseflow, contributing to runoff and especially to dry season flows. Sustained river flows are important because they support people and communities who depend directly on rivers for their water, especially during the dry season and droughts.

The total area of the 2013 set of surface water-derived SWSAs (SWSA-sw) in South Africa, Lesotho and Swaziland (see Figure) is 102 172 km^2 (8% of South Africa) and they produce a mean annual runoff (MAR) of 25 099 million m^3/a (50% of the total). The updated, national and transboundary SWSA-sw (refer to the map below) cover about 124 075 km^2 (10% of the region) and provide a MAR of 24 954 million m^3 (50% of the total). With the addition of the sub-nationally important Pondoland Coast and Zululand Coast SWSA-sw, they cover about 148 478 km^2 (12% of the area) and provide a MAR of 29 354 million m^3 (59% of the total). This analysis also identified a set of seven smaller sub-nationally important areas which add less than 1% to the total MAR but are locally important (see Appendix 1). The greatest volume of MAR is generated by the Southern Drakensberg (9% of national and transboundary MAR), followed by the Eastern Cape, Northern and Maloti Drakensberg and the Boland. The Boland has the highest MAR per unit area (3 588 m^3/ha/year), followed by Table Mountain, the Northern Drakensberg and the Mpumalanga Drakensberg.

Seven of the SWSA-sw are transboundary areas because Lesotho and Swaziland include portions of important SWSA-sw for South Africa. The portions of the SWSA-sw that fall within Lesotho (Eastern Cape, Southern, Northern and Maloti Drakensberg) cover 18 570 km^2 and generate a MAR of about 3 522 million m^3. This MAR sustains the Orange and Caledon Rivers and supplies water to Gauteng via the

Lesotho Highlands water supply system. In the case of Swaziland the portions of the SWSAs falling into this country (Enkangala Drakensberg, Mbabane Hills, Upper Usutu) total 9 376 km^2 and produce a MAR of about 2 053 million m^3. In total, the SWSA-sw in these two countries produce about 11% of the total MAR, a substantial contribution which needs to be protected.



Strategic Water Source Areas for surface water and groundwater (SWSAs) in South Africa, Lesotho and Swaziland. Strategic Water Source Areas for groundwater were not identified in Lesotho and Swaziland because suitable data were not available.

The newly defined Strategic Water Source Areas for groundwater (SWSA-gw) cover around 9% of the land surface of South Africa (see Figure). They account for up to 42% of the baseflow in their areas and have a key role in sustaining surface water flows during the dry season. About 24% of the settlements that are reliant on groundwater lie within SWSA-gw, equivalent to 10% of all settlements in South Africa. SWSA-gw supply about 46% of the groundwater used by agriculture and 47% of the groundwater used for industrial purposes in South Africa. The total recharge for South Africa is estimated to be 34 912 million m^3/a, with the recharge generated by the SWSA-sw being 11 675 million m^3/a (33%) and the SWSA-gw accounting for 5 397 million m^3/a (15%). The relatively low recharge accounted for by SWSA-gw is due to the method used in their delineation, in which only the areas of overlap between high recharge and high levels of use or dependence were identified at the national level.

Summary of the key findings

This study identified 22 SWSA-sw and 37 SWSA-gw that are considered to be strategically important at the national level for water and economic security for South Africa. They include portions of the SWSA-sw which extend into Lesotho and Swaziland. The transboundary SWSA-sw that include Lesotho are critically important for the Gauteng metropolitan region which has the largest population and economy in southern Africa.

The total area for SWSA-gw is around 104 000 km^2, and 24% of this area delineated as SWSA-gw overlaps with the updated areas delineated for SWSA-sw. Considering the total area of South Africa delineated as a SWSA, SWSA-gw (without overlaps) accounts for 39%, surface water (without overlaps) account for 49%, with the overlaps contributing 12%. This study only defined SWSA-gw within South Africa as suitable data were lacking for Swaziland and Lesotho. Transboundary aquifers were considered, but did not meet the criteria established for nationally Strategic Water Source Areas for groundwater.

Benefits provided by SWSAs

There are many water-related benefits that society obtains from Water Source Areas, and this assessment has focused primarily on a few of the benefits received by urban settlements, namely water for urban and industrial purposes, and for irrigation. These benefits are derived both from SWSAs overlapping the urban areas as well as from ones 100s of km away and linked by large Water Supply Schemes (WSSs). Water from SWSAs is also critical for cooling at the power stations that generate most of the electricity in South Africa. For SWSA-sw, this study focussed on a set of 26 national and sub-national economic centres, some of which include both towns and cities, identified as important in the National Water Resources Strategy and linked to WSSs. Groundwater from SWSA-gw tends to be used locally so their links to urban settlements and to agriculture and industry within the SWSA-gw were analysed.

Urban centres and economic activity

The major urban centres of South Africa source a high percentage water of their water, generally >90%, from the SWSA-sw. In the case of the Vaal WSS, if the yield from the portion of the Vaal catchment outside the catchment's SWSA-sw is excluded, 67% of the water is from SWSA-sw. The lowest is the Olifants regional WSS which gets less than half of its water from SWSA-sw. In some cases, notably Pretoria, Richards Bay and Polokwane, a fair proportion of the urban centre's water is obtained from SWSA-gw. The urban centres that were examined included 60% of the population in 2011 and accounted for at least 70% of the national Gross Value Added, a sub-national measure of the economic activity. The population does not include rural people and communities and their economic activities downstream that depend on, for example, rivers as water sources.

About 12% of South Africa's population reside within sole groundwater supply towns or settlements where groundwater provides >50% total supply. Many settlements with sole groundwater supply are rural village clusters or small towns and (only) 24% of these settlements fall within SWSA-gw because the remainder do not coincide with areas of high groundwater availability. None of the 11 metropolitan municipalities with their large populations has groundwater as >50% of their supply. Although only 12% of the population has groundwater as their sole supply, these settlements depend on it. Few of the 26 areas of national economic importance are solely supplied by groundwater so only 8% of the economic centres are situated within national SWSA-gw. This assessment only included municipal supply but, "off grid" private abstraction for domestic use and towns using less than 50% groundwater were included, then the population that was supported would be much greater.

Water use for irrigation and groundwater use by industry

Water-use for irrigation was assessed because its annual requirement is about 60% of the national total, it provides almost all the vegetables and fruit for local use and export, directly or indirectly supports about 8.5 million people, and contributes about 3% to the national GDP. Accurate and up-to-date information on the extent of the irrigated areas is not available at present, but inferences can be made from a combination of land-cover, water allocation, and economic activity in the agricultural sector. The area under irrigation is about 17 645 km^2 and about 70% of the water used for the irrigation is derived directly or indirectly (e.g. through river flows) from water from the SWSA-sw. The greatest allocation of surface water is to irrigation schemes in the middle Orange River but the greatest GVA added is in the Western Cape, KwaZulu-Natal, Gauteng and parts of Mpumalanga and Limpopo. Groundwater abstraction for agriculture comprises only 14% of the total water abstracted agricultural purposes. However 47% of the groundwater abstraction for agriculture coming from within SWSA-gws. Similarly, industrial abstraction within SWSA-gw accounted for 47% of industrial use.

Protection status

Only 11% of all the SWSAs is under Protected Areas (PAs) with only 67 SWSA sections[1] having some PAs. For example, only 10% of the critically important Northern Drakensberg SWSA, which includes the Upper Wilge and Upper Tugela catchments, is under PAs. Much of this area is montane grasslands with extensive areas that have been severely degraded by overgrazing that poses a threat to water security and require restoration. The best protected SWSAs are mainly in the Western Cape, and include the Swartberg, Boland and Groot Winterhoek. The Mpumalanga Drakensberg SWSA-sw and overlapping Northern Lowveld Escarpment SWSA-gw have an area of 10 957 km^2 but only 10% is in PAs and the corresponding figures for the Southern Drakensberg are 17 092 km^2 and 14%.

A total of 44 of the SWSAs include Conservation Areas (CAs). They only make a relatively small contribution to the protection of the SWSAs because the total protected area only amounts to about 2 265 km^2. There are 10 SWSAs, or portions of SWSAs, which do not include any forms of protected area. They add up to about 20 437 km^2, or 12% of the total area of the SWSAs. The majority of these are SWSA-gw and are spread widely across South Africa with the Upper Vaal being the only SWSA-sw with no protection. The protected areas assessed here do not include such areas in Lesotho or Swaziland which would add to the total under some protection in the transboundary SWSAs.

Impacts on water flows and quality

The amount of rainwater which becomes stream flows or groundwater recharge depends on several factors, including the characteristics of the land and the vegetation growing on it because they affect key processes, including evaporation and infiltration. In general, tall, evergreen vegetation transpires and intercepts more water than short, seasonally green grasslands. Research has shown that commercial forest plantation species use more water than natural vegetation which is why the extent and location of plantation areas is regulated under the national Water Act as a Stream-Flow Reduction Activity (SFRA). Many of these trees species have invaded adjacent natural vegetation, especially riverine areas, and are significantly reducing in the mean annual runoff. Research has not shown that any other crops are SFRAs and it is likely that most dryland crops use less water than the adjacent natural vegetation. Irrigation typically increases the water-use per unit area because the farmers typically maintain the soil moisture as levels which are optimal, or even exceed optimal, for crop growth and can result in sub-surface or surface flows back to the river, known as return flows. The return flows offset the reductions but, ideally, they

[1] SWSA-sw, SWSA-gw and overlaps counted separately, some have multiple overlaps

should be minimized by investing in water efficient irrigation and irrigation scheduling systems to minimise return flows.

Changes in land cover and land management practices can alter the quality of the water draining from these lands. Impacts on water quality can be grouped into three broad classes: those involving the addition of chemical compounds and elements, those involving increases in suspended and transported sediments, and those involving living organisms (water-borne diseases, parasites and pathogens). The quality of the water in South Africa's river systems has been deteriorating for a long time, but has been exacerbated by the failure of many municipalities to maintain or upgrade their water-water treatments plants, stormwater management systems and regulate other point-sources of pollutants. Dryland agriculture typically is characterised by limited use of fertilisers and agrochemicals so the main impacts on water quality are through soil loss associated with poor tillage practices. In some cases where the groundwater has naturally high levels of salts, the salinity of the drainage water, and thus of river systems, can be increased by dryland cultivation. Crop growing under irrigation is typically much more intensive than dryland cropping, and involves agro-chemicals for controlling weeds and pests as well as fertilisation. Pollution of neighbouring water bodies and rivers through sub-surface water return flows is an important pathway which affects water quality in rivers and in groundwater. The increased nutrient levels in rivers and other water bodies can lead to algal blooms which can become toxic if cyanobacteria are involved. Mining can also have significant impacts on water quality, through unmanaged point discharges (e.g. from tailings dams) and through various groundwater impacts, particularly the generation of acid mine drainage. Increases in the sediment levels in water bodies due to land degradation or poor cultivation and road construction and design also have adverse effects on land productivity, increase turbidity and can result in sedimentation and the loss of storage capacity in dams.

Land cover changes

Most of the SWSA-sw are still under natural vegetation with the lowest proportions being found in Upper Usutu, Mpumalanga Drakensberg and Table Mountain. There is extensive cultivation in several SWSA-sw, including the Upper Vaal, and extensive irrigation in the Boland, Groot Winterhoek, Soutpansberg, and Wolkberg. As expected, plantation forestry is important in the SWSA-sw from KwaZulu-Natal to Limpopo. Mining occupies a relatively small percentage of the area of the SWSA-sw, but extensive prospecting licenses have been granted, particularly in Mpumalanga where most of the SWSAs (notably Enkangala Grasslands) could be transformed by open cast and longwall coal mining. The Table Mountain SWSA-sw has urban and industrial areas while the Soutpansberg also has extensive urban areas and dense rural settlements. The pervasive mixture of land-cover classes highlights the importance of managing these multifunctional landscapes to minimise the impacts of human activities in these landscapes on water quantity and quality.

Many of the SWSA-gw have high percentages of natural land but this vegetation is used as rangeland for livestock and so may be degraded because of overgrazing or, through lack of fires, by bush encroachment or thickening. The thickening may result in a reduction in surface water runoff as well as groundwater recharge. The Richards Bay GW Fed Lakes SWSA-gw has the least natural vegetation (23%), a high percentage under plantations (41%), formal residential areas (17%), and cultivation (primarily irrigation). The Eastern Karst Belt SWSA-gw also has as a low percentage of natural vegetation (40%), a high percentage of dryland cultivation and urban areas. Extensive dryland cultivation occurs within the West Coast Aquifer, Eastern Kalahari A & B, Central Pan Belt, Kroonstad and Westrand Karst Belt SWSAs. KwaDukuza, Vivo-Dendron, Sandveld, and Tulbagh-Ashton valley all have relatively high percentages under irrigated crops. The Cape Peninsula and Cape Flats has about 60% under urban and industrial areas, including extensive informal settlements and townships, which places this water source under a high risk of contamination, especially given that the SWSA-gw predominantly has high groundwater vulnerability (related to the unconfined sandy Cap Flats aquifer). SWSA-gw with the largest coverage of mining include Phalaborwa (11%), and Kroondal/ Marikana (6%).

Mining: coal, minerals, shale gas

Mining activities have adverse effects on both water quantity, mainly through water consumption in the mining processes, and on water quality in the forms of acid mine drainage (AMD), discharges, slimes dam overflows, or runoff. Although there has been a lot of emphasis on AMD from gold mines, open cast and extensive shallow coal mining (e.g. longwall mining) can have significant impacts over a much wider area through AMD.

South Africa has 19 coalfields within the Karoo super group strata with the total recoverable reserves estimated at 55 333 Mt or about 50 years of coal supply. Most of the coal reserves that overlap with SWSAs are located in the Highveld, Witbank and Ermelo fields, so there are substantial coal reserves in areas that do not overlap with SWSAs at all. There is complete overlap in the Upper Vaal and Kroonstad, the next most extensive being the Enkangala Grasslands (42%). The Upper Vaal has already been identified as a critical water-energy conflict area (Colvin et al., 2011). There are very large reserves in the Highveld and Ermelo coalfields which overlap with SWSAs, particularly the Upper Vaal and Enkangala, and the impacts need to be properly taken into account. The geographical distribution of South Africa's geological formations and its orogeny has resulted relatively little overlap between the SWSA-sw and mineral provinces but the SWSA-gw overlap more and this needs to be considered during the permitting process. Shale gas extraction from the Karoo shales could affect the Northern Drakensberg, Enkangala, Upper Vaal, Upper Usutu, Wolkberg and Soutpansberg as well as some of the SWSA-gw.

Invasive alien plants in SWSA-sw

This study only assessed the impacts of wattles (Australian *Acacia* species), pines and eucalypts – the genera which have the greatest impact on runoff. Invasive alien plants reduce the MAR by 485.8 million m^3/a, or 2.6% of the pre-development (virgin) MAR. This is greater than the estimated water requirement for 2015 for the eThekwini metropol which supports a population of over 4 million people. Thus the impacts of invasions by just three taxa on MAR from SWSA-sw amount to 33.7% of the total reduction in virgin MAR although they only represent 21.0% of the total invasions. By far the greatest reductions, by volume, are found in the South African portions of the Eastern Cape Drakensberg, Southern Drakensberg and Boland, while the greatest percentage reductions are found in the South African portion of the Maloti Drakensberg, Amatole, Enkangala Drakensberg, Outeniqua and Boland. These reductions are critical because they affect all downstream users and the extent of the invasions is still increasing at about 5-10% per year. This highlights the importance of giving priority to clearing these invasions.

Groundwater vulnerability focussing on contamination

Aquifers have varying susceptibility to contamination from surface sources related to hydrogeological properties such as porosity. This susceptibility has been mapped nationally as groundwater vulnerability, separated into categories ranging from very low to very high. The higher porosity Cenozoic Sand aquifers and the dolomite aquifers are the most vulnerable, notably the Ghaap Plateau, Bo-Molopo Karst Belt, Sishen/Kathu, Ventersdorp/Schoonspruit Karst Belt (dolomites), and the West Coast Aquifer area (Cenozoic Sand). These same SWSA-gw each have >50% of their area rated as "high" vulnerability. The most extensive areas of very high vulnerability include extensive Cenozoic Sand systems (Zululand Coastal Plain, Richards Bay, and Cape Peninsula and Cape Flats) and the Northern Lowveld Escarpment (dolomites) also has relatively large areas of very high vulnerability. The SWSA-gw that include greatest areas of groundwater with high vulnerability are at risk from the following sources: urban and industrial uses for the Cape Peninsula and Cape Flats SWSA-gw (49% very high vulnerability) and the Richards Bay SWSA-gw (69% very high vulnerability). Cultivated areas cover 48% of the West Coast Aquifer (58% high vulnerability) and 29% of the Ventersdorp/Schoonspruit Karst Belt (66% high vulnerability).

Groundwater drought risk

The groundwater drought risk increases away from the coastline and towards the interior of South Africa, and is more pronounced in the northwest, followed by north and northeast of the country. The SWSA-gw most affected by high to very high groundwater drought risk include those sub-national WSA-gw identified in the northwest of the country. Moderate groundwater drought risk is found in the north and northeast of the country, including the Southern Ghaap Plateau, Ixopo/Kokstad, Northern Lowveld Escarpment, and Northern Ghaap Plateau. SWSA-gw in coastal areas in the south and east of the country have very low drought risk, including Zululand Coastal Plain, Coega TMG Aquifer, and Richards Bay GW Fed Lakes.

Recommendations

Introduction to recommendations

The protection and restoration of Strategic Water Source Areas (SWSAs) is of direct benefit to all downstream users and this dependence needs to be considered in decisions relating to these primarily headwater catchments. The protection of both water quantity (flows) and quality must be addressed. Any failure to address impacts on water quality or quantity will have impacts on the water security all those depending on that water downstream. Groundwater is the main or only source of water for numerous towns and settlements across the country so protecting the capture zone, specifically for municipal supply well-fields, the recharge area, and the integrity of the aquifers is very important as well.

The protection and management of SWSAs is a responsibility that reaches across many government departments and all spheres of government, the private sector (particularly agriculture and mining), and even the public at large. SWSAs must be recognised and valued by all for the role they play in sustaining the people and the economy of the country. Much can be done to protect, and even improve, the integrity of our SWSAs.

General Recommendations

1. That SWSAs for surface water and groundwater be agreed to and accepted by all Departments and spheres of government responsible for land use and land protection and water use management on the basis of the framework developed through this research. Attention needs to be given, in collaboration with DEA and SANBI, to establish how best to delineate SWSAs so that they can be declared as formally protected areas for water source protection.
2. That the critical importance of sustaining the societal and economic benefits of SWSAs as sources of water, particularly in this era of changing climates, growing populations, urbanisation and increasing expectations, is fully recognised by investing SWSAs with the highest practical level of protection.
3. That land and resource use planners – from developing the National Development Plan, Water and Environmental Master Plans, to IDPS and all other plans – understand and accommodate the need for SWSAs.
4. Effective groundwater protection in the SWSAs (and everywhere groundwater is used) requires a range of measures including protecting recharge areas by addressing land use and land management practices, especially to prevent sealing of surfaces, and protecting the soils to maintain water infiltration, percolation and aquifer recharge and prevent contamination. Well-field protection zones

must be identified and implemented for all domestic supply schemes, and abstraction managed to ensure, for example, that abstraction does not have significant adverse impacts on aquifer integrity.

5. Activities such as mining or shale gas extraction must be regulated to ensure they do not damage or destroy any aquifer.
6. That the DWS, DEA and WRC adopt and champion the concept of SWSAs and that a programme be developed and promoted to ensure that these become part of the public domain. The value and importance of SWSAs must be popularised, recognised, and adopted as essential to the sustainable future water supply and water security in South Africa.
7. This project has identified the national-level SWSAs and the same process needs to be taken up at the Water Management Area and sub-WMA levels. Some sub-national water source areas have already been identified in this study. For groundwater, the SWSA are only really useful at national scale, and aquifer-scale assessments are appropriate at sub-WMA level. The boundaries for the SWSAs as defined in this study are indicative and intended for national-level delineation.

To achieve these outcomes the Department of Water and Sanitation must:

a) Address protection measures for both groundwater and surface water in an integrated way, noting that the key components of surface water (e.g. baseflows) depend on groundwater recharge.
b) Prioritise the completion of all the Water Resources Classification projects in these areas, so that gazetted Resource Quality Objectives (RQOs) are all in place, and the ecological Reserve in these river systems is implemented and enforced.
c) Regulate land-use practices to minimise impacts on water resources in co-operation with other departments and spheres of government and governance. This includes continued regulation of forestry and streamflow reduction activities, consideration of other land uses as potential SFRAs, regulation of surface and subsurface pollution activities, control of all water licences and allocations in managing unsustainable development and protecting downstream users, the implementation and enforcement of the ecological Reserve, strict implementation of Resource Quality Objectives and the many other tools available to the DWS to ensure that SWSAs (surface and groundwater) are ably protected.
d) Incorporate SWSAs into the National Integrated Water Information System to inform DWS management decision-making, strategies and plans at the national, provincial and municipal level. This system could also make the information on the SWSAs available to the public via the DWS, DEA and SANBI websites to support private sector and NGO initiatives such as Water and Land Stewardship as supported by, inter-alia WWF-SA and other conservation organisations.
e) Re-affirm its Planning Divisions (Integrated Water Resource Planning, National Water Resource Planning, Water Quality Planning, Water Services Macro Planning, Groundwater Planning) as critical and core functions within the Department – and allocate the necessary budgets to undertake their planning functions. Water source and resource planning should be on 10, 25, 50 and even 100-year horizons.
f) Integrate SWSAs into the National Water Resources Strategy and National Water and Sanitation Master Plan as a critical issue and high priority for water source management strategies and planning addressing water security issues and the environment. Ensure that SWSAs are addressed through planning and actions in all water resource reconciliation strategies for metropolitan and development regions, Catchment Management Agencies, and in revisions to the All Towns Strategies. CMAs in particular can provide direct engagement with water users and catchment forums about the importance of protecting and restoring the SWSAs they depend on

and in planning to ensure sustainable sources are targeted for future water resource development where growth requires water supply augmentation.

g) Incorporate SWSAs into the revised National Water Act as a specific category requiring protection, and into policies and guidelines for the assessment of water-user licence applications.

h) Together with the Department of Environmental Affairs, the Department of Cooperative Governance and the Metros, ensure that SWSAs, and considerations and guidelines relating to their protection and restoration, are incorporated into cross-sectoral planning measures such as any revisions to the National Development Plan, Integrated Development Plans, and Spatial Development Frameworks at the national, provincial and local government levels. This is directly aligned with a key objective of WWF-SA in the water sector.

i) Along with its international obligations towards ensuring that South Africa considers its neighbours when using international rivers, so too the protection of water production landscapes (SWSAs) in neighbouring countries should be encouraged and supported – through advice, expertise, and even financial incentive.

j) Re-introduce the publication of Green Drop assessment reports for Waste Water Treatment Works – both as incentive and deterrent and prioritise investments in such facilities within SWSAs.

k) Implement existing water management policies and strategies, including the Integrated Water Quality Management Policy, Wetland Policy, and the National Groundwater Strategy, to support effective management in the SWSAs.

l) Strengthen and re-build the water resources monitoring network, especially in the SWSA. A comprehensive network providing rainfall, streamflow and climate data is essential in these times of climate change and drought, growing demand, observed scarcity, and the need to share limited resources equitably. Modelling, predictions, and allocations all require good data. The DWS network has been severely cut over the years and must be re-invigorated. The monitoring of groundwater and especially of borehole water abstractions should be mandatory in all situations. Monitoring is fundamental to the management of SWSAs and is essential in assessing the success of measures taken for their protection.

m) Extend and expand the River Health Programme to prioritise the restoration of river systems within the SWSAs and downstream to ensure that these systems are effective in protecting the quantity and quality of the water they convey.

<u>Co-operative Governance</u>

8. The fact that SWSAs are multi-purpose landscapes means that the DWS's leading role in water resources will have to be exercised in close collaboration with other departments at the national level, provincial level and local government level. This would include all government agencies that have a role in land management planning and the regulation of land use and land-use practices. Key departments would be national and provincial Agriculture, Environment, Rural Development and Land Reform, and Minerals and Energy and, indirectly, Tourism. The role of local government in the SWSAs is very important for implementing measures that can minimise their impacts on water quality, such as combining built infrastructure and ecological infrastructure in water, waste water and stormwater treatment and re-use, and Water Sensitive Design.
9. The DWS needs to determine ways of financing the restoration of the SWSAs, where necessary, including supporting DEA's programmes on controlling invasive alien plants which have an impact on water quantity and quality. At present the funding for such work comes primarily from the

Extended Public Works Programme through DEA-NRM who fund operations directly through the Working for Water Programme, or indirectly through a range of implementing agents under their Land-User Incentive Programme. In many cases though, the restoration or the clearing requires well-trained and skilled workers and the use of machinery which requires skilled operators. Once trained these people need to be retained so an employment model is needed which can provide competitive remuneration and a career path for such workers, which is not possible at present under the EPWP employment models. One approach that has been successful in various countries is for water users to fund the restoration and clearing and this can be done through the DWS Trading Account or through funding provided through Catchment Management Agencies or Water User Associations. An approach which works well for the private sector is to provide financial incentives for investment in restoration and clearing and some stewardship models are based on this approach. The precedents are there, but the Department needs to take up this challenge and find ways to move from the concept to the implementation, possibly through pilot projects. The catchment restoration projects listed under Environmental Governance and the national Department of Environmental Affairs could be models for piloting the funding options.

10. The DEA, together with provincial and local government should ensure that the protection and restoration of these SWSAs is integrated into Spatial Development Frameworks at all levels of government. Likewise, ensure that SWSAs and their protection and restoration are addressed in Strategic Environmental Assessments and in Environmental Impact Assessments.
11. The fact that several key surface water SWSAs extend into Swaziland and Lesotho means that DWS will have to address their importance and management as part of their water-sharing negotiations with these countries.

Institutions with a direct responsibility for Environmental Governance

The government departments with an environmental and biodiversity mandate each have a key role to play in the protection of both water quantity (flows) and quality within and flowing from SWSAs through the protection of natural environments from developments that cause unacceptable and irreparable impacts.

National Department of Environmental Affairs

1. The Department has already begun a process of evaluating the measures available in the National Environmental Management Act and related Acts to protect SWSAs together with the South African National Biodiversity Institute. This process needs to be taken through to its conclusion.
2. The Branch: Environmental Programmes and the Natural Resource Management programmes must complete the process of incorporating SWSAs into the prioritisation of their management interventions and investments. They have indirectly incorporated surface water SWSAs by prioritising high mean annual runoff catchments for Working for Water but the process needs to be taken further and for all programmes which include groundwater SWSAs.
3. Prioritise the expansion of protected areas, both formal and informal, within the SWSAs. This would include both private land and land under traditional authorities.
4. Promote more catchment-level restoration projects. The current initiatives in the Ntabelanga-Lalini Ecological Infrastructure Project, Umzimvubu Catchment Partnership Programme, and "Investing in ecological infrastructure to enhance water security in the uMngeni River Catchment" Project are all examples of participatory, catchment-based restoration programmes. A project with a longer history is the research into the practical implementation of Integrated Water Resource Management in the Sand and Blyde River catchments which focused on collaborative strategic planning and action, and skills development. These projects are all founded on working with

people and institutions at various levels to protect water, land productivity and biodiversity and parts of each of these catchments are SWSAs. They all involve the establishment and expansion of land-owner stewardship and knowledge, and could serve as models for the implementation of protection measures for SWSAs.

Provincial Conservation Agencies and the Environmental Sector

1. Many provincial environmental conservation departments and conservation agency stewardship initiatives have focused on protecting biodiversity and wildlife, but they could easily be expanded to include land and water stewardship. The South African National Biodiversity Institute, WWF-SA and provincial conservation agencies are all actively developing stewardship models that could be applied in SWSAs. The corridors that allow the movement of organisms to increase the resilience of ecosystems to climate change are often the river systems that need protection and restoration, and there is much else in common between modern biodiversity conservation planning and what is needed for SWSAs. The SWSAs, and particularly the high conservation priority freshwater ecosystems within SWSAs, should be integrated into these plans and prioritised for protection.
2. The provincial conservation agencies have already started the process of incorporating the SWSAs (at least for surface water) into their provincial conservation planning and in their support to local government in developing their Spatial Development Frameworks. They should continue this process and explore ways of providing effective protection to SWSAs in working landscapes.

National and Provincial Departments of Agriculture including the LandCare programmes

Poor agricultural practices are a significant source of water wastage, sedimentation of water courses and water pollution within SWSAs. The national Department of Agriculture, Fisheries and Forestry (DAFF) plays a critical role, both as the department responsible for agricultural resources and through co-operative governance, in minimising the impacts of agriculture on water within and flowing from the SWSAs.

1. The Department is responsible for the enforcement of the Conservation of Agricultural Resources Act and its Regulations which include provisions for:
    a. The protection and conservation of agricultural resources including rangelands
    b. Prevention of land degradation through unwise land management practices
    c. The control of invasive alien species, especially weeds
    d. Protection of river systems and wetlands from cultivation and disturbance through buffers and other measures.
2. The Department must ensure these provisions are enforced within SWSAs to ensure that the quality and quantity of water they supply is effectively protected from adverse impacts.
3. There are some excellent resource conservation and river restoration programmes being run through the *LandCare* programmes, especially in the Western Cape. The Department should actively support and promote provincial and private initiatives (e.g. *SmartAgri* in the Western Cape) aimed at restoring land productivity and protecting water and land resources by clearing invasions and restoring rangelands. Initiatives that prove to be successful should be actively supported and rolled out to other provinces and regions.
4. The Department can and should do more to support *LandCare* and to make this a landholder-driven initiative as opposed to a programme driven by government initiated projects.

South African National Biodiversity Institute

In addition to their other activities noted above, SANBI are championing the value of protecting and sustainably using Ecological Infrastructure in various ways which will support the protection of SWSAs:

1. Development and use of maps that map the ecological infrastructure related to specific ecosystem services.
2. Policy advice relating to the implementation of Chapter 5 of the National Water Resources Strategy.
3. Inclusion of these maps and datasets in in protected area expansion & stewardship strategies.
4. Developing ecosystem accounts accounting work already being funded by the Water Research Commission and led by Statistics South Africa and SANBI.
5. Together with partner organisations pilot approaches for effective protection and management of SWSAs through the GEF-funded Biodiversity and Water Security Project.

WWF-SA

WWF-SA have strong relationships with the private sector, and with private sector funding such as the Green Fund, and should:

1. Use the maps and the associated to information to develop projects that enhance the management of these areas and support restoration projects and scientific research within these areas.
2. Continue to play a strong advocacy and lobbying role in government and elsewhere to have SWSAs incorporated in to strategies and planning at the various levels to help ensure that SWSAs are protected and restored for South Africa's long term water security.
3. Champion and guide private sector initiatives that contribute to the protection and restoration of SWSAs especially those that will improve the protection of water resources from the impacts of unwise land management practices. These include incentives such as environmental certification for farming that is effective in protection water resources, such as adequate buffering of water courses, and better containment and control of invasive species used in commercial plantations by the forestry industry.

<u>Research, particularly the Water Research Commission</u>

A number of issues for research have already been identified above. The Commission already has some research themes under the Lighthouses and various KSAs which are aligned with:

1. *Research on benefits*: This project has drawn linkages between the SWSAs and the people and economic activities that depend on the water they provide. More work is required to develop approaches to quantifying the full range of benefits to be gained from retaining areas under natural vegetation, and from the restoration and modification of existing land uses and land-use practices to protect and enhance water quantity and quality. These include the benefits of reduced water treatment costs and of being able to defer investments in water supply infrastructure. The findings of such studies can then be used to assess the impacts and benefits of proposed developments and enable decision-makers to make better-informed decisions. Those decisions would include the full range – from strategic development plans to water user licensing processes. This work can build on the ecosystem accounting work already being funded by the WRC and SANBI.

2. *Improving rainfall surfaces*: The current boundaries for surface water SWSAs depend on a mean annual runoff surface derived from an interpolated rainfall surface and rainfall-runoff relationships developed to quantify water resources for water resource planning. There are various research projects on improving the rainfall database, funded from various sources including the Water Research Commission, but none that is developing a new rainfall surface to replace that of 2004, which is out of date and used, for example, relatively coarse digital elevation data compared to what is available today. There have also been significant advances in the prediction of flows from ungauged catchments which could be used to improve both the rainfall-runoff relationships and the delineation of the catchment

areas to which these relationships apply. The DWS should fund a WRC research project to improve surface runoff information, and thus the delineation of the surface water SWSAs.

3. *Water Sensitive Design*: Research is needed to inform and incentivise local governments to invest in water sensitive design, in the use of ecological infrastructure for ecosystem-based adaptation to climate change, and the green village approaches.
4. *Freshwater governance*: The WRC has invested in research into freshwater governance through various projects. This study has highlighted the fact that SWSAs are lived-in and working landscapes whose protection is inherently cross-sectoral and involves a range of government departments and agencies at national, provincial and local authority levels, as well as the private sector, non-government organisations and civil society. Essentially this comes down to Integrated Water Resource Management which recognises that without effective and wise management of the land, society cannot effectively protect water source areas and the quality and quantity of water they provide. There are many documents which describe IWRM and its implementation but translating this into practice has proved difficult, primarily due to established ways of thinking and doing things rather than technical obstacles. Nevertheless, there are some examples of approaches (e.g. poly-centric governance) which could be taken beyond the pilot stage and into practice so that they can guide and support the implementation of effective IWRM in all spheres of water governance and management.
5. *Climate change and SWSAs*: The ability of global climate change models to make reliable predictions of temperature, rainfall and many other important factors that determine water runoff and recharge is improving rapidly. Increases in computing power are also enabling these models to be run at fine spatial resolutions (e.g. 64 km^2) that allow for the incorporation of features such as mountain ranges and their effects on the projected climates. Models which can simulate the possible changes in vegetation that could result from the changes in climate, and other factors such as increasing CO_2 concentrations, are also improving rapidly. Combining these two modelling streams would permit assessments of the impacts of climate change on key process such as infiltration, recharge and runoff generation at the level of SWSAs. Approaches like these could provide indications of how climate change may affect different SWSAs and water security and could help prioritise their restoration and protection.

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ACRONYMS

ACAP	Agricultural Policy Action Plan
ARC	Agricultural Research Council
ASR	Aquifer Storage and Recovery
BD	Biological Diversity
CoCT	City of Cape Town
CoGTA	Co-operative Governance and Traditional Affairs
CSI	Custodian of Spatial Information Act
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEA & DP	Provincial Department of Environmental Affairs and Development Planning of the Western Cape Government
DM	District Municipality
DMR	Department of Mineral Resources
DRM	Disaster Risk Management
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DWS: NWRP	Department of Water and Sanitation: National Water Policy Review
EIA	Environmental Impact Assessment
EKZNW	Ezemvelo KZN Wildlife
GDP	Gross Domestic Product
GIAs	Groundwater Impact Assessments
GRAII	Groundwater Resource Assessment II
GRIP	Groundwater Resource Information Project
GVA	Gross Value Added
GW	Groundwater
GWS	Government Water Scheme
IB	Irrigation Board
IDPs	Integrated Development Plans
LM	Local Municipality
KZN CMA	KwaZulu-Natal Coastal Metropolitan Area
MAR	Mean Annual Runoff
million m^3/a	million cubic metres per annum
MM	Metropolitan Municipality
NBA	National Biodiversity Assessment
NDP	National Development Plan
NGA	National Groundwater Archive
NGOs	Non-governmental organizations
North West READ	North West Department of Rural, Environment and Agricultural Development
NPC	National Planning Commission
NRM	Natural Resource Management
NWRS	National Water Resource Strategy
SADAC	Southern Africa Development Community
SADC	Southern African Development Community
SALGA	South African Local Government Association
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SEA	Strategic Environmental Assessment
SIP	Strategic Integrated Project
SW	Surface water
SWSA	Strategic Water Source Areas
SWSA-gw	Groundwater SWSA
SWSA-sw	Surface water SWSA
TMG	Table Mountain Group
WARMS	Water Authorisation and Registration Management System
WC/WDM	Water Conservation/Water Demand Management
WCWSS	Western Cape Water Supply System
WfW	Working for Water
WoF	Working on Fire
WR2005	Water Resource Assessment 2005
WR2012	Water Resource Assessment 2012
WRC	Water Research Commission
WSA	Water Source Area – WSA-sw for surface water, WSA-gw for groundwater
WSS	Water Supply System
WTW	Water Treatment Works
WULAs	Water Use License Applications

WWF	World Wildlife Fund

TERMINOLOGY

Aquifer	A geological formation which has structures or textures that hold water or permit appreciable water movement through them (National Water Act 1998). A saturated stratum which contains intergranular interstices, or a fissure/fracture or a system of interconnected fissures/fractures capable of transmitting groundwater rapidly enough to supply a borehole or spring directly.
Baseflow	The volume of water in the stream when at its minimum or base level of flow; this is the level to which the stream flow returns between storms; in climates with seasonal rainfall it is often treated as the dry season flow; it is derived from groundwater flow or discharge (termed the groundwater contribution to baseflow), and from drainage from deep soil and weathered material (i.e. interflow); generally synonymous with the term low flow.
Beneficiaries	The people benefiting from a particular ecosystem service. In the context of strategic water source areas, beneficiaries are defined broadly as those who benefit from the water supply and quality regulation performed by healthy ecosystems in the associated strategic water source area.
Groundwater	Water occurring underground: (i) In the unsaturated zone as soil water and interflow (see below), (ii) in the saturated zone as groundwater in aquifers (extractable), and (iii) groundwater in aquitards and aquicludes (not extractable) (Colvin et al., 2007). In common usage and in this document, the term groundwater includes all subsurface water in the zone of saturation with a focus on water contained in aquifers. This is in line with both the wetlands and groundwater literature.
Interflow	Refers to the (rapid) lateral movement of subsurface water from rainfall through the soil layers above the water table to a stream or other point where it reaches the surface; generally synonymous with subsurface stormflow. In the context of this report, interflow is considered as lateral flow in the unsaturated (vadose) zone.
Mean Annual Runoff	Mean annual run-off is the amount of water flowing over the surface of the land (mainly in water courses) over the period of a year; the average (or mean) is calculated over several years (typically at least 10 years).
Protected Areas	The Protected Areas Act recognises two categories: Protected Areas which are areas of land or sea that are formally protected in terms of the Protected Areas Act and managed mainly for biodiversity conservation. This includes most categories of protected government land (e.g. national parks, provincial nature reserves) as well as various forms of contractually protected private land (e.g. stewardships). Conservation areas are portions of the land or seas of land or sea that are not formally protected in terms of the Act but are nevertheless managed at least partly for biodiversity conservation.
Strategic water source areas	A <u>subset</u> of water source areas that are considered of strategic significance for water security. In this report, the term strategic is based on national water resource planning considerations and includes groundwater and surface water source areas (both national and transboundary). Criteria for identifying nationally strategic water source areas (SWSAs) have been developed as part of this project. Those which are not considered nationally strategic are identified as sub-national WSAs. The term SWSA also was used for the 2013 version of the SWSAs which only included surface water. This study has modified the 2013 definition of strategic and also includes groundwater, which has changed the definition of a strategic water source to include use and dependence on groundwater. We use the following abbreviations: SWSA for any type, SWSA-sw to indicate surface water and SWSA-gw for groundwater.

Water source areas	Natural areas for that provide disproportionate (i.e. relatively large) volumes of surface water and/or groundwater water per unit area, or which meet critical social, economic and environmental water requirements and provide water security.

1. INTRODUCTION

1.1 Defining Strategic Water Source Areas

Water Source Areas (WSAs) are internationally known as "water towers", a term that was first used by (Meybeck et al., 2001) to describe mountain areas that supply disproportionate quantities runoff compared to adjacent lowland areas (Nel et al., 2013b; Viviroli et al., 2007; WWF-SA, 2013). The recognition of mountain catchments as water source areas in South Africa has a long history and became a national concern following water shortages during droughts in the 1800s and in the 1920s and 1930s in South Africa (Beinart, 1984). In this report, WSAs which are recognised as being of particular importance for national-level water security (i.e. strategic) have been delineated for both groundwater and surface water. Thus, Strategic Water Source Areas (SWSAs) are defined in this report as areas of land that either: (a) supply a disproportionate (i.e. relatively large) quantity of mean annual surface water runoff in relation to their size and so are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b). They include transboundary Water Source areas that extend into Lesotho and Swaziland.

Strategic Water Source Areas (SWSAs) are areas of land that either: (a) supply a disproportionate quantity of mean annual surface water runoff in relation to their size and are considered nationally important; or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b).

1.2 Background

International experience shows that managing and protecting water source areas is a very cost-effective means of delivering a continued supply of good quality water to users, both *in situ* and downstream. This extremely relevant in the South African context. Firstly, the country is characterised by highly variable climate and rainfall, which is reflected in the uneven distribution of water resources – just 8% of the country produces 50% of the water (Nel et al., 2013a). Secondly, South Africa has a looming water supply crisis, with 98% of its surface water already developed, demand outstripping supply in most catchments, and a growing water quality problem (CSIR, 2011; DWAF, 2013). The 2015-2016 drought in the summer rainfall areas and current drought in the winter rainfall areas (2014/15 onwards) have highlighted the vulnerability of our water supplies. Water managers are inevitably faced with finding new and innovative ways of improving both water quality and quantity to meet the increasing water demands of the country. Managing SWSAs is a key way to meet this challenge because it can ensure that our catchments and aquifers proved sustained flows of high quality water.

In South Africa, the first national effort to identify and protect SWSAs began in 1959 with the Soil Conservation Board's interdepartmental committee. They developed conservation strategies for the principal mountain catchments of South Africa, considered to be the main sources of the country's water supply. This study identified 109 important mountain catchments based on mountains or relatively high lying areas together with data on the key rivers, mean annual runoff and its importance, area of State Forest land and ecological condition (Government of South Africa 1961).

This SWSA study follows on from, and updates two previous efforts. In 2004, the first National Spatial Biodiversity Assessment of South Africa (Driver et al., 2005) analysed mean annual runoff data at a quaternary catchment level to identify those quaternary catchments that provided 20% of South Africa's mean annual runoff. This work was subsequently refined using data on rainfall and runoff at a 1 x 1 minute resolution to identify South Africa's surface water-based source areas. The 2013 study showed that just 8% of the country's land surface area contributes 50% of its mean annual runoff (Nel et al., 2013b) (Figure 1).

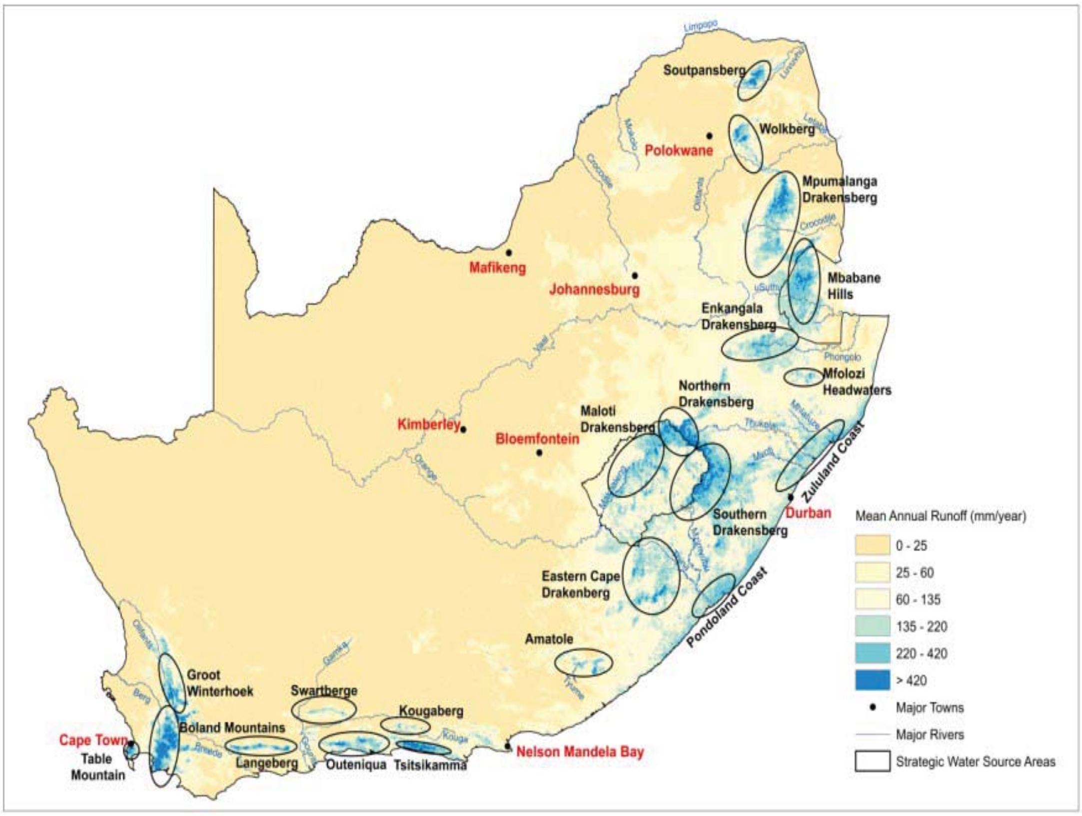

Figure 1: Strategic (surface water derived) water source areas defined in 2013, on which this project builds (Nel et al., 2013a)

These statistics are based exclusively on surface water runoff, i.e. water in rivers or wetlands and made available for human use, often via dams and water supply schemes; groundwater had not yet been considered. Groundwater is critical for meeting future water demand in the country (DWAF, 2013) but was not considered in the previous work. This study addresses this critical gap and has developed a method for delineating WSAs for groundwater so which clearly defines them and enables their importance to be assessed.

The 2013 SWSAs (Nel et al., 2013a) were based on a raster dataset for mean annual runoff, which is like a grid or chessboard. Squares or grid cells with a mean annual runoff ≥135 mm were set as the threshold for ≥50% of the surface runoff, and the resulting dataset shows distinct concentrations such cells (highlighted by the ellipses in Figure 1) but also smaller clusters and many single, scattered cells. The ellipses were not intended to be the boundaries, they were created to provide easily place names for these extensive concentrations of high runoff cells that the public could easily identify. If these cell values were used as is to define the boundaries, they would result in many small, fragmented Water Source Area units which would be difficult to manage and protect. So a key aim of this study was to define boundaries around the clusters to include the concentrations and to exclude many of the individual cells and small clusters. The approach we used to do this is described in detail in Section 3.4.

1.3 Project aims

This report emanates from a 3-year Water Research Commission project (July 2015-December 2017) led by the Council for Scientific and Industrial Research (CSIR) and Delta-h Water Systems Modelling. The study was aimed at addressing gaps in the previous delineations of strategic water source areas, by producing an integrated map of surface water and groundwater-derived strategic water source areas, and advancing knowledge on the benefit-flows and management of these areas.

Specifically, the project aimed to:

1. Review and refine the understanding of the hydrological processes that lead to the generation of runoff and groundwater recharge in South Africa's water source areas, and especially in groundwater systems.
2. Develop an integrated method to identify and delineate water source areas that include run-off generation and groundwater recharge (i.e. surface water and groundwater).
3. Link the water source areas and their associated water resources to key benefit flows.
4. Identify key pressures and recommend management and protection options water source areas.
5. Explore policy mechanisms for the uptake of the products.

1.4 Purpose and structure of this report

This report is the seventh in a set of eight deliverables (see the Preface) and summarises all the technical components and outputs of the project thus far. The project also has produced a separate report, the Implementation Framework which provides information on policy, legislation and other measures relating to their protection and management. The third output is a Knowledge Dissemination Report which provides a summary of the importance of the SWSAs and the key findings and recommendations for the wider public.

This Integrated Report first sets out the approach and methods used to identify and delineate the Strategic Water Source Areas for groundwater (SWSA-gw), and to refine the findings of the 2013 analysis of Strategic Water Source Areas for surface water (SWSA-sw) (Nel et al., 2013a). Next, the water source areas are placed into the context of the hydrological cycle to show the important links between groundwater and surface water, and how water flows above and below ground are regulated by ecosystems. The following section deals with the use of the surface water and groundwater water generated by SWSAs to illustrate the economic and social benefits generated by the water. This assessment explicitly links SWSAs to downstream users of water in urban centres, and the last section assesses potential impacts on, and threats to water source areas. We recommend that people not interested in those technical details go directly to Section 4.

1.5 Research methodology and process

The project had both a research component and a stakeholder consultation and review component in addition to the Reference Group required for each Water Research Commission Project. The research component addressed the first four aims (see Section 1.3 above) and the consultation focused on policy integration and implementation. In addition to the standard practice of appointing a reference group to guide the work and assess progress, stakeholder workshops were organised. These workshops involved a broad range of people with knowledge and expertise in the fields of water research, water resource planning and management, and environmental conservation to inform them of the findings of the research, solicit their comments and critiques, and to obtain agreement on the final set of Strategic Water Source Areas. The project team specifically involved representatives from the policy sections of the national Departments of Water and Sanitation and Environmental Affairs to ensure that the Strategic Water Source Areas are incorporated into both water resource protection and environmental conservation related policy and legislation, and that their protection is promoted. Indeed the outputs of this work have now been included in the draft National Water Master Plan and in the draft National Strategic Development Framework.

2. IDENTIFYING STRATEGIC GROUNDWATER SOURCE AREAS

2.1 Introduction

2.1.1 Broad approach

The intended purpose delineating Strategic Water Source Areas for groundwater (SWSA-gw) should inform the methodology. However, the potential reach and applicability of the SWSA-sw was not recognised until they were mapped, and as such, the results of the mapping can also influence their ultimate purpose. There has therefore been a somewhat iterative procedure between the development and design of the product.

The proposed methodology for delineation of groundwater-derived SWSA-gw, the technical challenges and proposed solutions to address them, were presented at the inception workshop. A draft set of SWSA-gw were developed, based on a preliminary methodology, and after discussion with stakeholders, a final set of SWSA-gw are presented here. Only the final methodology is included in this report, with a comments and responses table included in Appendix 6.

SWSA were, prior to this project, defined as areas that have disproportionately high surface water availability, with runoff being the primary factor controlling surface water availability (prior to consideration of man-made storage). Applying the same definition to SWSA-gw requires mapping areas of high groundwater availability. There is no single parameter however for groundwater availability, neither is there one that can be mapped at national scale in two dimensions. An aquifer yield is dictated by the ability of abstraction to capture natural discharge and enhance recharge, and the acceptability of the associated impacts dictating the sustainability (Section 2.1.2). As such, groundwater recharge was used as a proxy for groundwater availability. Groundwater use is also considered as somewhat of a proxy for high groundwater availability and favourable hydrogeological characteristics, enabling the use of groundwater.

Implementing a strict definition of “source” area (note, not “resource” area), would include consideration only of groundwater availability. The intended purpose of delineating SWSA-gw was in order to raise awareness of the country’s water sources, and lead to their protection (for sustained current or future human use, or protection of contribution to surface water and hence support of ecological functioning). As the results show, high groundwater availability areas generally coincide with SWSA-sw. It is therefore not useful to delineate SWSA-gw based only on high availability. The mapping of SWSA-gw in addition therefore incorporates areas where groundwater is important for use (i.e. thus also incorporating to some degree “resource” areas not just source areas). A number of criteria have been outlined to achieve this.

In summary, a SWSA for groundwater can be defined as an area with high groundwater availability and where this groundwater forms a nationally important resource.

2.1.2 Recharge as a proxy for groundwater availability

Areas of high runoff can be directly related to areas of high surface water availability. The use of recharge mapping was specified in the Terms of Reference, however is important to recognise that recharge is not a direct indicator of groundwater availability.

When an aquifer is pumped, the abstracted water is offset by a combination of reduced discharge (often baseflow), and enhanced recharge (often streamflow depletion), and groundwater storage may be reduced (i.e. water levels may drop). Groundwater availability is therefore dictated by the ability of pumping to "capture" natural discharge, and enhance recharge without continually depleting an aquifer (Devlin and Sophocleous, 2005; Lohman, 1988, 1972; Seward et al., 2007; Theis, 1940). Groundwater availability is not directly dependent on recharge rates. The ability of pumping to "capture" natural discharge, and enhance recharge without continually depleting an aquifer, can only be determined at an aquifer-scale. Nevertheless, the project requires an indicator for groundwater availability at national scale. Prior to pumping an aquifer is in a state of dynamic equilibrium in which natural recharge is numerically equivalent to discharge. As these are equivalent, recharge can be considered a proxy for one of the factors influencing groundwater availability (discharge). It would over-estimate groundwater availability in areas where capture of discharge is not technically possible. As it does not consider enhanced recharge, it could be an under-estimate of groundwater availability (note: this discussion is on availability, not sustainability which involves the socio-economic-environmental acceptability of these impacts). It cannot therefore be considered a direct indicator. In the absence of a better dataset, recharge is used as an input to identify groundwater source areas.

National recharge datasets provide information on recharge derived from direct infiltration. This is only one mechanism by which recharge occurs. There is however no national dataset for information on rivers that recharge groundwater ("losing rivers") (Parsons and Wentzel, 2007). Time frames are also different when considering recharge and runoff. Rainfall generates runoff which is imminently stored in dams and available for use (time frame of hours and days). Groundwater recharge is slower, and abstracted water may have been recharged several hundreds or even thousands of years previously. This is an important consideration when determining how to protect groundwater resources, as in some aquifer settings, protection of recharge zones may only benefit future generations, hence the use of wellfield capture zones (Chave et al., 2006).

It has been acknowledged by DWS that there are "no reliable national recharge estimates" available (DWA, 2010a). The best available national dataset (GRAII: (DWAF, 2006a)) is largely based on the Chloride-method, but its reliability is hampered by an insufficient national coverage of rainfall chloride measurements, the interpolation methods used, and application of data to a 1 km grid (DWA, 2009a). Recent research has also shown the chloride content of rainwater varies by 3 factors seasonally (Van Wyk, 2010). However, locally to regionally, more detailed recharge information is available, derived for aquifer scale or regional scale groundwater resource investigations or for research purposes. The challenges with the national scale recharge mapping were acknowledged in the proposal, however development of a new recharge map is not feasible as part of this project scope. Although not considered central to the definition of a SWSA-gw, one deliverable for this project was to "refine the understanding of processes that generate recharge" and a literature review of recharge processes is presented in Appendix 4 (Section 12).

2.1.3 Groundwater use

Groundwater use is also considered a proxy for high groundwater availability, as high groundwater use suggests high availability and favourable hydrogeological characteristics. Furthermore groundwater use is considered a factor for delineation of SWSA-gw because areas where it is used (i.e. an important resource), warrant the protection feasible from the project more so than areas where groundwater is simply a source (yet may be remote or inaccessible).

2.2 Criteria and thresholds for identification of strategic groundwater source areas

2.2.1 Recharge

Given that recharge is being used as a proxy for groundwater availability, criteria and thresholds were sought that could highlight high (absolute) recharge values (in mm/a). National level recharge was mapped for the Groundwater Resource Assessment II (DWAF, 2006a) and shows that its distribution is largely controlled by the relationship between the topography (Figure 2) and the precipitation (Figure 3), which is strongly controlled by orographic gradients between the montane areas and the adjacent coast.

At the national scale, areas of high rainfall largely correspond (at least in the theoretical datasets) to areas of high recharge. In certain areas the correlation is not direct and the underlying geology, and aquifer type, influences the recharge. For example, the eastern limb of the Campbell Group and Malmani Subgroup dolomites, which form a karstic aquifer, (between Pretoria and Johannesburg (Figure 4, Figure 5, Figure 6, and Figure 7) is mapped with higher recharge than neighbouring areas of similar precipitation. These geological controls on recharge appear more strongly in the earlier national recharge mapping effort of (Vegter, 1995) (Figure 8) than they do in the data from the GRAII study (Figure 9), although the combination of rainfall and geology still highlights some local effects (Figure 9). The GRAII (DWAF, 2006a) dataset was used in the analysis that follows.

Recharge values greater than 65 mm/a were selected as significant for use as a SWSA-gw (criterion 1), based on a calculation showing that the areas with >65 mm/a contribute more than 50% of the national recharge volume (Table 1). The areas with >65 mm/a cover 9% of the land surface.

Table 1: National recharge statistics based on an analysis of GRAII data (DWAF, 2006a)

Recharge category (mm/a)	Recharge volume contributed by category (million m^3/a)	Recharge contributed by grouping (% towards total SA recharge)	Land area occupied by recharge category (km^2)	Land area contributed by grouping (% towards total SA land area)
150+	3,641	10%	14,687	1%
>=100	11,228	32%	44,920	4%
>=65	17,980	52%	111,416	9%
>=35	28,884	83%	287,231	23%
SA total recharge	34,912[2]			
SA total land area	1,272,835			

As recharge is so dominated by high rainfall areas large portions of the country are not captured by criterion 1. An additional recharge criterion is considered necessary, which is not based on absolute values in mm/a. This can be achieved through mapping the recharge ratio of a particular area compared to a larger area. Areas with a ratio less than 1 have recharge below the average of that area and, for example, an area with

[2] Note that this volume was calculated by summing the 1 km^2 disaggregated recharge. It differs from the data provided in the GRAII datasets which was calculated by summing the GRAII average recharge per quaternary catchment to national scale and equates to 30,366 million m^3/a.

a ratio of 2 has twice the average. Various approaches were tested, including for example recharge per quaternary catchment, compared to the average recharge of the primary catchment (Figure 11).

The boundary of the areas delineated by a ratio higher than 2 is affected by the quaternary catchment boundaries, which may themselves include significant spatial variability in recharge, suggesting that the quaternary catchment scale is too large. Furthermore the areas mapped as high (ratio above 4 for example) generally coincide with high absolute recharge values (in mm/a), showing that the size of the area used in calculating the ratio (primary catchment) is too extensive to usefully capture spatial variability. The ratio of recharge per 1 km^2 grid cell, compared to the average recharge of the secondary catchment provides more useful results (Figure 12).

This approach succeeds in highlighting the variability especially in catchments where there is high recharge variability, for example:

- Just south of Springbok, where MAP is slightly higher, typical borehole yields are slightly higher.
- The Gouritz area, where the mountainous areas (high rainfall, high recharge to the TMG aquifers) have 4 to 5 times the regional average compared to the drier low-lying areas with Karoo sediments.
- The eastern wetter part of the country (sub-humid region in Appendix 4 Figure 66) generally has lower regional variability with ratios of up to 2-3.

The ratio of recharge per 1 km^2 grid cell, compared to the average recharge of the secondary catchment was selected as the second criterion for SWSA-gw. Various thresholds were tested (1.0, 1.5, 2.0, 2.5) and based on the results, the threshold of 1.5 was selected as it contained a subset of areas that seemed most appropriate for potential consideration as a SWSA-gw. This setting of the threshold was therefore iterative and subjective, based on the intended result.

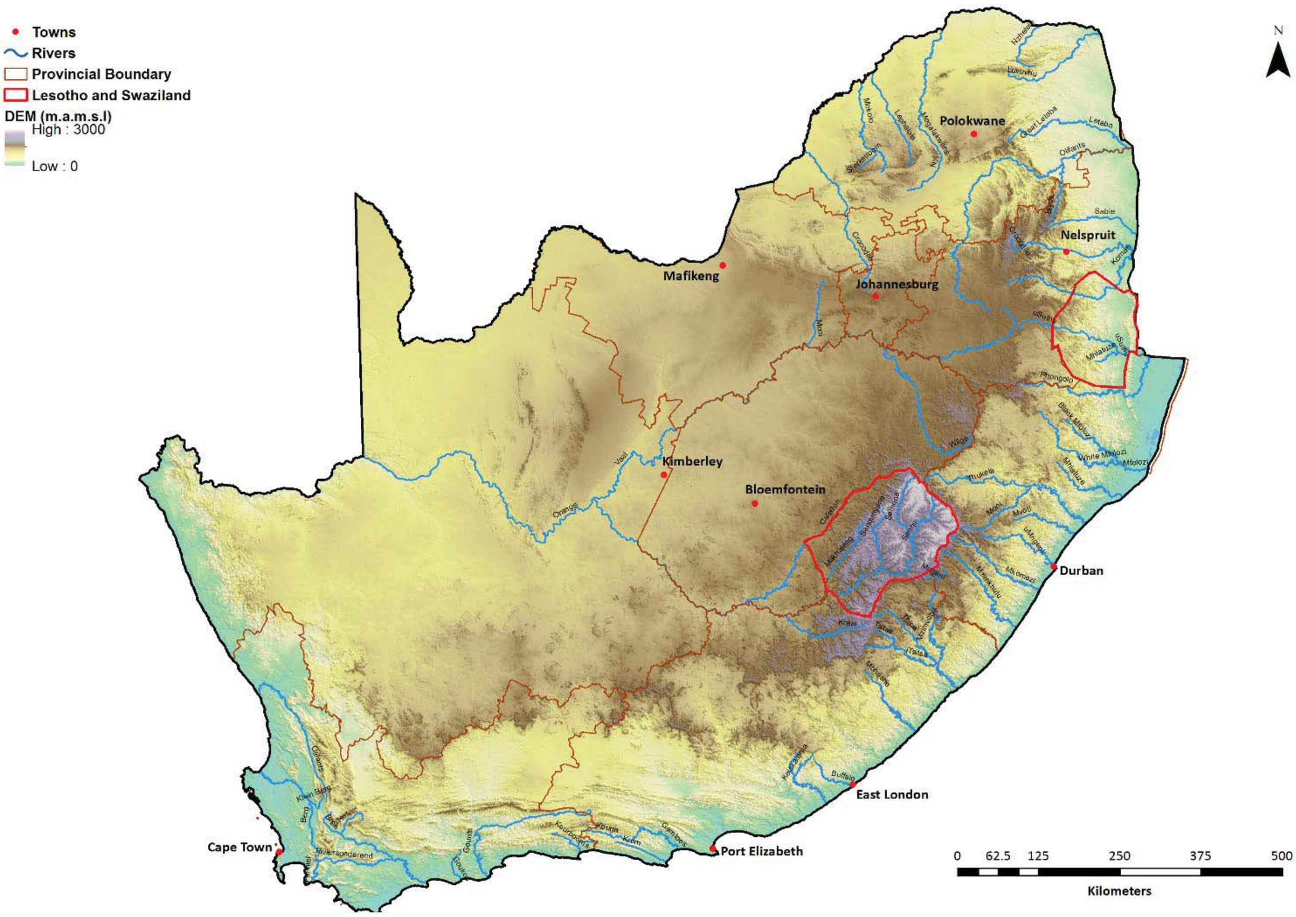

Figure 2: The topography of South Africa showing the high elevation interior plateau outlined by the Great Escarpment which extends from the south-west to the north-east.

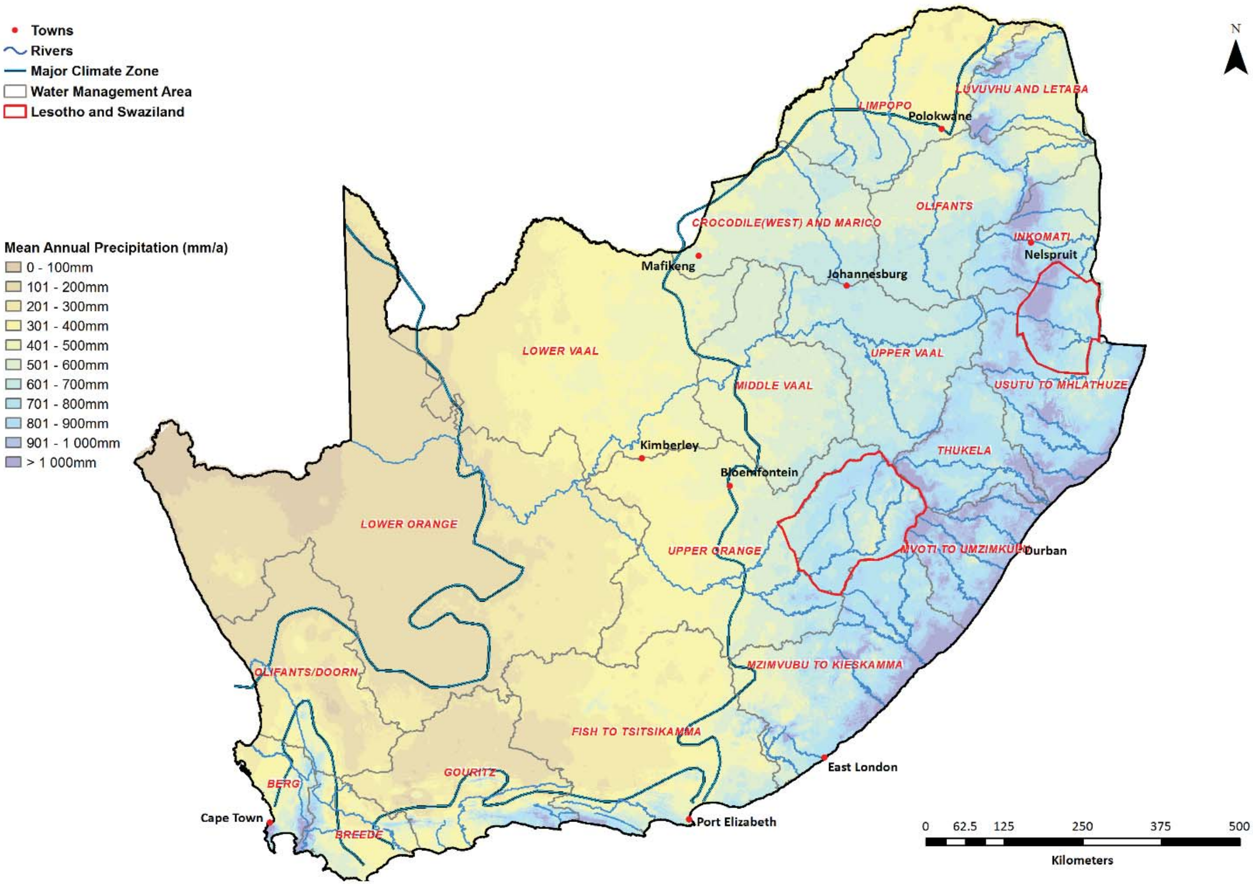

Figure 3: Mean annual precipitation based on data from the WR90 study.

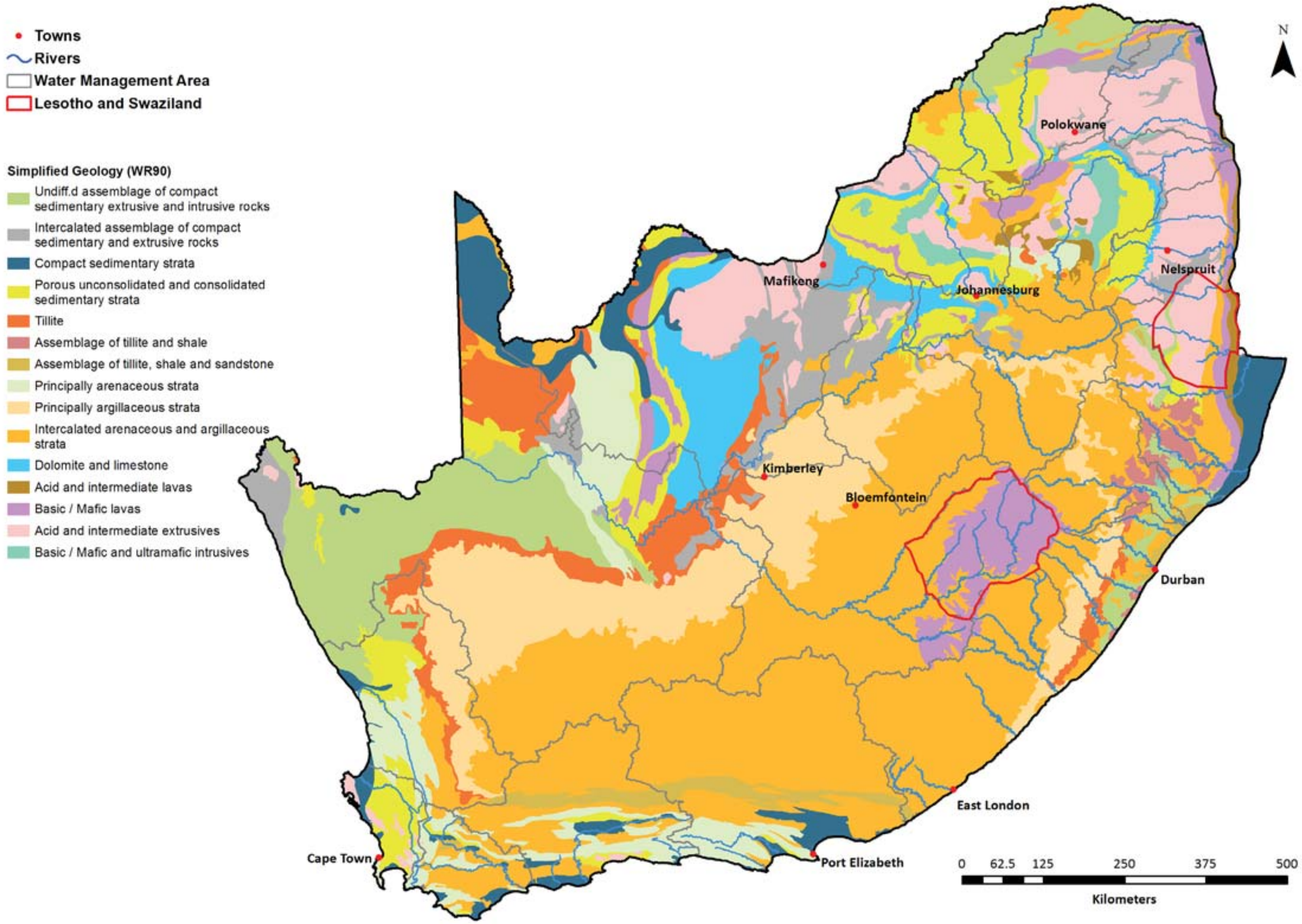

Figure 4: Geology showing the main rock type based on data from the WR90 study (Midgley et al., 1994).

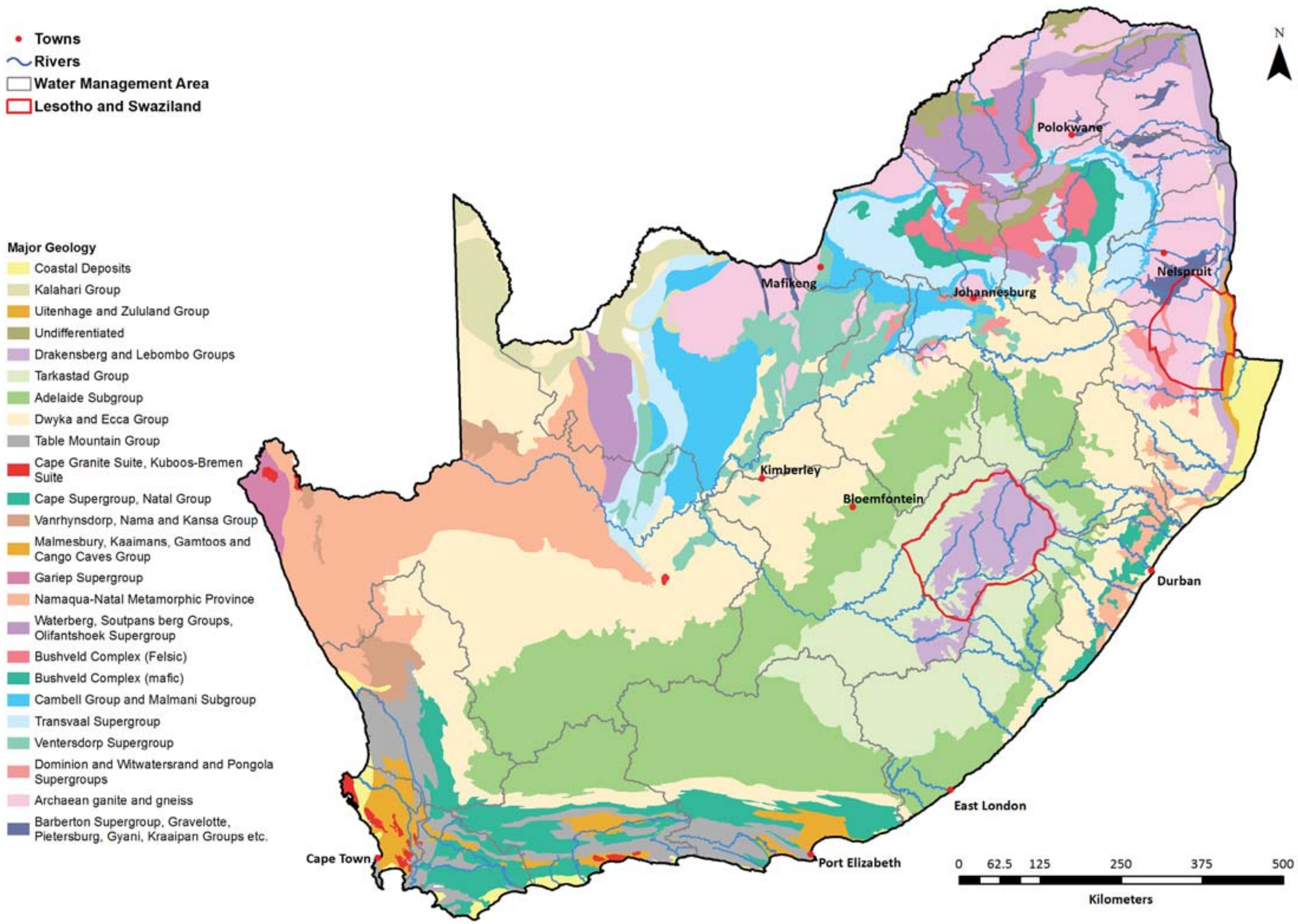

Figure 5: Geology showing the stratigraphy based on data from the CGS.

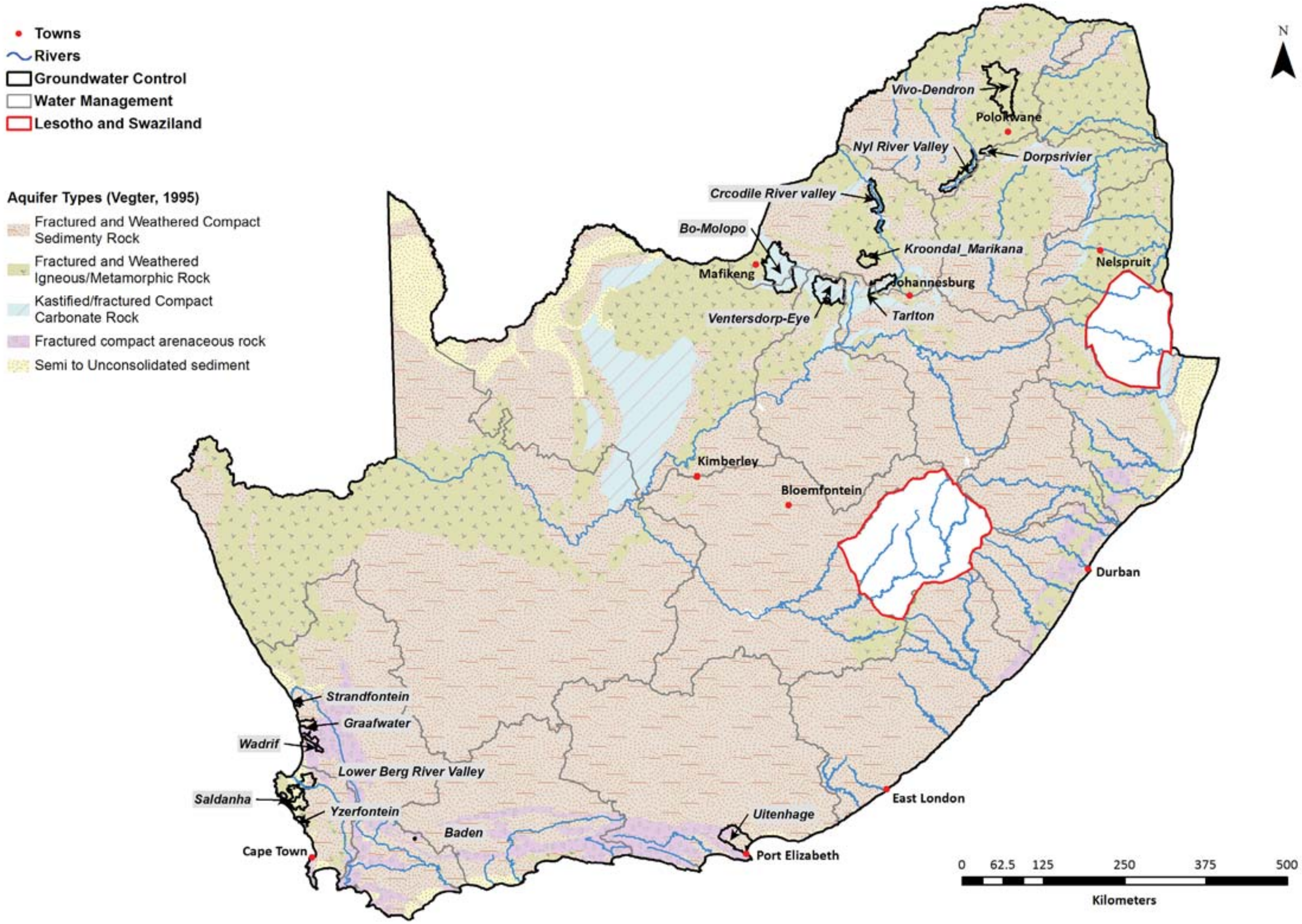

Figure 6: Aquifer types, including Groundwater control areas based on (Vegter, 1995).

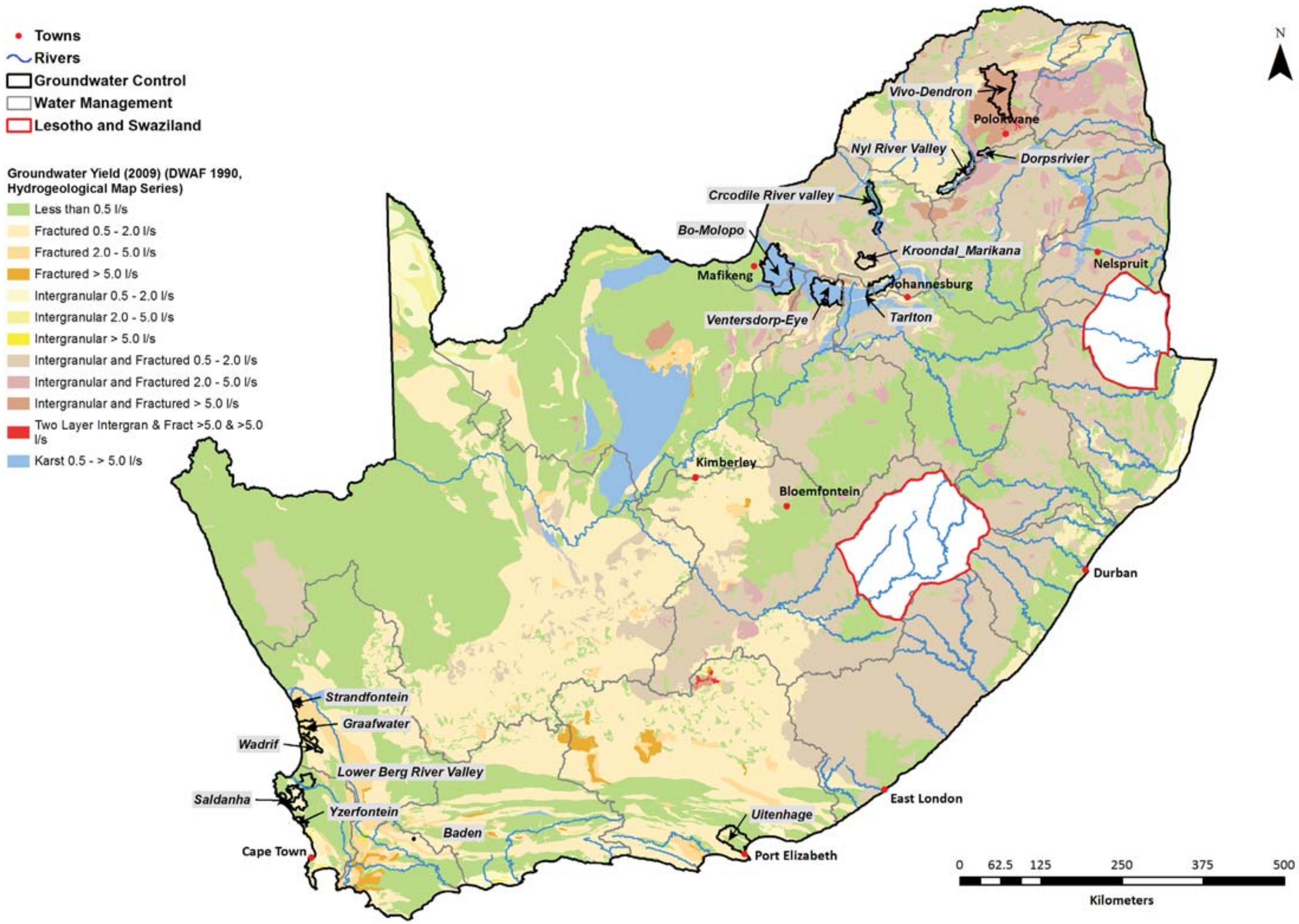

Figure 7: Aquifer types showing including typical borehole yields based on data from the National Groundwater Database (DWA).

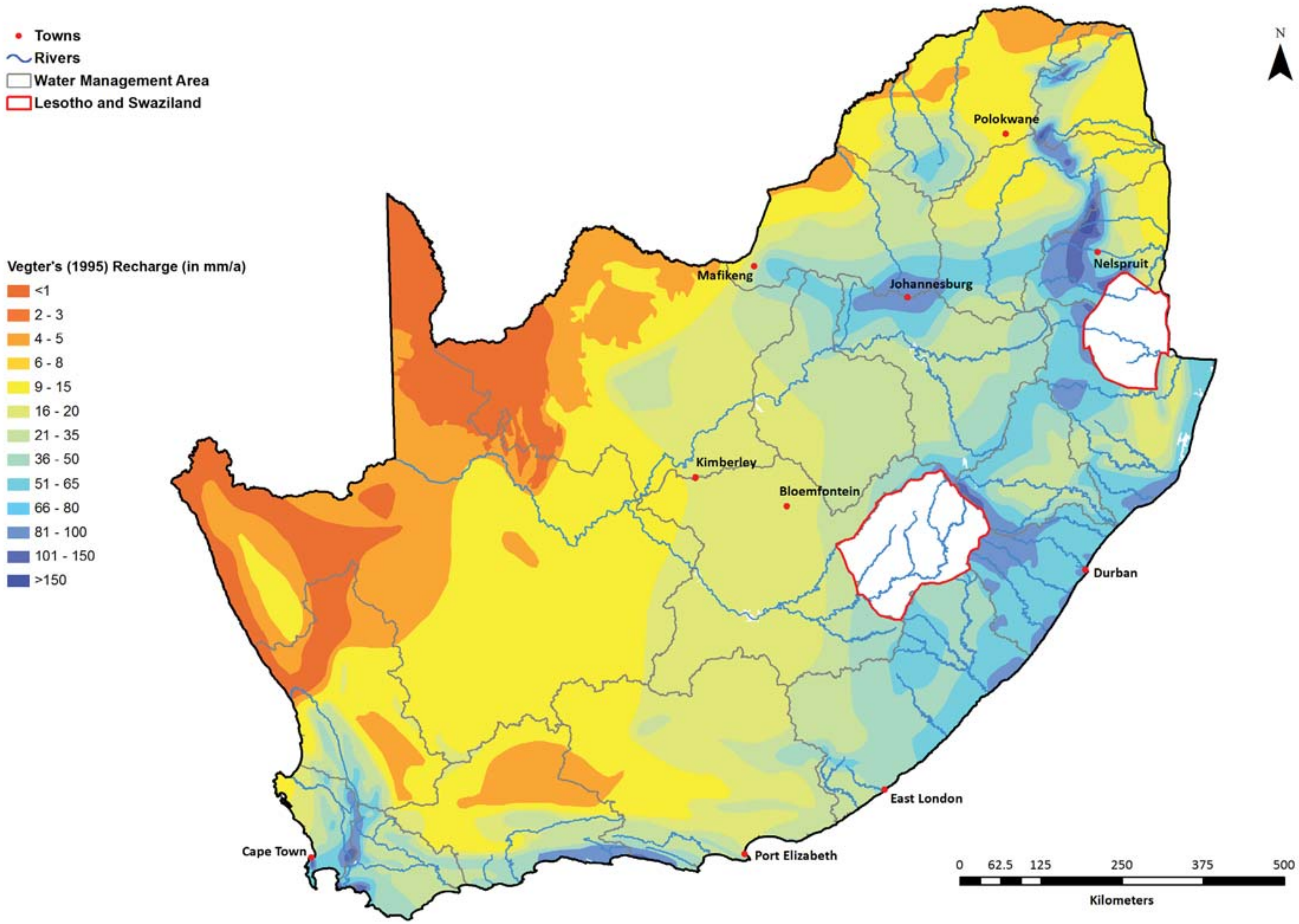

Figure 8: Aquifer recharge (Vegter, 1995).

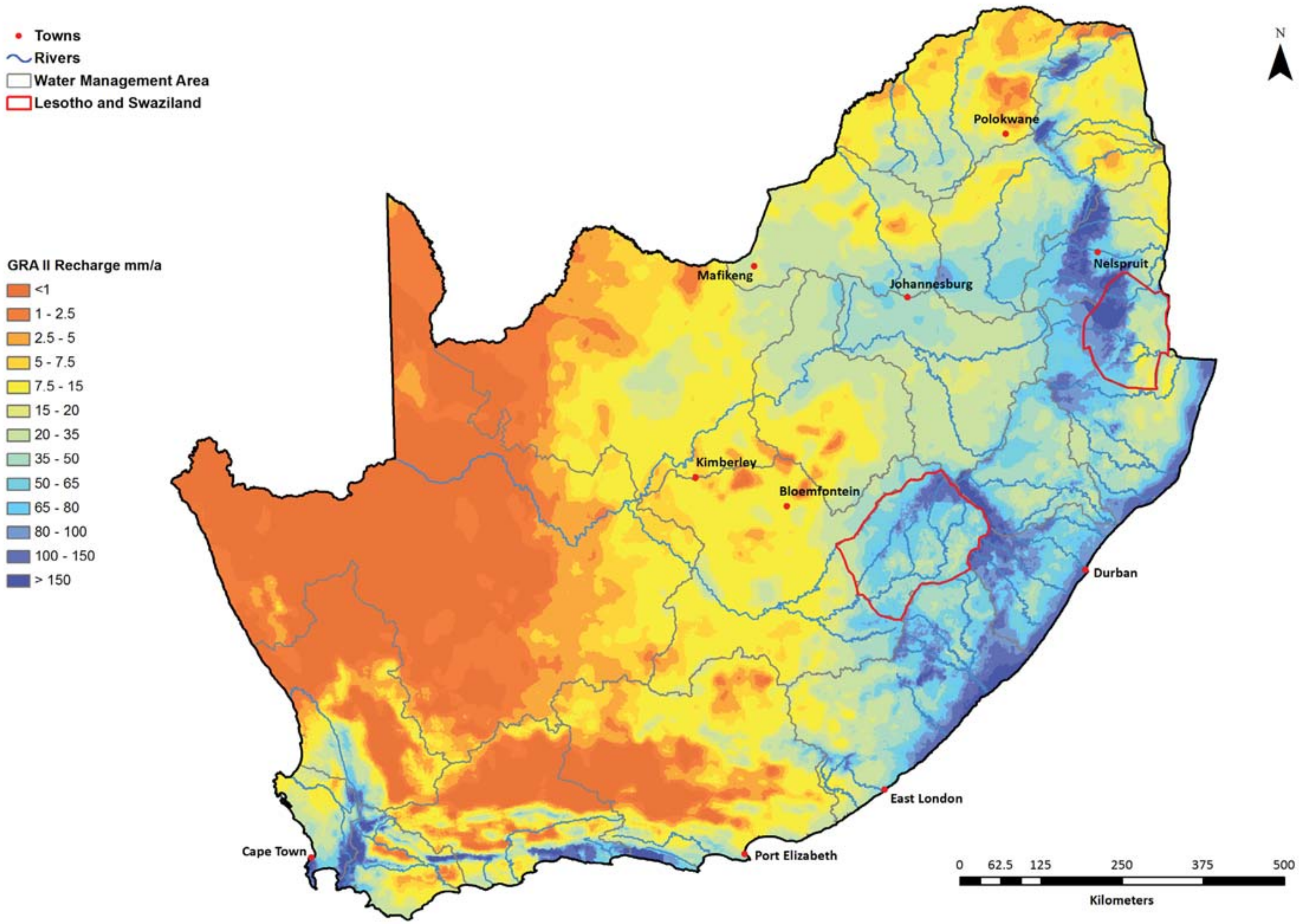

Figure 9: Aquifer recharge based on data from GRAII (DWAF, 2006a).

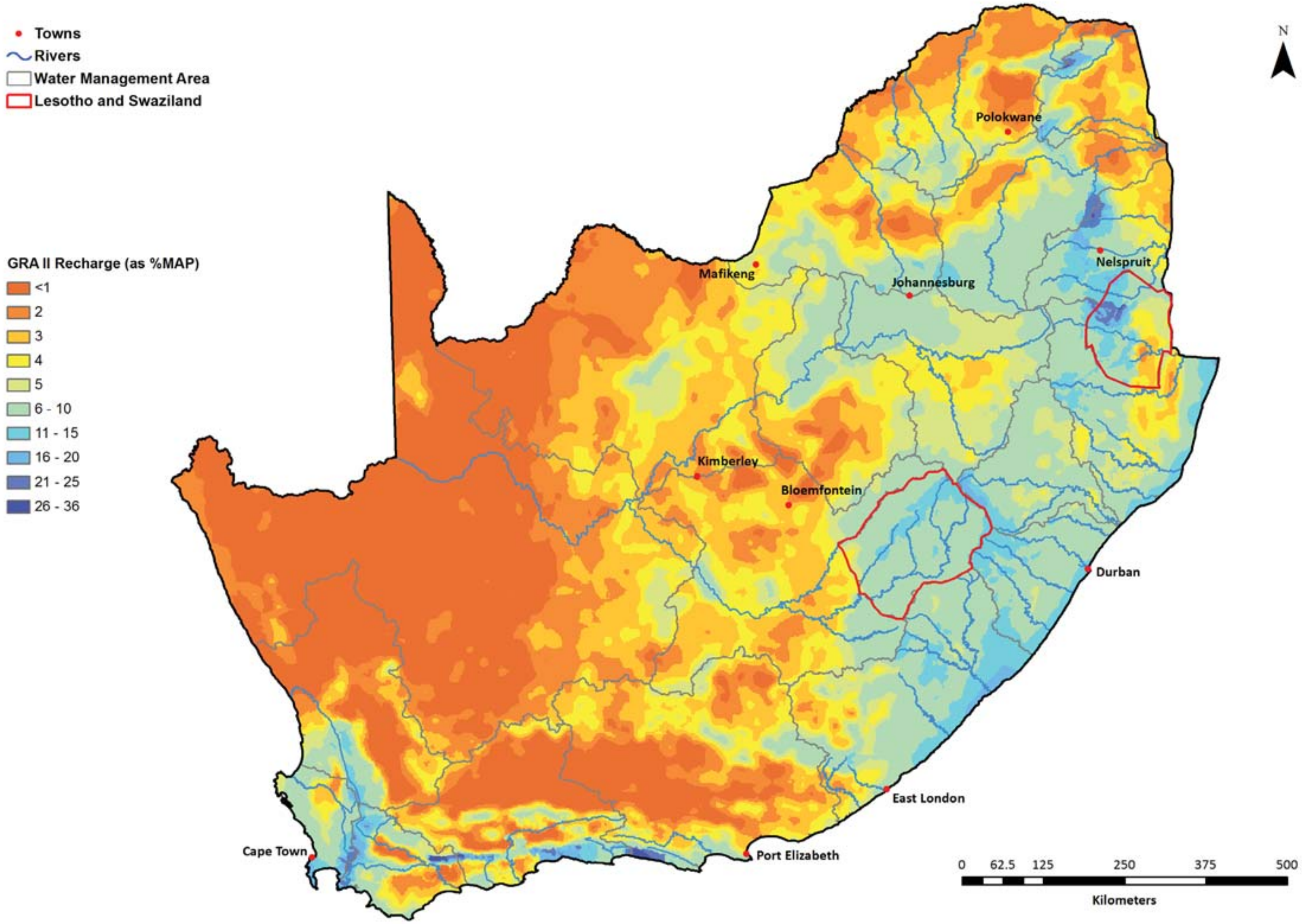

Figure 10: Aquifer recharge as a percentage of the mean annual precipitation based on the GRAII data (DWAF, 2006a).

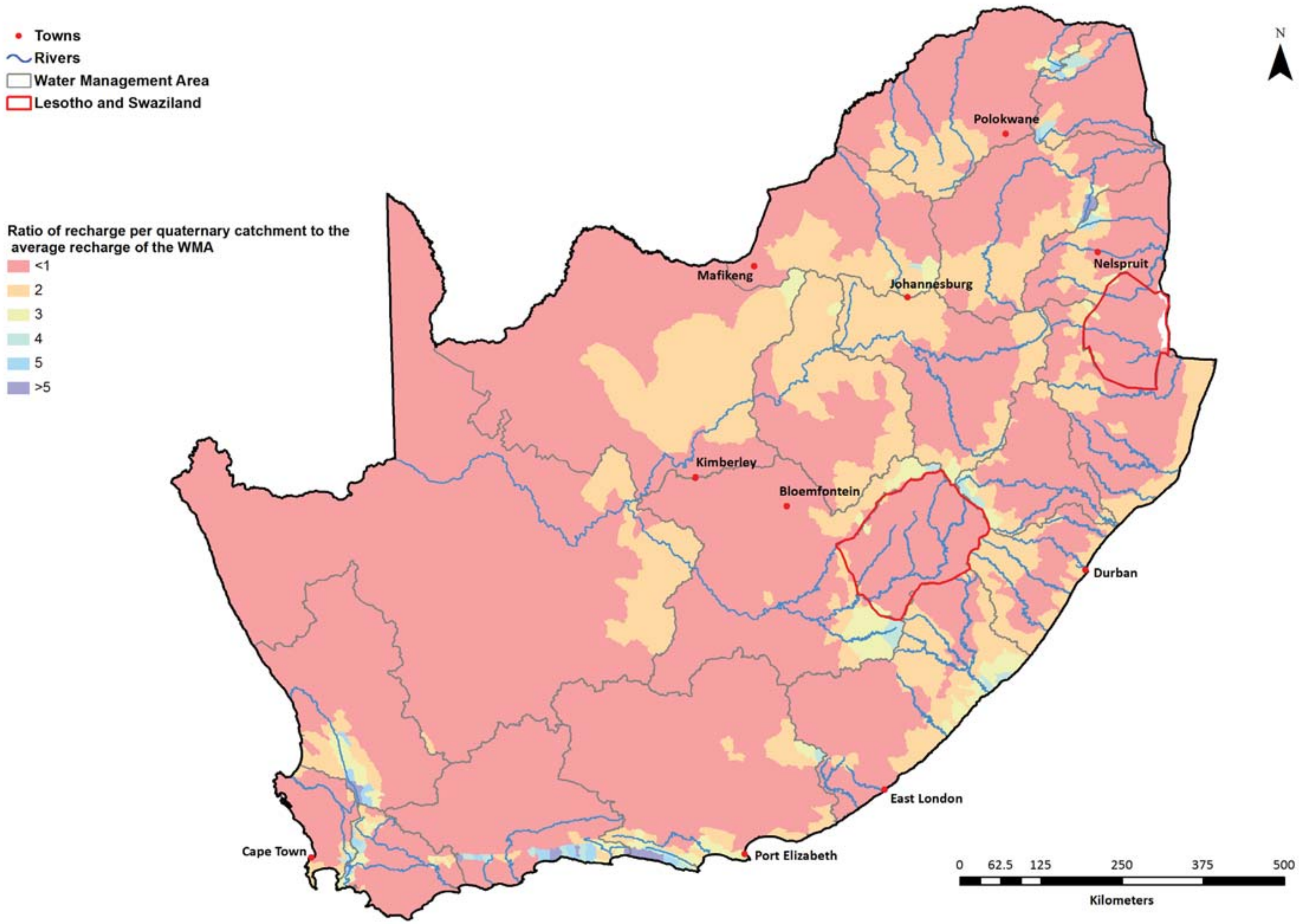

Figure 11: Ratio of recharge (GRAII) (DWAF, 2006a) per quaternary catchment to the average of the primary catchment into which it falls

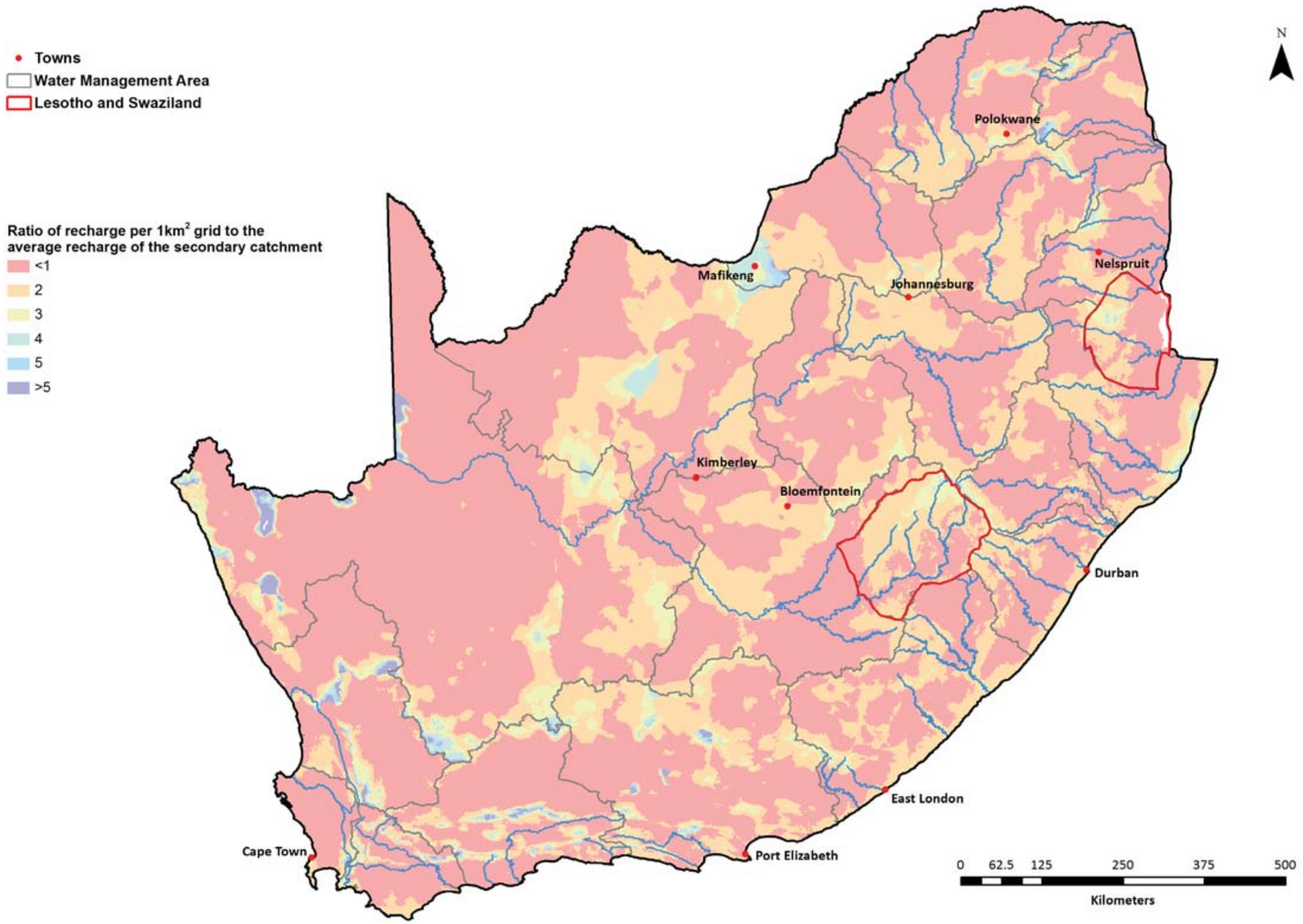

Figure 12: Ratio of recharge (GRAII) (DWAF, 2006a) per 1 km^2 grid cell, to the average of the secondary catchment into which it falls [Criteria 2]

2.2.2 Groundwater use

Various datasets are available for an analysis of groundwater use. The ideal dataset would contain actual groundwater use (location and volume), including domestic groundwater use and/or use by a water services provider. For domestic supply, the percent supplied by groundwater compared to the total supply source is also of interest.

The DWS database of authorised or registered abstraction (WARMS database), was extracted in January 2016. This is the primary dataset for groundwater use, especially private agricultural or industrial use. A known challenge with the dataset is the inaccuracies of the user-supplied coordinates. The property details per registered user were used to adjust coordinates that did not match the property details. This generally assumes that the abstraction occurs on the property of the registered user, which may not always be met. Large users with different use coordinates to property were manually assessed, however for small users the assumption is adequate especially at national scale, and improves the dataset from one with inaccurate user-supplied coordinates. The major assumption applied is that registered groundwater use equates to actual use; necessary in absence of any other national dataset. A further challenge is that the database reflects registered use, and it is not known (at national scale) whether actual use is greater than or less than registered.

The resulting sum of registered abstractions per quaternary catchment is provides useful information but, again, is the boundary of the high use areas (for example use > 5 million m^3/a) is affected by the quaternary catchment boundaries (Figure 13). The quaternary catchments are large especially in the north and northwest of the country, and may contain significant variations in groundwater use (and variations in aquifers). The variability in size of catchment means comparisons across the country are meaningless. The use of quaternary catchment boundaries is too large a scale for a useful analysis.

When the WARMS registered abstractions are mapped as points it becomes clear that the high use areas extend over catchment boundaries (Figure 14).

As a pragmatic approach for grouping areas with clustered groundwater use, and those with higher registered volumes, the registered groundwater use was mapped using a density function normally applied for calculating population density (the Kernel function). For each registered use, the function sums the values of the point values of groundwater use within a 1 km^2 search radius. The result is a continuous surface with values representing the registered use per unit area (l/s/km^2). Areas with high densities of use and/or high volume abstractions will therefore be highlighted in high use per unit area values in the density surface. Although groundwater use occurs almost across the country, there are areas in which groundwater use is more significant (clustered or higher use) (Figure 14):

a) In the Western Cape Winelands areas that largely use TMG or alluvial aquifers (Stellenbosch and Franschhoek in the Berg, and the Breede Valley)
b) The Sandveld region on the West Coast
c) Around Bloemfontein
d) Kuruman, between Mafikeng and Gauteng, corresponding to the karstic dolomite aquifers
e) Limpopo province

The registered groundwater use data plotted as l/s/km^2, was selected as a third criterion for SWSA-gw. Various thresholds were tested (>0.1, >0.3, >0.5) and, based on the results, the threshold of 0.3 l/s/km^2 was selected as it contained a subset of areas that seemed most appropriate for potential consideration as SWSA-gw. Again the setting of the threshold was therefore iterative and subjective, based on the intended result. There are several areas with an apparent high density of WARMS registrations, that fall outside of the lowest category (<0.03 l/s/km^2) such as the Eastern Cape, Transkei area, KwaZulu-Natal, and the Karoo. The individual registrations in these areas are lower and, therefore, the total per km^2 is lower.

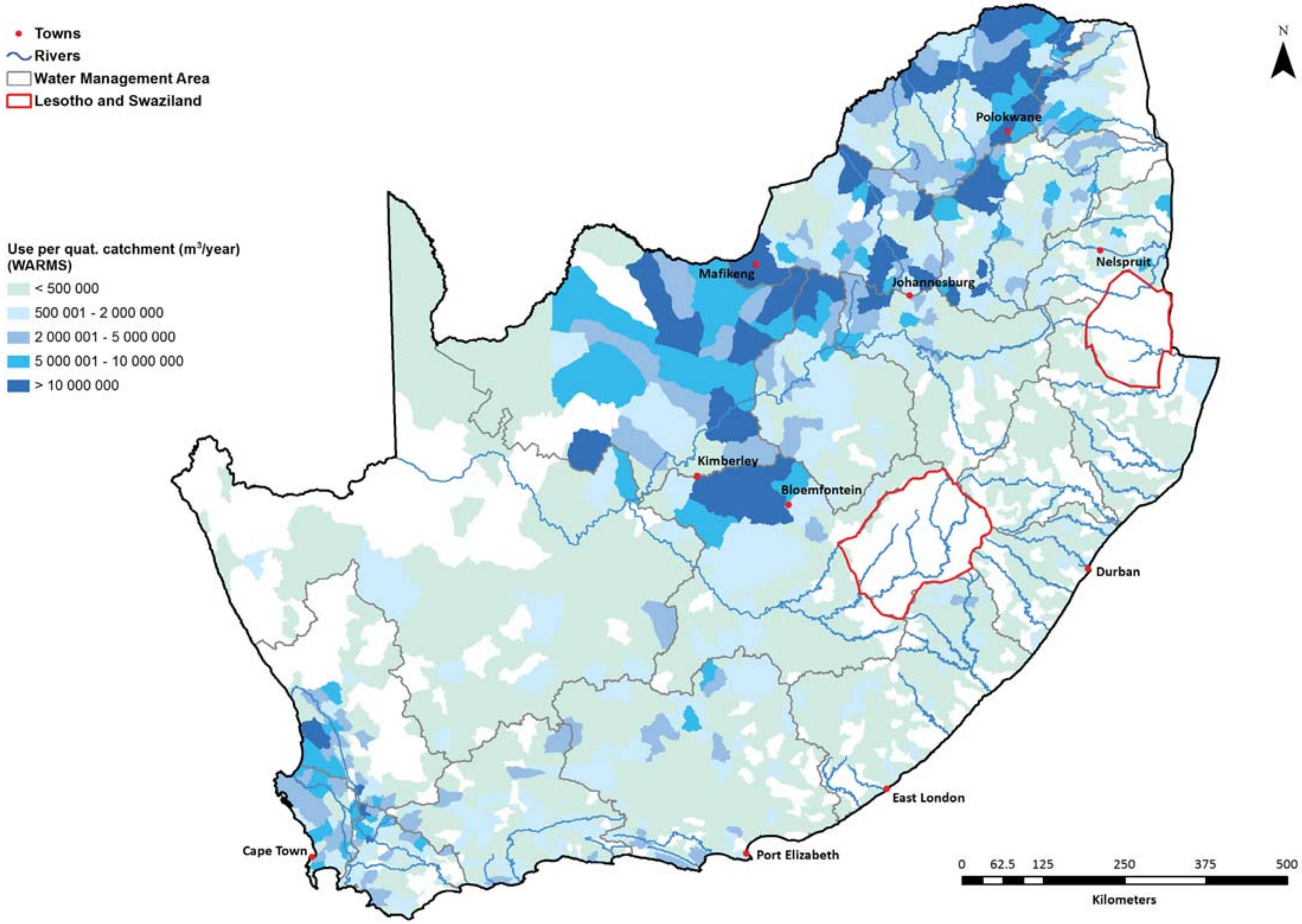

Figure 13: Groundwater use in WARMS – expressed as sum per quaternary catchment (WARMS data extracted in January 2016).

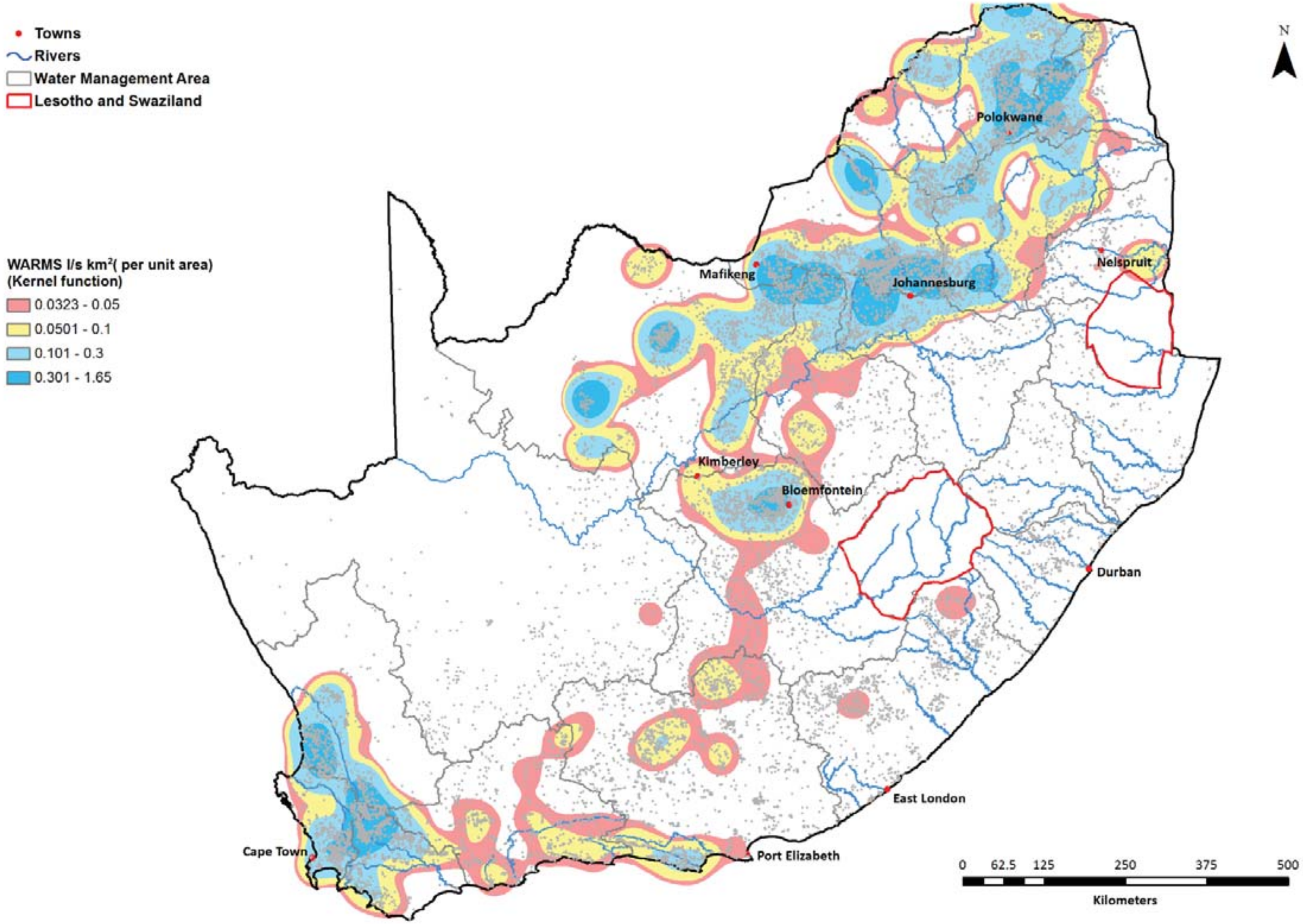

Figure 14: Groundwater use in WARMS – expressed as l/s per 1 km^2 (using Kernel function, WARMS data extracted in January 2016) [Criterion 3]

However, not all groundwater use is registered, even use by water services providers and/or municipalities. Domestic use is generally considered more important, or at least planned with a greater reliability of supply, than private industrial or agricultural use by DWS. So domestic use was included in the delineation of SWSA-gw. Domestic water supply was informed by the first and second phase of the DWS All Towns Reconciliation Strategy Study (DWA, 2012a), and from the DWS reconciliation strategies for each of the major metropolitan municipalities (i.e. those areas not included in All Towns) as outlined in Box 1. Through the merging of datasets and application of several assumptions, a dataset of the current water supply makeup to all settlements (towns and villages) was generated. All those with a groundwater supply of greater than 50% of the total available water supply are shown in Figure 15. A groundwater supply of greater than 50% is classified as "sole supply" from groundwater, according to (DWA, 2011a).

The results are similar to WARMS (as expected):

a) A clear clustering of sole groundwater supply settlements is evident running from the Kuruman area in the west via Mafikeng and Gauteng to Polokwane in the northwest. This area extends beyond the dolomites and groundwater control areas, and is also underlain by various basement geologies (primarily the pre-Karoo Supergroup), most of which form fractured and weathered igneous/ metamorphic rock.

b) Settlements with sole groundwater supply are scattered across most of the interior of the country (i.e. the Karoo Supergroup: aquifer type fractured and weathered compact sedimentary rock).

The results also highlight areas in which the WARMS threshold is not necessarily high (because the volumes are not high), but there are several sole groundwater supply settlements:

c) Coastal towns in the Hessequa and Bitou Local Municipality, and between East London and Port Elizabeth where a number of small towns all use groundwater.

d) Towns such as Lambert's Bay, Eland's Bay and Graafwater in the Sandveld region of the West Coast (of the Western Cape)

e) Towns such as Hermanus, Stanford, Struis Bay on the southern coast of the Gouritz primary catchment, (Overberg District Municipality, Overstrand and Cape Agulhas Local Municipalities).

The groundwater resource unit associated with the supply source is not available from the DWS All Towns Reconciliation Strategy Study datasets. One challenge with the All Towns dataset is that the spatial data refers to the scheme area or settlement only as points, and those points may not include the resource supplying the town, if the wellfield is distant from the town. The point data (Figure 15) are located at the centre of the supply scheme area and have been given a 10 km radius. The 10 km radius was selected to hopefully incorporate the groundwater resource unit (although it is unlikely to include all of the resource units). No threshold was applied to this dataset: thus all areas within the 10 km radius of sole groundwater supply settlements are considered to meet criterion 4.

Box 1 Explanation of datasets used in the generation of SWSA-gw criterion 4

Datasets used for generation of sole groundwater supply settlements map and criterion

The following datasets were used:

1. Review of DWS reconciliation strategies for each of the major metropoles (i.e. those areas not included in All Towns) were reviewed (with information informing criterion 5). *None of the major metropoles are sole groundwater supply*.
2. Summary spreadsheets of second phase strategies generated by each of the four teams completing the various regions, supplied by DWS
3. Spatial dataset summarising the first phase All Towns data, showing; scheme name, scheme outline, supply sources, etc., generated by J. Du Plessis of Pula Consulting, which was shared with CSIR. However, ~25% of schemes had source information missing.
4. Individual strategies were consulted where necessary, accessible online (https://www6.dwa.gov.za/DocPortal/)
5. A summary spreadsheet of supply source was shared from M Cole, which was developed as part of *Cole, MJ, Bailey, RM and New, MG 2016. Spatial disaggregation of national sustainable development indicators: A case study of water use and access in South Africa. In preparation.*

The following processing was carried out:

- Summary spreadsheets capturing the latest 2016 data for supply source, generated by each of the four teams completing the various regions, were combined into one dataset. Several data gaps (for supply source) were filled through application of various assumptions.
- The names of the strategies in the combined dataset were matched to the names of the strategies in the national shape file from 2012, to provide a spatial dataset. This caused several data gaps as many strategy names did not remain consistent between 2012 and 2016 and, furthermore, individual workers have assigned different names to strategies in the summary sheets or spatial datasets which did not match the individual pdf strategies.
- Several assumptions were applied for supply source and naming, in order to minimise data gaps, however some remain. Therefore, the information shown in Figure 15 should be considered a minimum representation of sole groundwater supply areas.

The 10 km radius was a best available approach given that it is not possible to map all of the groundwater resource units for domestic supply, in a national scale project. The focus of the project is on protecting the SWSA that are significant at national scale. Therefore, the 26 "areas of national economic significance" as listed in the National Water Resources Strategy (DWAF, 2013) were selected as a subset of "key areas" that can be considered significant at national scale (Table 2). For these key areas, it was deemed appropriate that, if groundwater is part of the supply system (currently, or in future), its groundwater resource unit be included as a SWSA-gw. The current and proposed future supply source was investigated in greater detail for the 26 areas, and where groundwater is used (currently, or in future), the groundwater resource unit was mapped using existing reports (Table 2, Figure 16). Where resource units were not delineated in existing reports, the delineation was based on geology, topography, drainage and knowledge of the area. In some cases only a circular area 10 km radius of the town (as per criterion 4) could be applied, where there was no information on the future groundwater resource location, other than that it is likely to be local to the town. Each of the areas identified forms part of criterion 5 (strategic groundwater use).

Future use is therefore explicitly included for the 26 areas of national economic significance. It was not possible however to include future groundwater use for all settlements. Although future reconciliation interventions are included in the All Towns Study reports, the groundwater resource unit is rarely outlined, nor the future water supply makeup quantified (% supply) as it is often not known. Significant effort, beyond that possible in this project, would be required to collate the data from the summary spreadsheets and individual strategies. The groundwater control areas were initially setup to protect these areas for future municipal use, recognising the high groundwater potential in the areas. They were delineated based on several factors: for example not only the resource outline, but also to include agricultural/interest groups. Not all have been utilised. Groundwater control areas have therefore been included (within criterion 5, strategic use) as a proxy for future potential groundwater use (i.e. highlighting where there is potential that may not be used).

Each of the areas which meet the conditions of criterion 5 are included as groundwater source areas, i.e. no threshold is applied.

Criteria 4 and 5: Different approaches to % Groundwater considered, and area included:

Criterion 4 includes those settlement points that are >50% supplied by groundwater. However, for the 26 areas of national economic significance, *any* current or future use of groundwater as part of the supply system to that key area (>0 to 100%) has been included (and its groundwater resource unit delineated where possible, rather than using a point with 10 km radius from the town) to meet the requirements of criterion 5. This approach was largely dictated by the data available and the scope of this assessment, and it is in line with the national focus of the project. Furthermore, it is assumed that future water demand is likely to increase in these key areas and thereby also the overall or strategic contribution by groundwater.

The distribution of groundwater use (from WARMS data and from DWS data) correlates strongly with settlement type: the high groundwater use in the Limpopo and North West Province and, to a slightly lesser extent in the Eastern Cape and KwaZulu-Natal, correlates with locations of rural settlements (Figure 17). Other clustered groundwater use is likely to be supporting agriculture (i.e. Western Cape).

Table 2: Groundwater contribution to current or future water supply at 26 areas of national economic significance (part of Criterion 5)

Area	Current % Groundwater supplied	Current Aquifer	Future groundwater use, aquifer	References for delineation of current groundwater resource unit, and potential future supply
Cape Town, Worcester	2%	TMG Albion springs (Cape Peninsula) & Atlantis	Yes; Cape Flats aquifer, TMG aquifer in Southwestern Cape Fold Belt, increased abstraction at Atlantis	(CCT, 2015, 2012; Delta-h, 2016; DWS, 2016a; H Seyler et al., 2016)
Saldanha	11%	Langebaan Road Aquifer System	Yes; Langebaan Road Aquifer System, Elandsfontein Aquifer System	(DWAF, 2007a; H. Seyler et al., 2016)
George, Mossel Bay	0% (backup/drought relief only)	Local TMG aquifer	Yes; Peninsula aquifer north of George town	(DWS, 2014a)
Port Elizabeth	2%	Uitenhage springs	Yes: Coega TMG aquifer	(Groundwater Africa, 2012)
Richards Bay	<6%	Supply source is (GW fed) lakes and transfers from river systems. The lakes receive 6% of their yield from groundwater.	No increased groundwater supply planned	(DWS, 2015a, 2015b) Delineation of lake groundwater catchment based on geology, topography and surface water drainage.
Welkom, Kroonstad	None	n/a	Yes; Kroonstad groundwater local to Kroonstad	(DWA, 2012a) All Towns strategy
Gauteng (Tshwane)	6[*3]%	Pretoria Springs (Dolomite)	No	(DWA, 2009a, 2009b; DWAF, 2009)
Mafikeng	71%	Grootfontein spring (Dolomite): Molopo Grootfontein Compartment	Yes; increased use of same aquifer	(DWA, 2009b), DWS All Towns strategy
Lichtenburg	>50% *[1]	Lichtenberg dolomites compartment/NW Dolomites	Yes; increased use of same aquifer	(DWA, 2009b), & based on information in DWS All Towns strategy
Thabazimbi	34%	Alluvial aquifer around Crocodile River	No	Based on information in DWS All Towns strategy
Rustenburg	No	n/a	Yes; groundwater local to Rustenburg	DWS All Towns strategy
Phalaborwa	No	n/a	Yes; groundwater local to Phalaborwa	DWS All Towns strategy
Polokwane	>11% *[2]	Basement aquifer local to Polokwane	Yes; increased use of same aquifer	Assumed based on information in DWS All Towns strategy
Tzaneen	No	n/a	Yes; groundwater local to Tzaneen	Assumed based on information in DWS All Towns strategy
Gyani	26%	Basement aquifer local to Gyani	Yes; increased use of same aquifer	Assumed based on information in DWS All Towns strategy

*[1]No yield information is contained within the Lichtenburg All Towns strategy, however >50% can safely be assumed based on the supply make up to surrounding towns in the Ghaap Plateau

*[2] Groundwater yield in the Polokwane All Towns strategy was listed as a minimum yield, hence this translates as >11%.

*3 Percent reflects use in Tshwane Metropolitan municipality, groundwater is not currently a supply source in other parts of Gauteng Johannesburg or Ekurhuleni Metropolitan Municipalities (excluding treated AMD, Section 6.3.4)

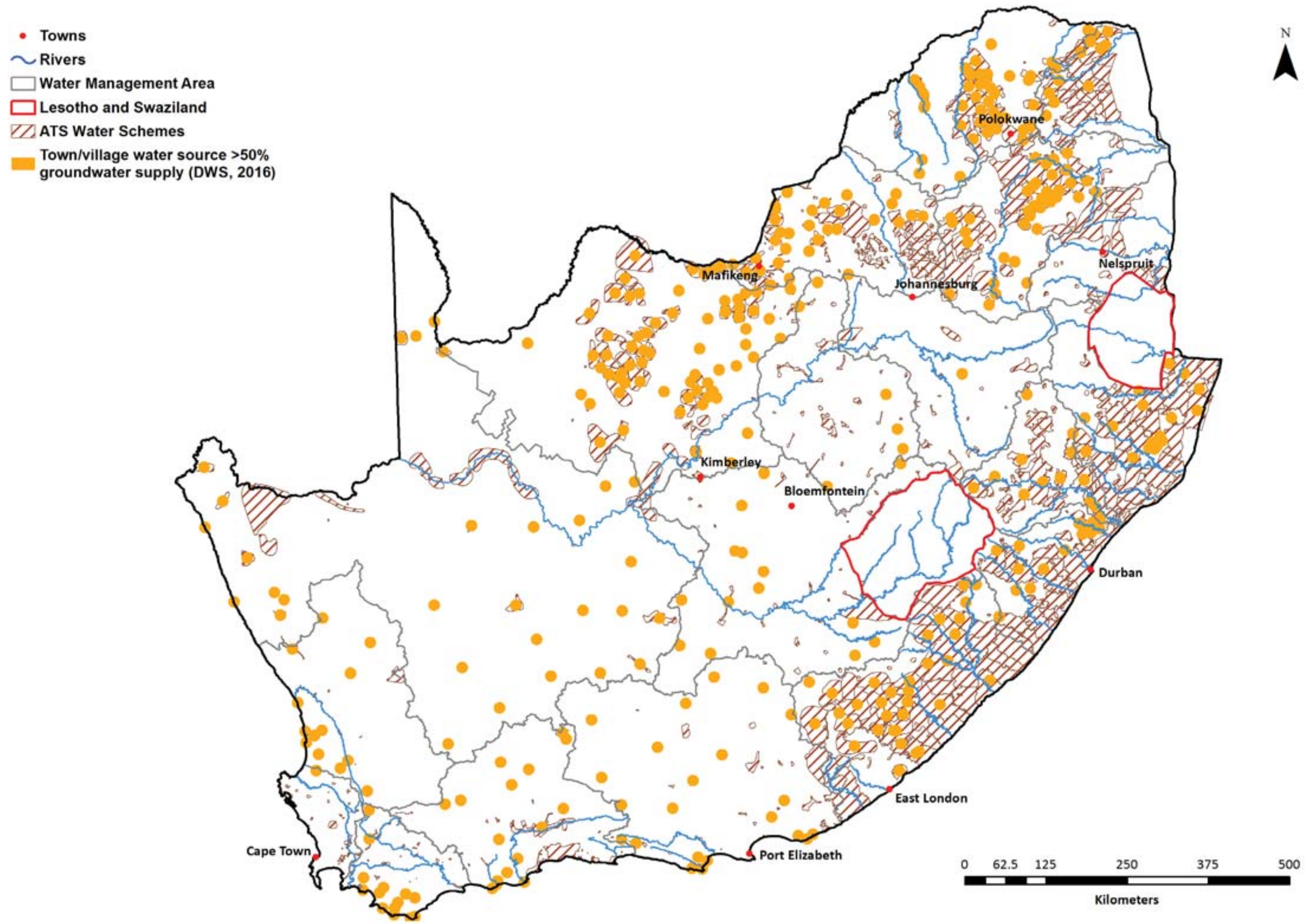

Figure 15: Towns and villages where groundwater is >50% of the water supplied and thus qualifies as the sole supply (DWA 2011). [Criterion 4]

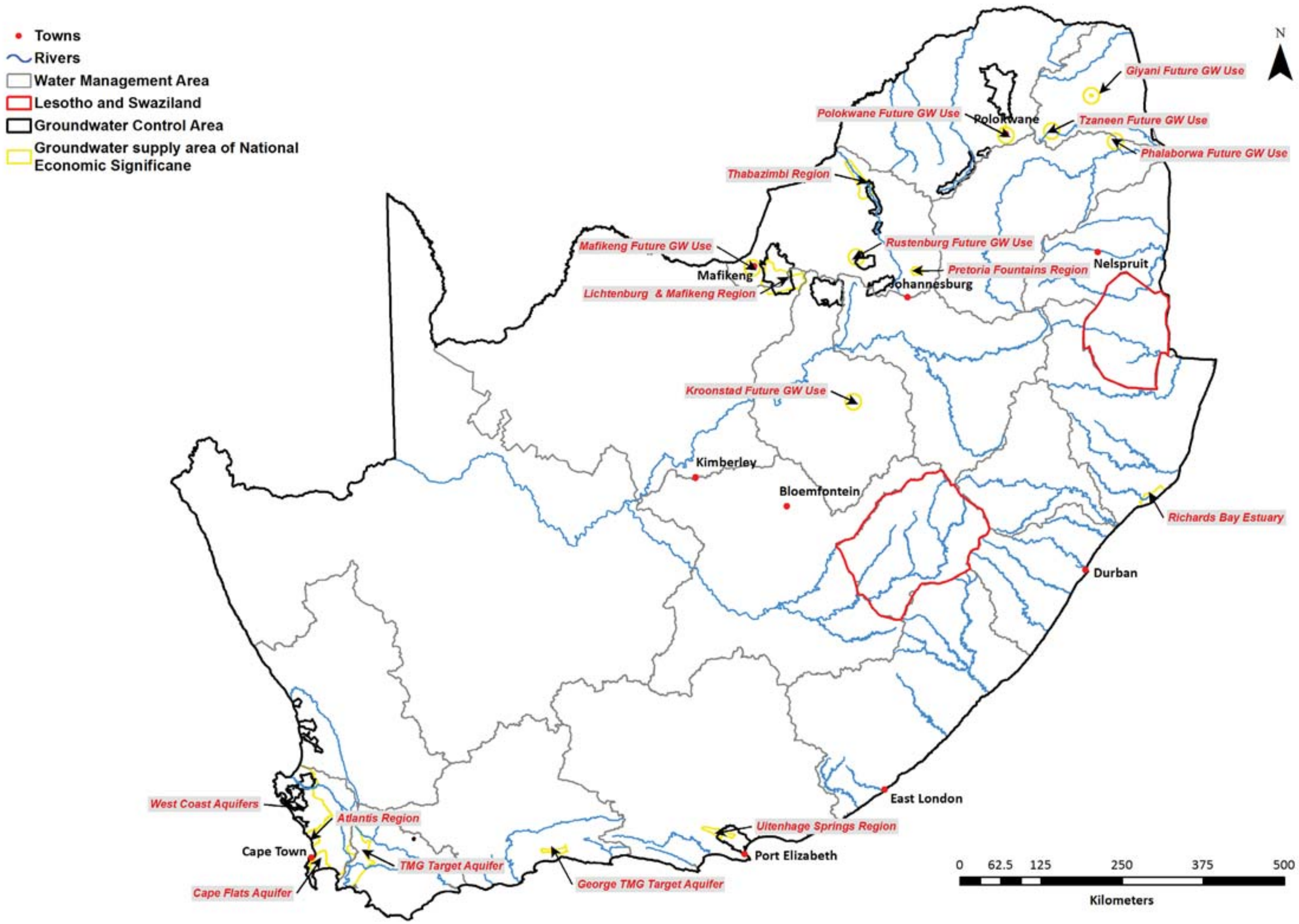

Figure 16: Current and future groundwater supply to 26 areas of national economic significance and groundwater control areas [Criterion 5].

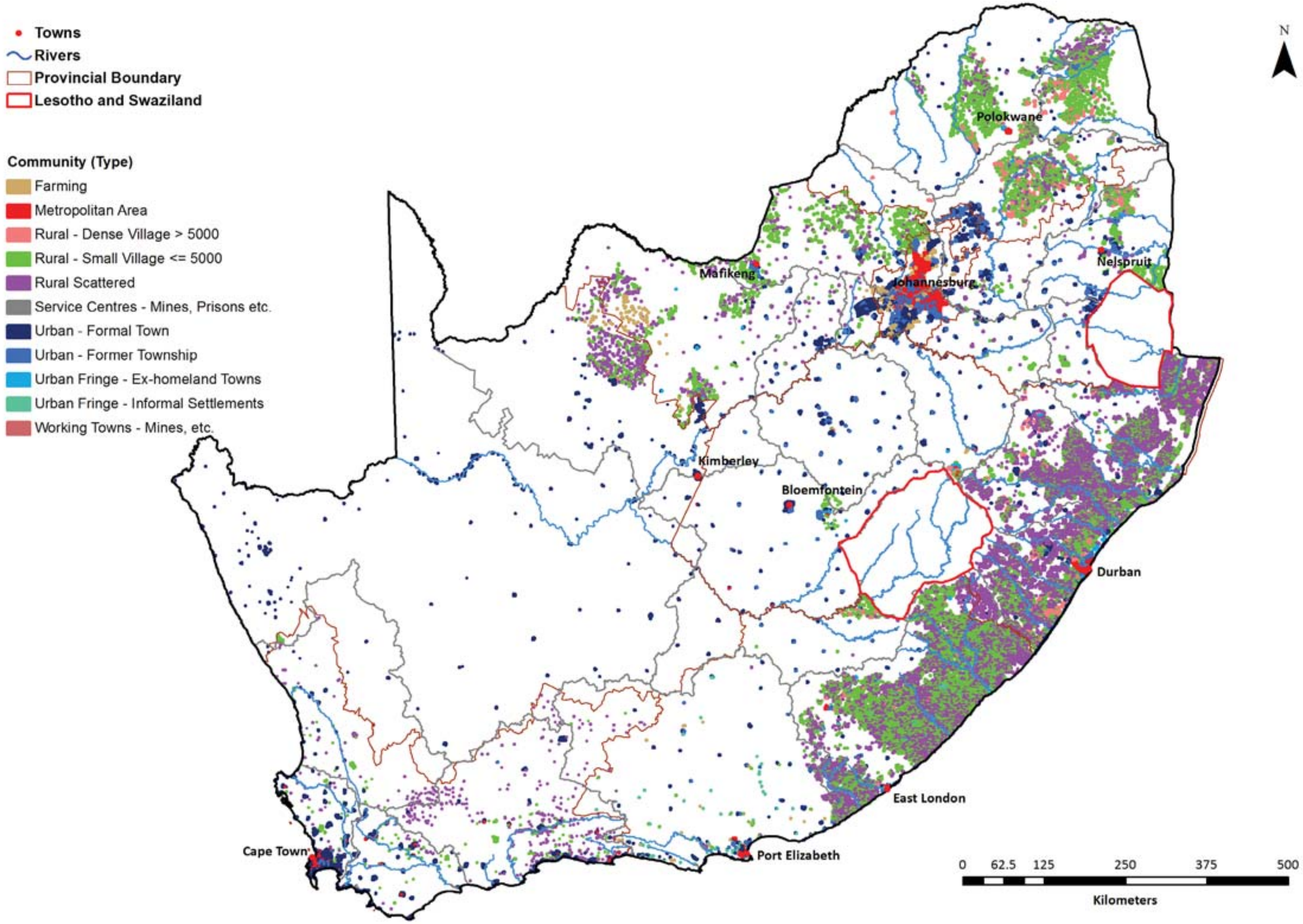

Figure 17: Distribution of the different settlement types across South Africa.

2.3 Draft Strategic Groundwater Source Areas

2.3.1 Delineation approach

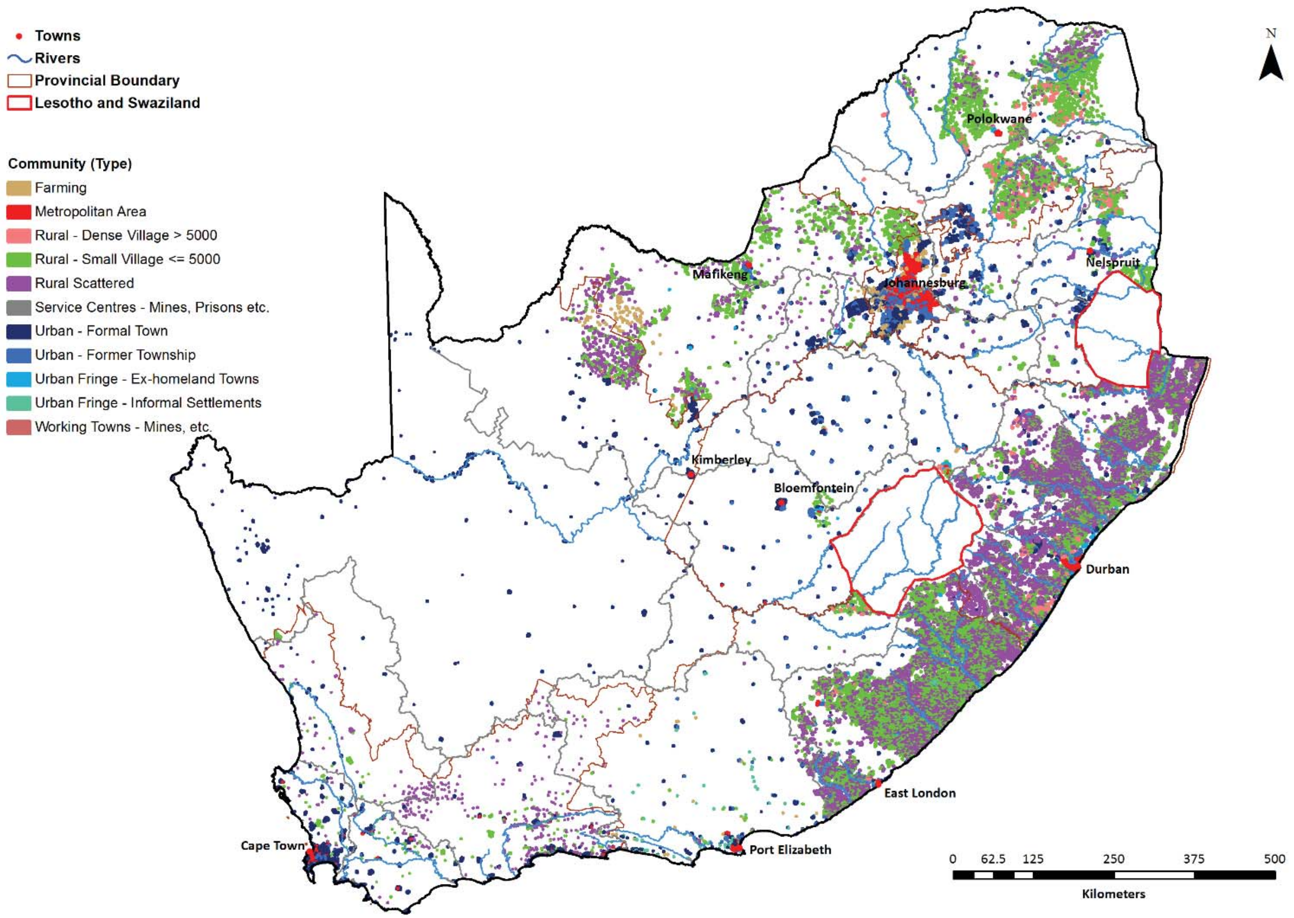

Figure 18: Distribution of the different settlement types across South Africa.

2.4 Delineated SWSA-gw

2.4.1 Delineation approach

The five criteria and the associated thresholds (as described in 2.2) can be summarised as follows (Table 3):

Table 3: Summary of criteria and thresholds used in groundwater source area delineation

Criteria	Description	Threshold	Motivation
1	Recharge as mm/a (GRAII, (DWAF, 2006a))	>65 mm/a	Corresponds to >50% national recharge volume
2	Ratio of recharge per 1 km^2 grid cell compared to the average recharge of the secondary catchment	>1.5	Threshold set iteratively and subjectively
3	Registered groundwater use (WARMS) as l/s per km^2 (Kernel function)	>0.3 $l/s/km^2$	Threshold set iteratively and subjectively
4	Towns/village clusters with groundwater sole supply, for *current* domestic water supply, mapped as points with 10 km radius.	None (i.e. all areas included)	All areas are relevant, no threshold to be met
5	Groundwater resource unit used for current or future supply to an area of national economic importance, and groundwater control areas	None (i.e. all areas included)	National interest

Areas that meet any of the criteria and thresholds are shown together in Figure 19. Translating areas that meet any of the five criteria (and their thresholds) into groundwater source areas is a process dictated by the purpose and definition developed for SWSA-gw. Implementing a definition of "source" area that relates only to availability (note, not "resource" area), would include consideration only of groundwater availability, i.e. areas meeting criteria 1 and 2 could be included in a delineation.

As the results show, areas meeting criterion 1 generally coincide with SWSA-sw, as is to be expected given that high rainfall translates to high recharge and, in turn, high baseflow. High rainfall also translates to high runoff, and surface waters are furthermore supported by high baseflow in the same areas (Vegter, 1995; Winter, 2007; Woodford et al., 2006). As the areas overlap, there is already some protection potentially available to areas with high groundwater recharge, provided by the fact that these are SWSA-sw. It is therefore not useful to delineate areas based only on criteria 1 and 2. The intended purpose of delineating SWSA-gw is in part to raise awareness of the country's water sources, and lead to their protection (for sustained current or future human use, or protection of contribution to surface water and hence support of ecological functioning). As such, the mapping of SWSA-gw incorporates areas where groundwater is important for use (i.e. thus also incorporating to some degree "resource" areas not just source areas). SWSA-gw have therefore been considered areas where groundwater availability ***and*** use is high.

Therefore, a SWSA-gw can be defined as an area with high groundwater availability *and* where groundwater forms an important resource and is therefore delineated wherever criteria 1 or 2 overlap with criteria 3, 4 or 5. In addition, even if only criterion 5 is met, this area also is considered a SWSA-gw in order to include current and/or future groundwater sources to areas of national economic significance (Table 2).

Furthermore,

- areas with high groundwater availability only (meeting criteria 1 or 2) could be considered areas with high groundwater potential, and
- areas with high groundwater use only (meeting criteria 3 or 4) could be considered areas where groundwater is an important (and in some cases sole) resource,
- and these areas are shown in the maps provided, although not separately delineated.

2.4.2 Resulting Strategic Water Source Areas for groundwater

Based on the above definitions, 37 SWSA-gw have been identified, shown in Figure 20 and Table 4. The outlines were drawn manually to capture any area where **Criteria 1 or 2 *and* 3, 4 or 5 are met.** The outlines are considered indicative at national scale, but do not delineate exact areas at regional/local scale. In places the outlines follow geological boundaries to capture the aquifer unit (i.e. Ghaap Plateau, or where the outline is based on criterion 5 only) but in other areas they simply group areas that meet the criteria (i.e. KZN coastal).

The utilisable groundwater exploitation potential, or UGEP, ("the volume of available renewable groundwater", DWA, 2010) (Figure 21), was used to inform the delineation alongside criteria 1 and 2 although no fixed threshold was set. For example, some areas that are not highlighted with high recharge do have relatively high potential (i.e. parts of the dolomites). Conversely some areas shown as high recharge do not have a high groundwater potential due to (relatively) poor aquifer properties such as the Karoo Supergroup in KwaZulu-Natal.

In addition to the 37 SWSA-gw, a further 20 areas were delineated, but are considered sub-national importance (based on their scale and types of criteria met). These are shown in Figure 20 and Table 4 but are discussed any further in this main report. The total area of land included under SWSA-gw is 103 659 km^2, equivalent to 9% of South Africa (increasing to 11% if the sub-national WSA-gw are included).

Table 4: Strategic Water Source Areas for groundwater (including sub-national WSAs)

Number	SWSA-gw or WSA-gw Name	National or sub-national	Area (km^2)
1	Bo-Molopo Karst Belt	National	5 268
2	Cape Peninsula and Cape Flats	National	599
3	Central Pan Belt	National	3 368
4	Coega TMG Aquifer	National	1 682
5	Crocodile River Valley	National	2 163
6	De Aar Region	National	2 475
7	Eastern Kalahari A	National	2 010
8	Eastern Kalahari B	National	2 656
9	Eastern Karst Belt	National	1 984
10	Far West Karst Region	National	1 382
11	George and Outeniqua	National	727
12	Giyani	National	438
13	Ixopo/Kokstad	National	7 150
14	Kroondal/Marikana	National	795
15	Kroonstad	National	799
16	KwaDukuza	National	2 352
17	Letaba Escarpment	National	2 151
18	Northern Ghaap Plateau	National	6 274

Number	SWSA-gw or WSA-gw Name	National or sub-national	Area (km^2)
19	Northern Lowveld Escarpment	National	5 168
20	Northwestern Cape Ranges	National	3 638
21	Nyl and Dorps River Valley	National	2 036
22	Overberg Region	National	2 261
23	Phalaborwa	National	433
24	Richards Bay GW Fed Lakes	National	606
25	Sandveld	National	4 010
26	Sishen/Kathu	National	4 827
27	Southern Ghaap Plateau	National	6 542
28	Southwestern Cape Ranges	National	2 749
29	Soutpansberg	National	2 573
30	Transkei Middleveld	National	5 607
31	Tulbagh-Ashton Valley	National	3 560
32	Upper Sand (Polokwane) Aquifer System	National	966
33	Ventersdorp/Schoonspruit Karst Belt	National	2 875
34	Vivo-Dendron	National	2 555
35	West Coast Aquifer	National	4 586
36	Westrand Karst Belt	National	1 090
37	Zululand Coastal Plain	National	3 305
38	Arlington	Sub-national	1 553
39	Beaufort West	Sub-national	786
40	Blouberg	Sub-national	666
41	Carnarvon	Sub-national	659
42	Eastern Upper Karoo	Sub-national	6 131
43	Great Kei	Sub-national	1 416
44	Hertzogville	Sub-national	447
45	Kamieskroon	Sub-national	3 314
46	Komaggas Cluster	Sub-national	364
47	Lower Mzimvubu	Sub-national	1 199
48	Loxton	Sub-national	397
49	Nelspoort	Sub-national	509
50	Northern Highveld	Sub-national	1 345
51	Port Nolloth	Sub-national	512
52	Strandfontein	Sub-national	291
53	Sutherland	Sub-national	1 253
54	Upper Keurbooms	Sub-national	1 223
55	Van Wyksdorp	Sub-national	599
56	Vanrhynsdorp	Sub-national	1 423
57	Willowmore	Sub-national	289

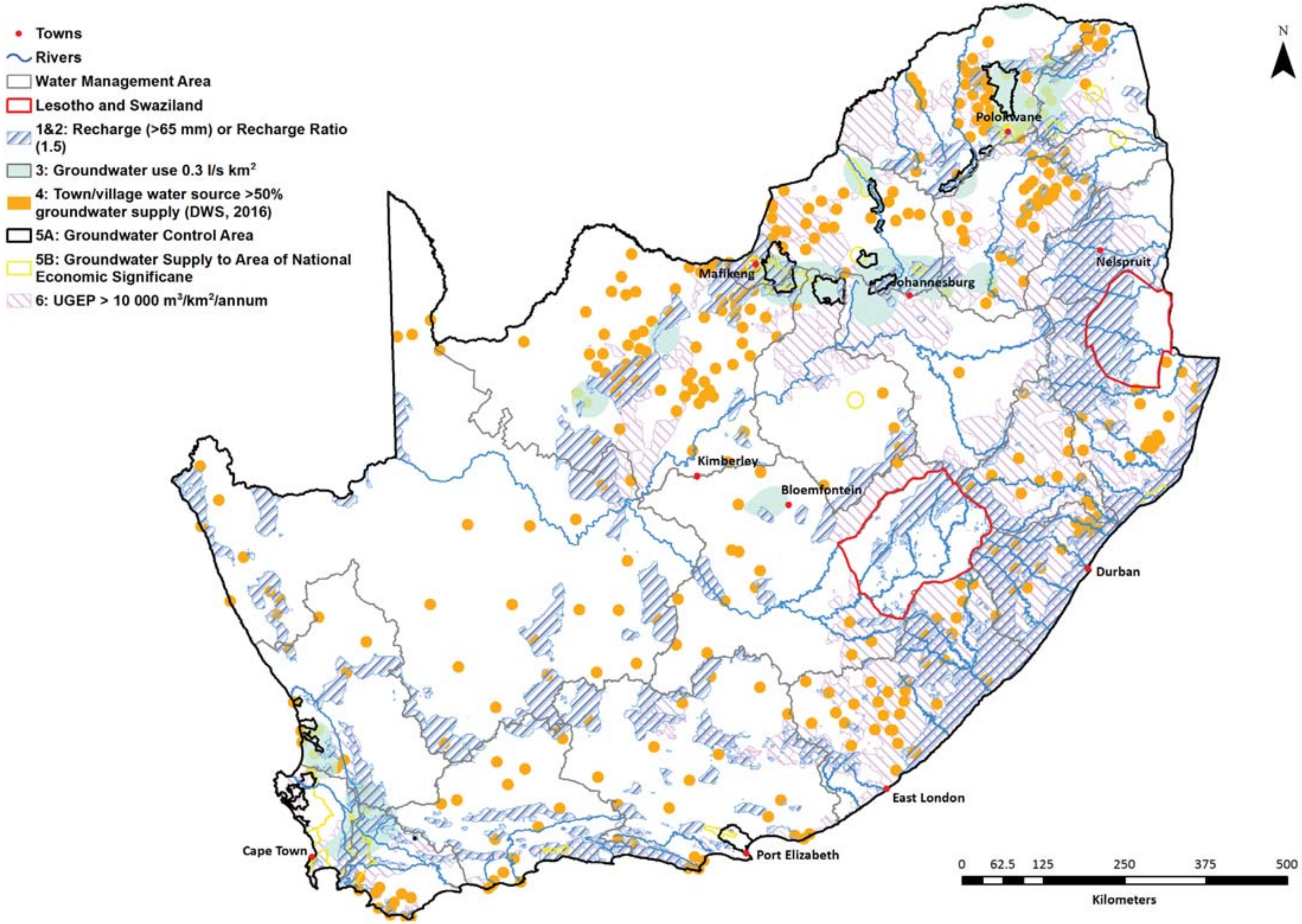

Figure 19: Areas meeting all five criteria for groundwater source area definition (see Table 3).

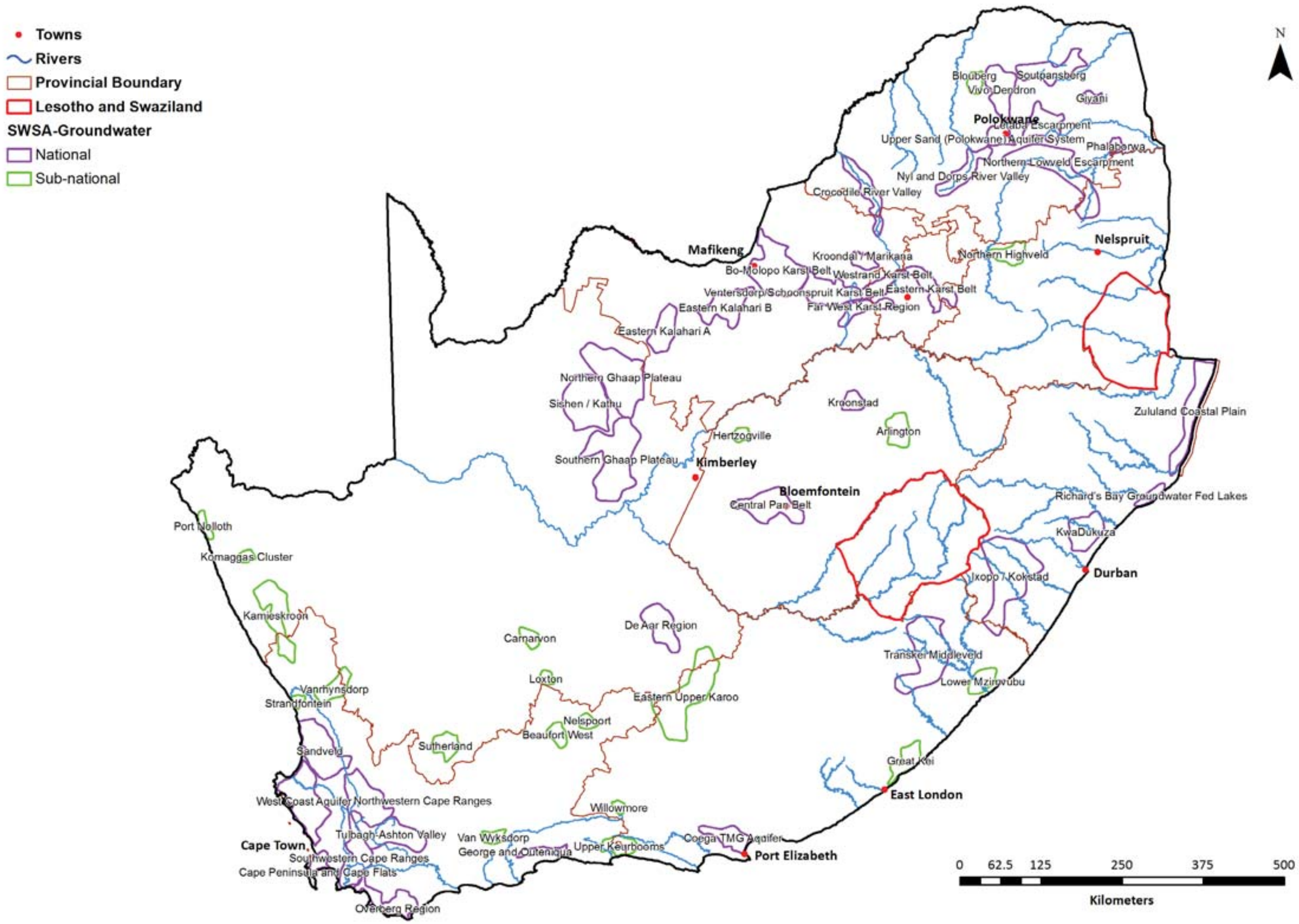

Figure 20: The final set of groundwater-derived SWSA-gw.

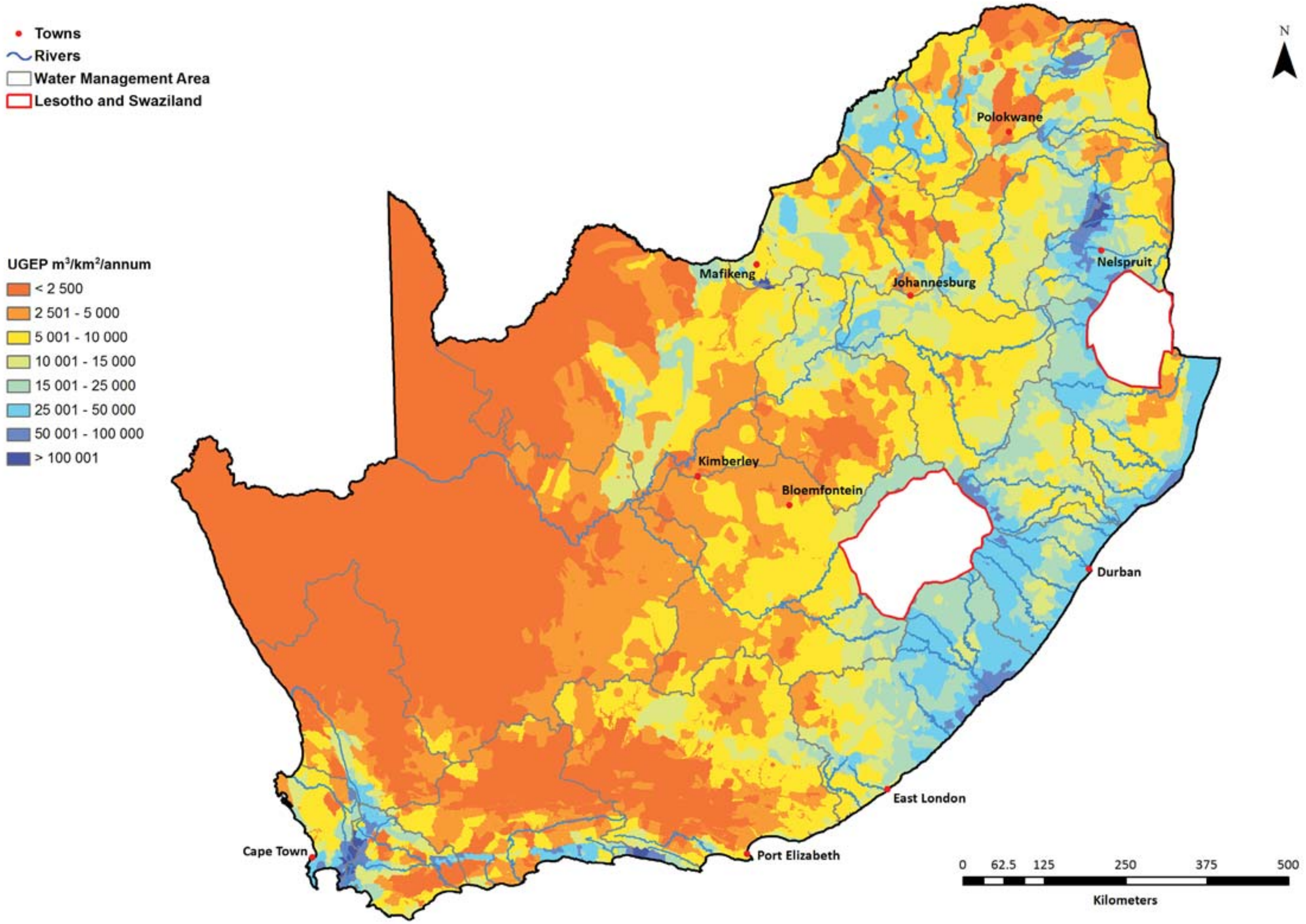

Figure 21: Utilisable groundwater based on the exploitation potential (DWA 2006).

2.4.3 Discussion and limitations

The resulting SWSA-gw hold a clear imprint of the underlying geology and corresponding aquifer types in the case of the TMG and the dolomitic karst aquifers. Interestingly, ***all*** of the SWSA-sw coincide with a SWSA-gw, or an area of high groundwater availability (areas that meet criteria 1 and 2 only). Where surface water is in abundance, so is groundwater. A significant number of the SWSA-gw do not overlap SWSA-sw. These areas are generally located away from high recharge (in mm/a) and away from high runoff, illustrating that groundwater use is important away from surface water resources. A key limitation of the project is the available recharge information, and especially the lack of national scale data for indirect recharge. Furthermore, data limitations certainly impact the representation of groundwater use.

The approach presented here, incorporating criteria and thresholds, was developed in order to provide a defensible, numerical approach, and minimise potentially subjective manual input. However, how the areas meeting the various criteria translate into SWSA-gw, and what is considered nationally important, are both subjective steps. Criterion 5 aimed to ensure that any area of national economic significance was incorporated, but use of criterion 5 *only* in the identification of SWSA-gw would certainly be an underestimate (and reflect resource only, not source). Yet including *all* areas met by the criteria would be an overestimate at national scale.

Several areas with sole groundwater supply (criterion 4) do not form a groundwater source area (strategic or otherwise), because they do not also meet criteria 1 or 2 (i.e. they are a resource area, not a resource *and* a significant source). They are (arguably) not areas of national significance, yet are areas that rely on groundwater and hence their resource should be protected.

3. REFINEMENT OF THE EXISTING SURFACE WATER STRATEGIC SOURCE AREAS

The 2013 map of surface water source areas (Nel et al., 2013a) included only the source areas with the highest surface water runoff, ignoring some important but lower run-off source areas that are linked to current or future national economic development nodes (e.g. the Waterberg energy development node). The areas that were named and highlighted with ellipses also excluded a number of smaller water source areas which met the criterion of MAR ≥135 mm. In addition, the potential supply of water provided by the source areas was not considered in relation to use of, and access to, the water supply. This strongly influences the importance of a WSA's contribution to the country's water security. An area that has low human need for the water supplied by the source, or is remote or inaccessible, is arguably less important from a water resource development perspective. Conversely, source areas with relatively low supply but high dependency are more critical areas.

We held a workshop with experts familiar with future water resource development thinking to help identify key gaps in the existing map of surface water source areas in 16 February 2016. This workshop was attended by representatives from the Directorate of National Water Resource Planning of the Department of Water and Sanitation, surface and ground water specialists and others.

3.1 Gaps identified in Waterberg, Upper Usutu and Upper Vaal

Three additional SWSA-sw were identified during the workshop:

Upper Usutu: Currently the Mbabane Hills SWSA-sw is located downstream of the dams which supply the Vaal WSS and the power stations in the Olifants Catchment. Creating an additional SWSA-sw for the Upper Usutu highlights the importance of protecting this area to ensure that water is available for interbasin transfers to the existing power stations and for the Kusile power station currently under construction. These power stations are classed as strategic water users so their water allocations have the highest priority (DWAF, 2013; Van Rooyen and Versfeld, 2010).

Upper Vaal: The relatively high MAR areas of the Upper Vaal are important for the overall flow in this system and sustain a mine-water and acid-mine drainage diluting function in this heavily mined area. There are no areas which meet the 2013 threshold of ≥135 mm of MAR in the Upper and Middle Vaal Catchment so we need to define and delineate additional SWSA-sw areas in the catchment. A small portion of the Upper Vaal and all of the Wilge River system are sustained by water from the Northern Drakensberg SWSA-sw.

Waterberg: The relatively high-yielding areas of the Waterberg need to be included because they are the source of the water for the Mokolo Dam and for Lephalale. This would protect these WSAs, and ensure that water is available for the future growth of Lephalale and coal mining. The water would also augment the transfer scheme from the Crocodile WSS which supplies water to the Medupi power station. A very small portion of the Waterberg meets the 2013 MAR threshold of ≥135 mm but a greater area needs to be protected to ensure the water supply.

3.2 Removal of the Pondoland Coast and Zululand Coast sub-national WSA-sws

Two of the 2013 SWSA-sw were identified as being sub-national priorities, namely:

The Pondoland Coast: the high MAR area identified as this SWSA in 2013 extends from just south of the Durban metropole in the north to the Pondoland and Wild Coast. It includes the KwaZulu-Natal South Coast which has extensive agriculture, mainly dryland sugar cane, and tourism developments and commercial forestry further inland. The towns in this area are not currently experiencing water shortages and supplies are generally drawn from river systems originating in the Southern and Eastern Cape Drakensberg SWSA-sw. The portion in the Eastern Cape is located in a remote and fairly sparsely populated area where the demand for surface water is relatively low, population densities are low and the soils are largely unsuited to agricultural development. There is little potential for industrial development because of its remoteness. Commercial plantation forestry has been identified as a potential land-use because the impacts on water resources would be acceptable (DWAF, 2005), but the remoteness and lack of road infrastructure is a significant constraint. There are heavy mineral deposits but these are located right on the coast and so would not affect water security. The current development plans focus on tourism. The Pondoland Coast is, therefore, not considered a national priority for water resource management and so has been classified as a sub-national WSA-sw.

The Zululand Coast: this extensive high MAR area extends from the southern boundary of the eThekwini Metropol to Maputaland in the north. eThekwini and the North Coast are undergoing rapid economic development for both industry and tourism with potentially high water demand. Almost all of the water supplies for this area are sourced from rivers with headwaters in the Southern Drakensberg SWSA-sw and connected into the KwaZulu-Natal Coastal Metropolitan WSS. There are important economic development nodes between there and Richards Bay but further north the coastal region is more rural, and includes the Isimangaliso Wetland Park and other provincial conservation areas. There is extensive agricultural development with about 23% being agriculture (mainly sugar cane, some irrigated) and 12% is under commercial forest plantations. About 17% is urban areas. However, the agricultural, industrial and urban developments are largely supplied with water from rivers that arise further inland so the local pressure on water resources is relatively low although there is some groundwater use. This area is also not seen as a national priority and has been classified as a sub-national WSA-sw.

3.3 Adding in the Upper Vaal, Upper Usutu and Waterberg

This section describes the approach taken to defining these additional SWSAs based on runoff thresholds that were considered appropriate for providing adequate protection for the relatively high MAR areas within each of these catchment areas.

Upper Usutu: Currently the Mbabane Hills SWSA-sw is located downstream of the dams which supply the Vaal WSS and the power stations in the Olifants Catchment. Creating an additional SWSA-sw for the Upper Usutu would ensure that the water used for this high priority purpose is protected and made available for interbasin transfers. We have added an ellipse to cover the headwaters of the Usutu River system (W5) which includes the dams used for water transfers for power generation and the Vaal WSS (Figure 21). There are MAR grid-cells that exceed the 135 mm/a cut-off for a national SWSA in the eastern part of the area, but only a few in the southern headwaters of the catchments that feed the dams used for water transfers. Some of the northern headwater quaternaries of the Usutu River system have an MAR <75 mm, but using a threshold of ≥75 mm includes important areas for water resource protection in the southern headwater quaternaries (Figure 21). Areas with a MAR of ≥75 in these catchments were, therefore, added to the original 2013 ≥135 mm dataset.

Upper Vaal: The Upper Vaal provides a diluting function in a heavily mined area and the water is critical for downstream users. Although the Northern Drakensberg SWSA-SW includes a portion of the headwaters of the Wilge River, there is no SWSA in the Upper and Middle Vaal River catchment which is an additional reason to delineate a SWSA in the catchment. We have added an ellipse which covers the headwaters of the Vaal, Olifants and Komati River systems. There are no MAR grid-cells that exceed the 135 mm cut-off for a national SWSA in this area. However, there are areas with an MAR ≥75 mm (Figure 21) and we have used these to define the important areas for water resource protection within the headwater quaternaries of these river systems. The portions of the MAR data that fell in the range ≥75 mm and on, or within, the boundaries of the Upper Vaal catchment (C1) were used to define the high MAR areas which were then added to the existing 2013 ≥135 mm dataset.

Waterberg: This area was included because it the main source of water to Mokolo Dam and to Lephalale, and ensures that water is available for the future growth of Lephalale and coal mining and for the Medupi and possible future power stations. We have added an ellipse to cover the headwaters of the Mokgalakwena, Lephalala and Mokolo rivers (Figure 21). There are a few MAR grid-cells that meet the ≥135 mm MAR cut-off for the 2013 SWSAs in the eastern part of the Waterberg but too few for effective protection. A MAR threshold of ≥75 mm was used to define boundaries of the polygons that identify the highest yielding areas of these catchments and these were added to the 2013 ≥135 mm dataset.

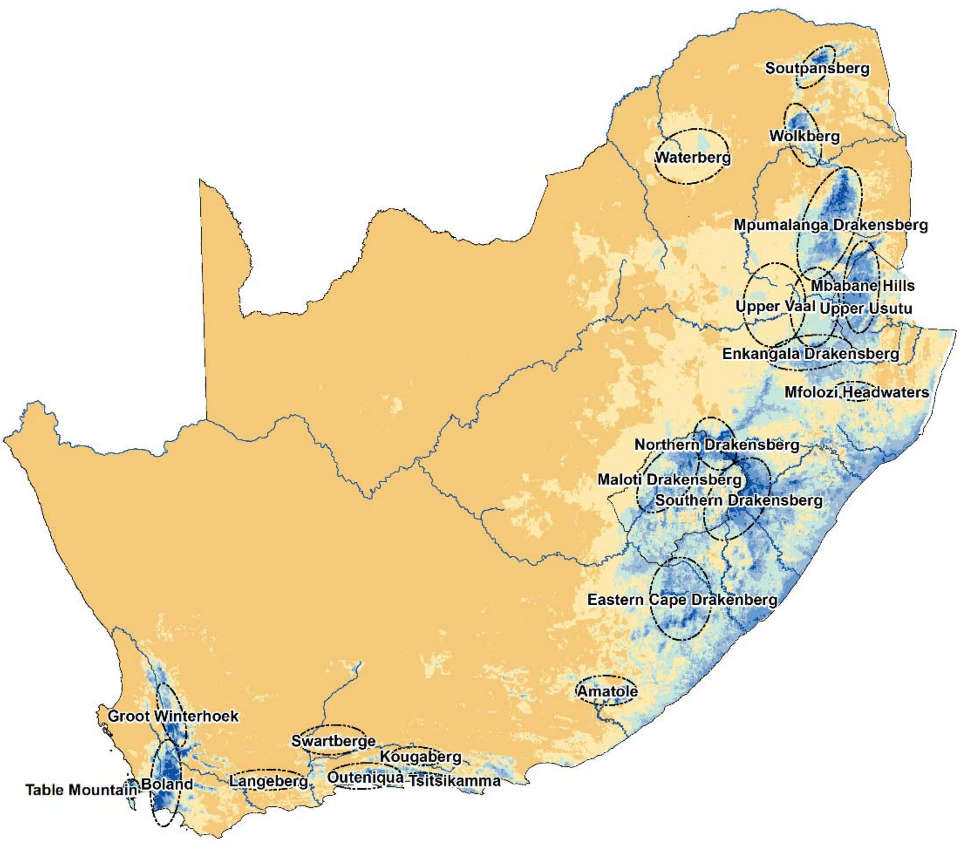

Figure 22: Revised map of Strategic Water Source Areas for surface water for South Africa showing location of the three additional SWSA-sw and with those in the high Mean Annual Runoff areas on the east coast removed.

3.4 Refining the revised surface water areas

3.4.1 Introduction

The initial approach to defining and naming Strategic Water Source Areas for surface water resources was logical and defensible and reasonably easy to grasp as it involved a single MAR threshold (Nel et al., 2013a). However, the combination of SWSAs defined by pixel or cell-level MAR thresholds, and the blobs or ellipses used to identify specific areas with memorable names generated some confusion. Many have mistakenly thought that the ellipses (Figure 21) define the SWSAs but they do not, their purpose was to name them so that stakeholders would recognise and associate with them (WWF-SA, 2013). The addition of a new MAR threshold of >75 mm for areas that the stakeholders in this study identified as important – Upper Vaal, Upper Usutu and Waterberg complicates the issue. So does the re-classification of the Pondoland Coast and Zululand Coast as sub-national WSA-sw although their MAR exceeds the 2013 SWSA threshold of ≥135 mm. The challenge for this study was to find a way of translating this more complicated definition into a set of areas (polygons) which would consolidate the high MAR clusters or concentrations and remove the scattered MAR cells while including at least 50% of the MAR.

The use of a raster (gridded) dataset to determine the MAR thresholds resulted in numerous, widely scattered, single grid cells, or small clusters of grid cells. These are impractical, potentially difficult and ineffective to protect or manage to sustain their water runoff and quality. In addition, the accuracy of the MAR data, which was generated from interpolated rainfall data with its own uncertainties (Lynch, 2004; Schulze et al., 2008), is probably not sufficient establish defensible boundaries based on the individual cell values. The best way to address the scattered cell problem is to consolidate high MAR areas and remove isolated cells and small clusters to produce interpolated (smoothed) areas or polygons to define the boundaries. The smoothing will result in the inclusion of some cells with a MAR <135 mm (and <75 mm in the three additional SWSA-sw), but the boundaries can be adjusted to ensure that at least 50% of the total MAR is included. This approach would create defensible and manageable boundaries for the SWSAs.

3.4.2 Smoothing the MAR data and creating polygons

There are three main ways of interpolating the MAR data set. The one is to run an averaging process over the raster dataset such as a focal mean, where each cell value is replaced with the mean value calculated from itself and its neighbours, or to produce MAR contours. However, this still tends to pick out small groups of cells unless a large number of neighbours are used, which then tends to overly smooth the surface. Another would be to fit a modelled surface using methods such as kriging or splines but this is technically demanding and, arguably, would not produce a more defensible result given the uncertainties in the underlying spatial rainfall data modelling. A third approach is to convert the cell values to points, extract the points that exceed the thresholds and then to interpolate the point values using a kernel density function. The smoothness of that interpolation is determined by the kernel density radius (i.e. the number of points included in the calculation) and the values of the points. The advantage of this approach is that it uses the density per unit area of the points to create a surface with density contours where the edges, as defined by the cell MAR threshold, are steep and so minimise the inclusion of low MAR areas. The relationship between the cell-level MAR data, kernel radius and density surface can then be analysed to identify a radius and density value which strikes a balance between removing scattered cells and including cells which were below the threshold.

The raster dataset was converted to a point dataset including all the points with a MAR >135 mm as well as those with >75 mm in the three additional SWSAs – Upper Vaal, Upper Usutu and Waterberg. All the other point values were set to a zero value. The Kernel Density tool in ArcMAP 10.3 was then used to generate a density surface with the same spatial resolution and spatial extent as the MAR dataset. Initially, the following settings were used: default search radius based on Silverman's rule (Silverman, 1986), population input was set to the MAR value, cell size was the same as the MAR cell, area unit scale was a hectare, output was densities, and the method was geodesic which takes the curvature of the spheroid (earth's surface) into account. After some further investigations, especially the degree of generalisation and consolidation, additional kernel density radiuses were tested, ranging from 4 km through to 12 km. Smaller radiuses include too few points in the density calculation because the grid cell or cell size is 1798.72 m or 1.8 km x 1.8 km. So, for example, a 2 km radius would include only the central point and the four direct neighbours and at least 2.55 km is needed to include all 9 neighbouring cells Figure 23).

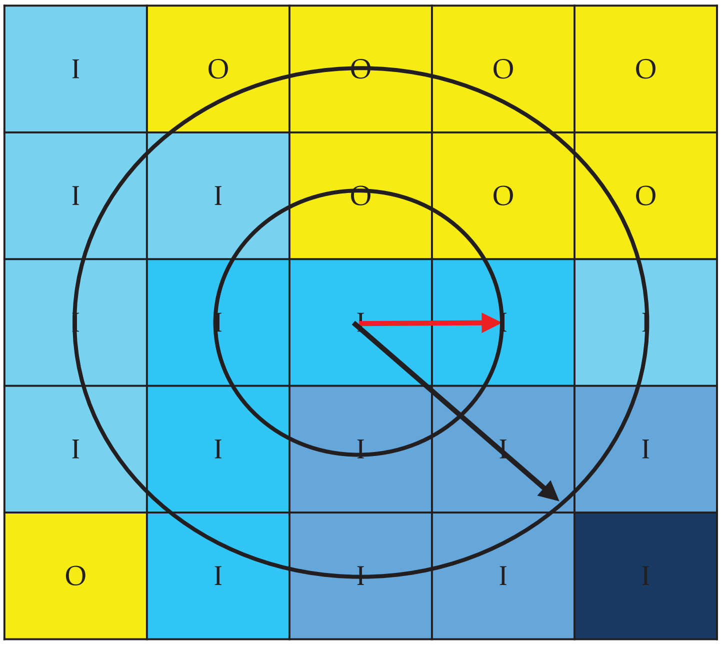

Figure 23: The effect of the radius setting in the kernel density on the number of points (0) that are included in the calculation. A radius of 1.8 km is indicated by the red arrow. The different shadings indicate different ranges of MAR values for the individual points, with yellow ones representing those points below the threshold MAR.

Essentially, as the value of the radius increases, the density surface becomes smoother and more generalised, and the values of single cells, and clusters of cells, with a high MAR are reduced to the surrounding values. The second factor in the kernel density processing is the selection of a density threshold to capture the desired proportion of the total MAR, namely 50%. We did this by selecting density thresholds, using them to define contours and then converting the contours to sets of polygons which include the portions of the kernel density surface that meets the threshold. The resulting polygons were then used as masks to determine the portion of the total MAR they included.

A range of threshold values of the kernel density was then tested to identify a density value which optimised the inclusion of areas with MAR greater than the selected thresholds while reducing the occurrence of isolated of small clusters of cells. Three tests were done: (a) the proportion of the total MAR which the SWSA-sw accounted for; (b) the degree to which the cells which exceeded the 135 mm MAR threshold were included; and (c) an examination of the degree of inclusion of two extreme cases of SWSAs. The one is the Swartberg where the cells with high MAR form a narrow strip only a few cells wide, the other was the Waterberg where two small areas have a MAR >75 mm.

Once the boundaries of the smoothed or consolidated SWSA-sw were defined, the extensive SWSA-sw polygons which extended across more than one of the named 2013 SWSA-sw (i.e. the ellipses) were sub-divided using quaternary and sub-quaternary catchment boundaries to keep them hydrologically consistent. In additional to the extensive polygons, this process identified a number of separate SWSA-sw polygons in areas that met the MAR thresholds. Wherever it was logical, we grouped those with one of the 2013 SWSA-sw and gave them the same name. So, for example, the Mfolozi Headwaters includes a number of polygons located with or on the boundary of the catchment of the Mfolozi River system. There also were some WSA-sw polygons which met the MAR threshold but were not logically or hydrologically linked to the 2013 SWSA-sw. We gave theses ones names relating to towns or river catchments where they were located. They have been grouped together with the Pondoland and Zululand Coast SWSA-sw polygons as sub-national WSAs. Information on the sub-national polygons is included in Appendix 1 but is not discussed in this report.

3.4.3 Results

An important aim in consolidating the SWSA-sw into a set of polygons and excluding single cells, or small clusters of cells, was to reduce the administrative complications involved in implementing their protection in practice. The complication involves two different things: (a) the number of separate areas that need to be addressed in the process, and (b) the convolutedness of their boundaries. We tested radiuses of 2, 4, 6, 8, 10, 12 km and the default, with different density thresholds and found the following:

- A small radius results in many small, complicated and convoluted polygons, including many situated well away from the existing SWSAs; a greater radius consolidated the polygons, resulting in less convoluted and complicated polygons and fewer separate polygons (Table 5).

- The extent of the area enclosed by the contours is similar for a given kernel density threshold value, regardless of the kernel radius (Table 6); thus the proportion of the area and MAR captured is also similar for a given kernel density threshold.

- There is no "ideal" combination of kernel density radius and kernel density value for the SWSA-sw.

Table 5: The relationship between the kernel density radius and the number of polygons which included cells that met the MAR threshold.

Kernel density radius (km)	Number of polygons
2	342
4	238
6	123
8	79
10	54
12	42
Default	38

Table 6: The relationship between the kernel density radius, the kernel density threshold and the percentage of the MAR and the study area that was included.

Kernel density radius (km)	Kernel density threshold	MAR included (% of total)	Area included (% of total)
Using the 2013 MAR threshold of ≥135 mm			
4	0.24	50.21	8.28
6	0.24	50.19	8.46
8	0.24	50.18	8.54
10	0.24	50.07	8.63
Using the dual MAR thresholds of ≥135 mm and ≥75 mm in three SWSA-sw			
4	0.14	57.87	10.73
6	0.14	58.53	11.04
8	0.14	59.22	11.38
10	0.14	59.99	11.68

There is a rapid initial decrease in the number of polygons as the kernel density radius increases but the rate of decrease declines steeply as the radius increases. The 2013 set of SWSA-sw was represented in the form of 20 ellipses which highlighted “blobs” (extensive clusters of high MAR cells), but a number of those ellipses included discrete clusters of cells that met the MAR thresholds. There were also high MAR clusters outside the boundaries of the ellipses. This means that the minimum number of polygons that could be created is in excess of 20 but to have more than 100 is clearly not practical. This suggests that the minimum radius for a manageable total number of polygons is about 8 km.

The effects of the different kernel density radiuses on consolidating the cell level data can also been seen when comparing them visually. The raw MAR data form a complex mosaic of high and low MAR values as can be seen in the KwaZulu-Natal Drakensberg and coastal regions (Figure 24). There is an extensive clustering of high MAR values from about Sehlathebe along the escarpment to Oliviershoek pass as well as high MAR values along the higher-lying catchment boundaries and the Mzimvubu headwaters. There are also extensive areas with relatively low rainfall and, thus, MAR in the lower lying parts of Lesotho, the central portion of the Mzimvubu catchment and Tugela catchment. When these raw data are compared with the surfaces generated by the kernel density processing with different radiuses (Figure 25), the consolidation around the concentrations of high MAR values and the removal of single and small clusters of high MAR cells is very clear. Note how the extent of the highest density class along the Drakensberg escarpment in KwaZulu-Natal consolidates and increases in the highest MAR areas, and how the number of smaller areas of high MAR density at the 6 km radius are reduced as the radius is increased.

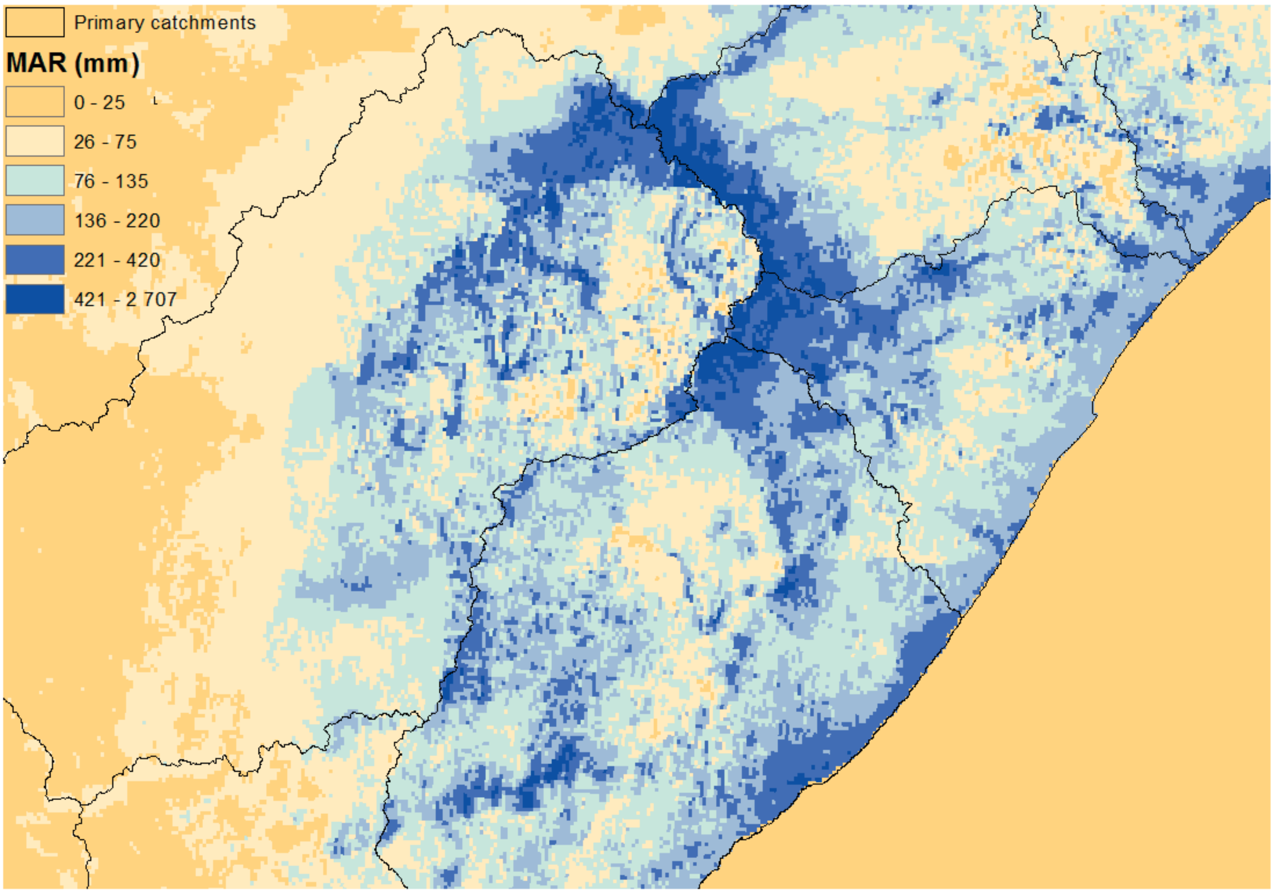

Figure 24: A portion of the Drakensberg in KwaZulu-Natal showing the raw cell-level MAR data using the classes defined for the 2013 study. All cells with ≥135 mm meet the threshold for inclusion in a SWSA-sw.

The next step was to compare how the inclusion of cells with a MAR that meets the threshold and exclusion of those that fall below the threshold varies with kernel density radius (Figure 26). For this comparison we used polygons generated with the 2013 single MAR threshold and with the two MAR thresholds chosen for this assessment (only the latter are shown here). Kernel density polygons with all the different radiuses included a small percentage of low MAR cells (e.g. <75 mm). This is typically due to steep rainfall and, thus, MAR gradients like those found on the inland slopes of the Western Cape mountain ranges. Since the aim of this assessment is to include high MAR areas, this issue is not considered to be important. All the highest class (420-2707 mm) cells were included except for the 12 km and default radiuses which dropped a single cell (0.04%). For the 220-420 mm class, only the 2 km radius included 100% with the maximum loss being 137 cells (1.35%) for the default radius. The 135-220 mm class shows steeper decline in its inclusion, with a 2 km radius excluding 451 cells (2.14%) and the default radius 2132 (21.49%). The 75-135 mm class shows the opposite trend as the increasing radius includes more of the lower MAR cells adjacent to clusters of those with a MAR exceeding the threshold. The ideal would be to include 100% of this range but even the 2 km radius excludes some of these because they are single cells which meet the threshold and none of those around them do. The 8 km radius included the greatest percentage of cells in the 135-220 mm MAR range while also generating a reasonable number of polygons.

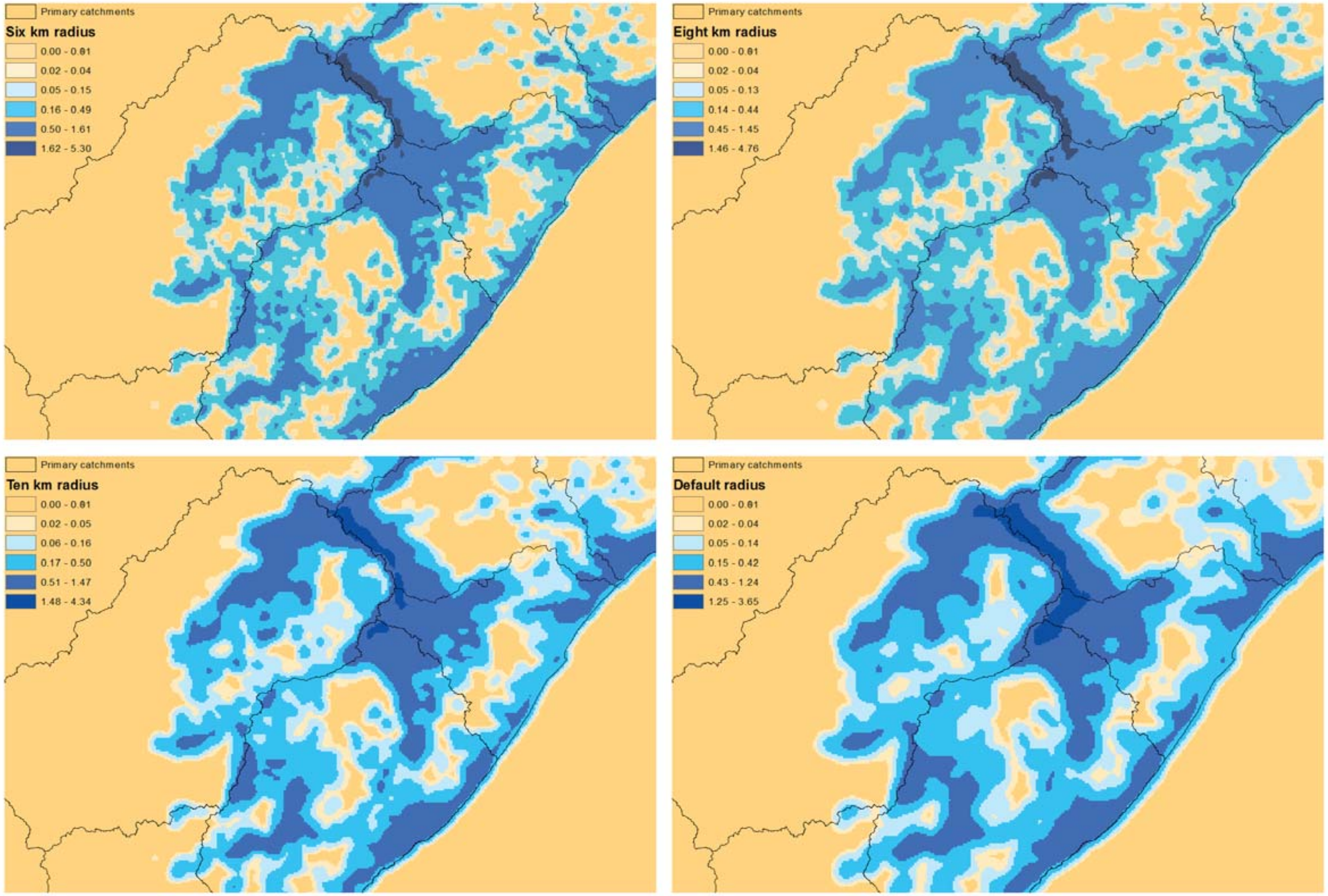

Figure 25: A portion of the Drakensberg in KwaZulu-Natal illustrating the effect of different kernel density radiuses on the density surface. The class boundaries are not the same because the range of density values differs but, because the class values are based on the geometric mean, they are comparable.

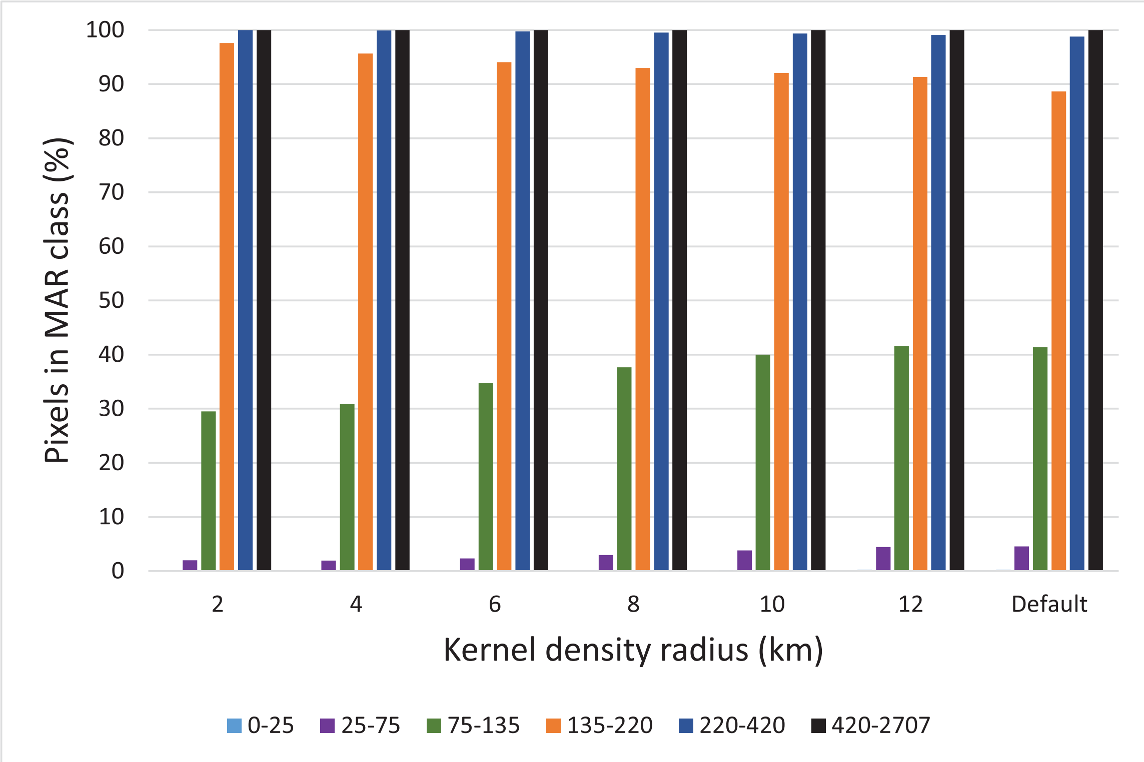

Figure 26: The relationship between the kernel density radiuses used to generate the polygons and the inclusion of cells in the different MAR classes defined for the 2013 study (Nel et al., 2013). A kernel density threshold of 0.14 was used for all the radiuses in this example.

Overall, a radius of 8 km for the kernel density function is the best option based on the number of polygons, the degree of generalisation, the exclusion of small clusters of cells exceeding the MAR thresholds, and the inclusion of the ≥135 mm cells.

The next step in the assessment was to choose an appropriate density threshold to ensure that the resulting polygons included at least 50% of the MAR. The first step in doing this was to try to match the 2013 cell-based delineation and identify the kernel density threshold which would most closely match the 50% of the MAR from 8% of the area of South Africa, Lesotho and Swaziland. This was done by generating a polygons for the following kernel density thresholds: 0.12 to 0.28 in steps of 0.02 (Table 7).

Table 7: The relationship between the kernel density threshold and the percentage of the MAR and the study area that was included. All the polygons were based on a kernel density radius of 8 km and the 2013 MAR threshold of ≥135 mm.

Kernel density threshold	MAR included (%)	Area included (%)
0.12	58.39	11.24
0.14	56.16	10.70
0.16	54.82	10.22
0.18	53.79	9.77
0.20	52.63	9.33
0.22	51.41	8.93
0.24	50.18	8.54
0.26	49.98	8.17
0.28	47.62	7.81

This analysis shows that for an 8 km kernel density radius, the kernel density threshold of 0.24 came closest to matching the 2013 definition of 50% of the MAR from 8% of the area. This gave us a starting point for a density threshold for the updated SWSA-sw.

Since the polygon data were generated from the MAR data which exceeded the updated thresholds (≥135 mm plus ≥75 mm in the Upper Vaal, Upper Usutu and Waterberg catchments), the resulting polygons would include all concentrations of high MAR. They were then modified to exclude sub-national WSA-sw, including the Pondoland Coast and Zululand Coast.

The third step in this assessment of the relationship between the kernel density threshold, and the inclusion of cells which exceeded the threshold MAR, examined two small SWSAs: the Swartberg which is a long and narrow mountain range; and the Waterberg which has two small areas with a MAR >75 mm. In both areas the proportion of cells included drops progressively more rapidly as the kernel density increases, particularly between 0.16 and 0.18 (Table 8). The loss of cells ≥135 mm for the Swartberg shows an increase as the density threshold is increased, especially from 0.20 onwards. But this is far less than for the default kernel density radius where only 37.5% were included at a density threshold of 0.20. The inclusion of cells ≥75 mm for the Waterberg declines more steeply than for the Swartberg, especially from 0.18 onwards. This is still better than it was for the default kernel density radius where only 43.4% of cells were included at a density threshold of 0.20.

Table 8: The relationship between the kernel density and the percentage of the cells which exceeded the MAR threshold in two of the smallest SWSA-sw.

SWSA	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24
Swartberg	93.33	92.59	91.85	91.85	89.63	87.41	85.93	80.00
Waterberg	90.84	88.24	85.29	81.05	74.18	64.38	55.23	48.37

Based on these three assessments, a kernel density radius of 8 km and a kernel density threshold of 0.12 was selected as providing an appropriate balance between inclusion and exclusion of high MAR areas, and thus for defining the boundaries of the consolidated SWSAs.

This value is obviously open to debate and different values could be applied in different SWSAs but we believe that it is an appropriate value to use at the national level, especially for the three SWSAs where areas were identified with a lower MAR threshold of >75 mm.

The results show that the consolidated SWSAs, excluding the eastern coast, form much more coherent grouping of the key surface water runoff generating areas (Figure 27). Where the new high MAR envelopes included more than one SWSA, they were divided using catchment boundaries to avoid fragmenting them unnecessarily. One example where the watershed was not used is the Upper Usutu SWSA which includes areas within the Upper Vaal. This SWSA includes the watershed between these two rivers' catchments rather than attempting to split them exactly along the divide. Even where the divide is the watershed, management and protection interventions should focus on protecting the integrity of the whole high MAR area rather than on the particular catchments.

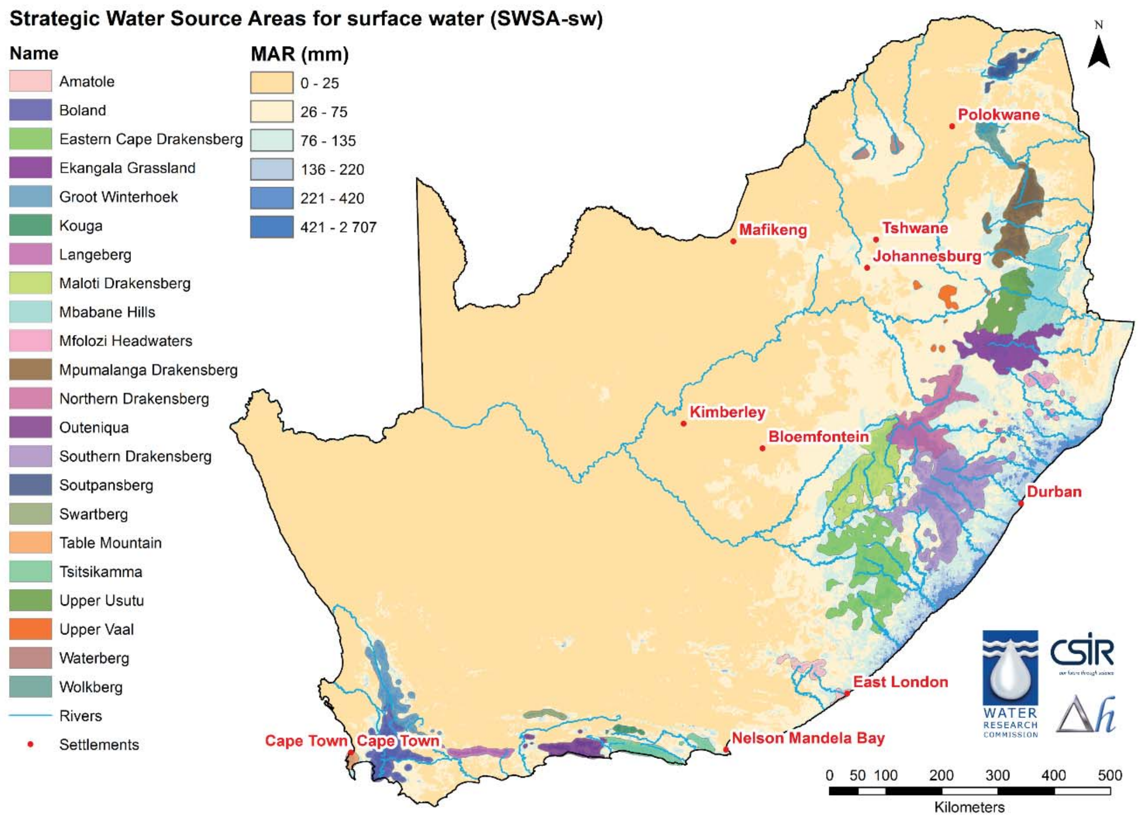

Figure 27: The new SWSA-sw based on the kernel density threshold and the use of catchment boundaries to divide them where a continuous envelope covered more than one SWSA. The Pondoland and Zululand Coast SWSAs (see Figure 1) have been excluded from the national SWSA-sw as described in Section 2.2 (see Figure 22).

4. COMBINING SURFACE WATER AND GROUNDWATER SOURCE AREAS AS STRATEGIC WSAs

The revised SWSA-sw (Section 3) have been combined with the newly identified SWSA-gw (see Section 2). Both surface runoff and groundwater recharge are positively related to rainfall so they too are closely related. This results in a close spatial correspondence or overlap between areas of land with a MAR of >135 mm (i.e. accounting for 50% of the total MAR) and areas with a recharge >65 mm (i.e. accounting for 50% of the recharge, criterion 1 for definition of SWSA-gw). Where there are overlaps between SWSA for surface water and for groundwater, the outer boundary should be used to define the important areas for protection. Every one of the nine Water Management Areas has a substantial number of SWSAs to take account of in their planning for the protection of water sources, whether for the protection of ground water, surface water, or both (Figure 28). The Eastern Cape, Southern and Northern Drakensberg SWSA-sw are all transboundary SWSA-sw and the Maloti Drakensberg SWSA-sw falls almost entirely within Lesotho. So much of their protection, which is vital for all the downstream water-users and ecosystems, can only be realised through close inter-governmental negotiation and co-operation with the Lesotho government. The same applies to Swaziland where the Mbabane Hills SWSA-sw falls largely within Swaziland but crosses the border in South Africa. The Upper Usutu SWSA-sw also extends into Swaziland and needs inter-governmental measures for its protection.

SWSA-gw could not be defined for Lesotho or Swaziland because the data used to inform criterion 3, 4 and 5 do not extend to Lesotho or Swaziland. So only the Strategic Water Source Areas for surface water extend into Lesotho and Swaziland although is it clear from the recharge data that these areas generally meet criterion 1 (recharge >65 mm/a). The SWSA-sw are retained in these two countries because they are considered nationally important for South Africa, especially those in Lesotho which supply water to Gauteng and to the Orange River.

The total mean annual runoff (MAR) for the study area, including Lesotho and Swaziland, was estimated to be 49 251 million m^3/a by the WR2012 study (Bailey and Pitman, 2015a), slightly up on the previous estimate of 49 210 million m^3/a by the WR90 study (Middleton and Bailey, 2008). The MAR data used in the original analysis, which found that 8% of the area generated 50% of the runoff, which was adjusted to compare with the WR90 study (Nel et al., 2013a), gives a total of 49 520 million m^3/a, just 0.5% more, so we have used this total in calculating the surface water statistics in this report.

The result of combining the surface and ground water is a set of water source areas which are important for both surface and groundwater.

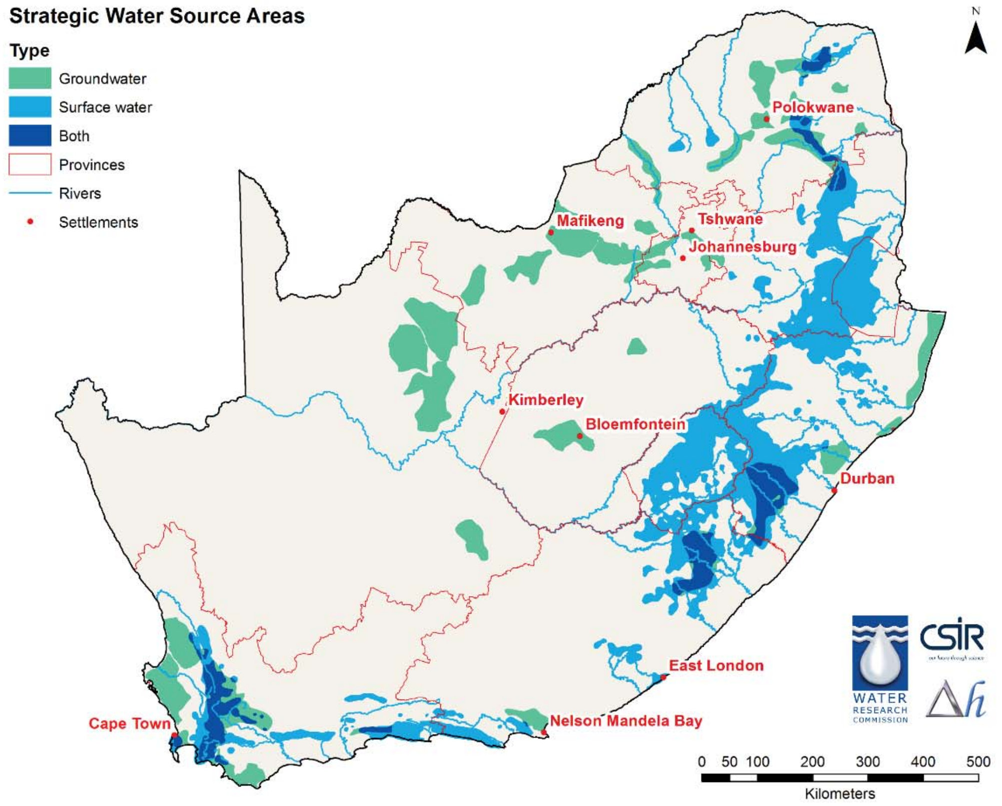

Figure 28: The new national and transboundary Strategic Water Source Areas as defined by this assessment. The portions of these areas falling within Lesotho and Swaziland have been included.

4.1 Summary for surface water SWSAs

The total area of the national SWSA-sw in the region is 124 075 km^2 (10% of the region) and provide a MAR of 24 954 million m^3 (50% of the total). With the addition of the sub-nationally important Pondoland Coast and Zululand Coast SWSA-sw, they cover about 148 478 km^2 (12% of the area) and provide a MAR of 29 354 million m^3 (59% of the total) (Table 9). If the contributions of the SWSA-sw within Lesotho and Swaziland are excluded, the updated SWSA-sw now cover about 96 129 km^2 (8% of the area) and provide a MAR of 19 379 million m^3 (39% of the national volume). The greatest volume of MAR is generated by the Southern Drakensberg (9% of national and transboundary MAR), followed by the Eastern Cape Drakensberg and the Boland, but the Boland has the highest MAR per ha followed by Table Mountain and the Northern Drakensberg.

The areas of the SWSA-sw within Lesotho and Swaziland are 18 570 and 9 376 km^2, respectively. The total MAR for Lesotho is about 4 445 million m^3 and the portions of the SWSAs that fall within Lesotho (Eastern Cape, Southern, Northern and Maloti Drakensberg, totalling 61% of Lesotho's area) generate about 3 522 million m^3 or 79% of that county's MAR. In the case of Swaziland, the total MAR is about 2 465 million m^3 and the portions of the SWSAs within this country (Enkangala Drakensberg, Mbabane Hills, Upper Usutu, totalling 54% of the country's area) generate 2 053 million m^3 or 83% of the total MAR. These SWSA-sw generate a MAR of about 3 522 million m^3, about 79% of its total MAR. In total 27 913 km^2 of the SWSA-sw fall within these two countries and account for about 5 575 million m^3/a or about 11% of the three countries' MAR.

Table 9: Summary of the updated surface water SWSAs for South Africa only with the estimated pre-development MAR (total and per unit area volume) and their extent.

Name	MAR (million m^3)	Percent of national MAR	MAR (m^3 per ha)	Area (km^2)
Amatole	333	0.67	1662	2 001
Boland	2 182	4.41	3588	6 083
Eastern Cape Drakensberg	2 673	5.40	1671	15 997
Enkangala Drakensberg	1 412	2.85	1646	8 582
Groot Winterhoek	1 002	2.02	1931	5 191
Kouga	77	0.16	1262	613
Langeberg	343	0.69	1989	1722
Maloti Drakensberg	2232	4.51	1859	12 003
Mbabane Hills	2237	4.52	2234	10 015
Mfolozi Headwaters	277	0.56	1438	1 925
Mpumalanga Drakensberg	1 929	3.90	2304	8 374
Northern Drakensberg	2 448	4.94	2376	10 302
Outeniqua	580	1.17	1929	3 005
Southern Drakensberg	4 317	8.72	2135	20 225
Soutpansberg	532	1.07	2267	2 345
Swartberg	96	0.19	1239	775
Table Mountain	127	0.26	2730	465
Tsitsikamma	708	1.43	2203	3 213
Upper Usutu	722	1.46	1166	6 191
Upper Vaal	122	0.25	872	1 401
Waterberg	99	0.20	957	1 033
Wolkberg	506	1.02	1937	2 614
Total	24 954	50.39	2011	124 075
South Africa	49 520		391	1 267 814

4.2 Summary for SWSA-gw

The total recharge for South Africa was estimated to be 34 912 million m^3/a (Table 1) (DWAF, 2006a) and the SWSA-gw generate only 5397 million m^3/a (15%). The average contribution to national recharge of each of the 37 SWSA-gw is relatively small, varying from less than 0.01% to more than 2.3% (Table 10). The greatest volume of recharge was for the Ixopo/Kokstad SWSA-gw, followed by the Southwestern Cape Ranges, followed by the Transkei Middleveld, and the Northern Lowveld Escarpment (Figure 29).

Table 10: Summary of the SWSA-gw for South Africa with the estimated recharge, and relative contribution to national recharge.

Name	Recharge (million m^3/a)	Area (km^2)	National recharge (%)
Bo-Molopo Karst Belt	5268	144.8	0.4%

Name	Recharge (million m³/a)	Area (km²)	National recharge (%)
Cape Peninsula and Cape Flats	599	59.5	0.2%
Central Pan Belt	3368	53.6	0.2%
Coega TMG Aquifer	1682	32.3	0.1%
Crocodile River Valley	2163	38.9	0.1%
De Aar Region	2475	32.5	0.1%
Eastern Kalahari A	2010	26.4	0.1%
Eastern Kalahari B	2656	37.8	0.1%
Eastern Karst Belt	1984	108.1	0.3%
Far West Karst Region	1382	65.8	0.2%
George and Outeniqua	727	95.8	0.3%
Giyani	438	5.3	0.0%
Ixopo/Kokstad	7150	792.2	2.3%
Kroondal/Marikana	795	24.4	0.1%
Kroonstad	799	11.7	0.0%
KwaDukuza	2352	177.0	0.5%
Letaba Escarpment	2151	165.5	0.5%
Northern Ghaap Plateau	6274	82.6	0.2%
Northern Lowveld Escarpment	5168	457.6	1.3%
Northwestern Cape Ranges	3638	287.7	0.8%
Nyl and Dorps River Valley	2036	57.5	0.2%
Overberg Region	2261	71.6	0.2%
Phalaborwa	433	3.9	0.0%
Richards Bay GW Fed Estuary	606	91.5	0.3%
Sandveld	4010	85.9	0.2%
Sishen/Kathu	4827	40.9	0.1%
Southern Ghaap Plateau	6542	67.6	0.2%
Southwestern Cape Ranges	2749	629.5	1.8%
Soutpansberg	2573	247.2	0.7%
Transkei Middleveld	5607	555.0	1.6%
Tulbagh-Ashton Valley	3560	184.3	0.5%
Upper Sand (Polokwane) Aquifer System	966	16.5	0.0%
Ventersdorp/Schoonspruit Karst Belt	2875	114.8	0.3%
Vivo-Dendron	2555	14.5	0.0%
West Coast Aquifer	4586	106.2	0.3%
Westrand Karst Belt	1090	63.3	0.2%
Zululand Coastal Plain	3305	347.2	1.0%

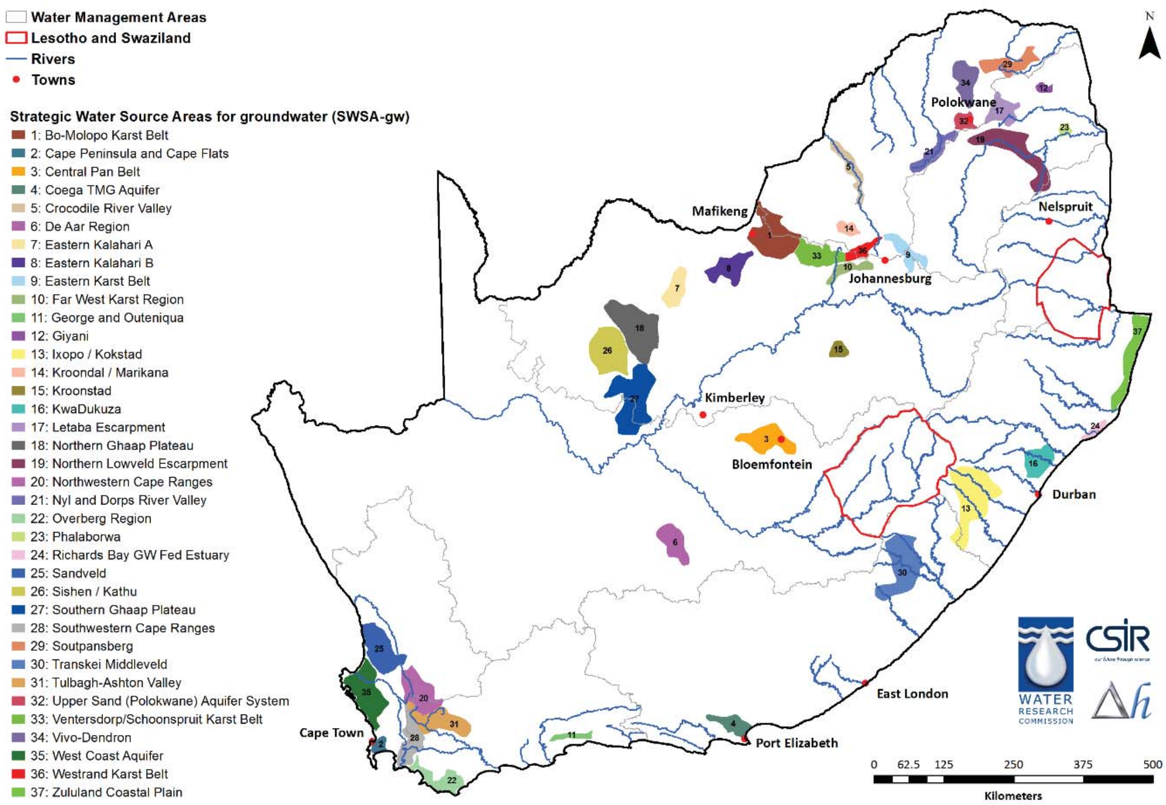

Figure 29: The national Strategic Water Source Areas for groundwater as defined by this assessment. Strategic Water Source Areas for groundwater were not identified in Lesotho and Swaziland because suitable data were not available.

5. AN INTRODUCTION TO WATER SOURCE AREAS

5.1 Background and Overview of Water Source Areas

Water source areas are places or areas, such as water catchments, which produce disproportionately greater volumes of water per unit area than other areas (Jobbágy et al., 2011; Messerli et al., 2004; Meybeck et al., 2001; Viviroli et al., 2007; Viviroli and Weingartner, 2004). One of the key features of these areas is that they are the sources of the largest and longest rivers in the world including the Amazon, Congo, Ganges, Indus and Nile Rivers, and even our own Orange River. The water from those headwater catchments flows downstream sustaining human livelihoods and for 100s of kilometres downstream, often in other countries, but often being placed at risk by human interventions and climate change (Conway, 2017; Nobre et al., 2016; Palmer et al., 2009; Senay et al., 2014; Winemiller et al., 2016).

The reasons for high water production include climatic conditions like high rainfall, or physical properties such as the ability of the soils and underlying weathered material and rocks to store water as groundwater (Soulsby et al., 2011). The water in wetlands, streams and rivers is known as surface water or runoff, and large volumes are typically generated in high rainfall areas over the period of a year. Water in saturated layers or zones below the land surface is known as groundwater and discharges or outflows of groundwater sustain springs and river flows in the dry season (Hughes, 2004; Le Maitre and Colvin, 2008; Tetzlaff and Soulsby, 2008). High rainfall areas with a substantial water storage capacity are particularly important because they continue to produce water during dry seasons and droughts, which is critical for people who depend directly on rivers for their water and for other ecosystem services (Brauman et al., 2007; Harrison et al., 2016; Jobbágy et al., 2011; Nel et al., 2017). The importance of South Africa's mountain catchments as water sources, and of protecting them so that they would continue to provide large volumes of high quality water was recognised in the 1800s (Beinart, 1984; Bennett and Kruger, 2014). Large areas of South Africa's mountain landscapes were kept as state land and protected as Mountain Catchment Areas for the protection of water resources with conservation of biodiversity only becoming a goal much later.

Recognition of the hydrological services provided by mountain catchments and the adverse impacts of human activities has motivated downstream water-users to develop ways of paying for their protection and restoration, sometimes called payments for ecosystem services (Blanchard et al., 2015; Chichilnisky and Heal, 1998; Cosman et al., 2011; García-Llorente et al., 2016; Grima et al., 2016; Locatelli and Vignola, 2009; Roumasset and Wada, 2013). Similar approaches have been proposed for protecting water source areas in South Africa (Blignaut et al., 2008; Mander et al., 2010; Nel et al., 2011; Turpie et al., 2008) but they need to be approached with caution and based on sound evidence (Grima et al., 2016; Kinzig et al., 2011; Naeem et al., 2015; Polasky et al., 2014; Sánchez-Azofeifa et al., 2007). One of the aims of the this report is to identify and provide some evidence of the importance of South Africa's water source areas as motivation for effective protection.

5.2 Water Source Areas and the Water-Cycle

The water-cycle describes the ways in water is exchanged between the atmosphere and the earth's surface and sub-surface. Water that evaporates from the earth's surface, whether from open water such as rivers, lakes and the oceans, or vegetated areas, soil and rocks, condenses again to form clouds. The clouds then release their water as precipitation – which can be in the form of dew, captured mist or fog droplets, rainfall or snow – back to the earth (Figure 30). Water that infiltrates into the soil percolates through it and either flows out to rivers and wetlands (as interflow, or from perched groundwater systems) or continues downwards to the water table where it replenishes or recharges the aquifers. Groundwater flows under the surface from recharge areas (which may extend across an entire aquifer in the case of unconfined aquifers like the one shown in Figure 30) till it reaches a discharge point, which may be discharge to surface water in springs, streams and rivers. Groundwater plays an important role in sustaining our perennial (always flowing) rivers through groundwater discharges into rivers ("groundwater fed baseflow"). The travel time for groundwater is significantly greater than for surface water; water that recharges one year may discharge several years, even hundreds of years later. As such, groundwater's discharge to surface water can be significant in maintaining surface water flows during droughts when rainfall related runoff is limited or nil.

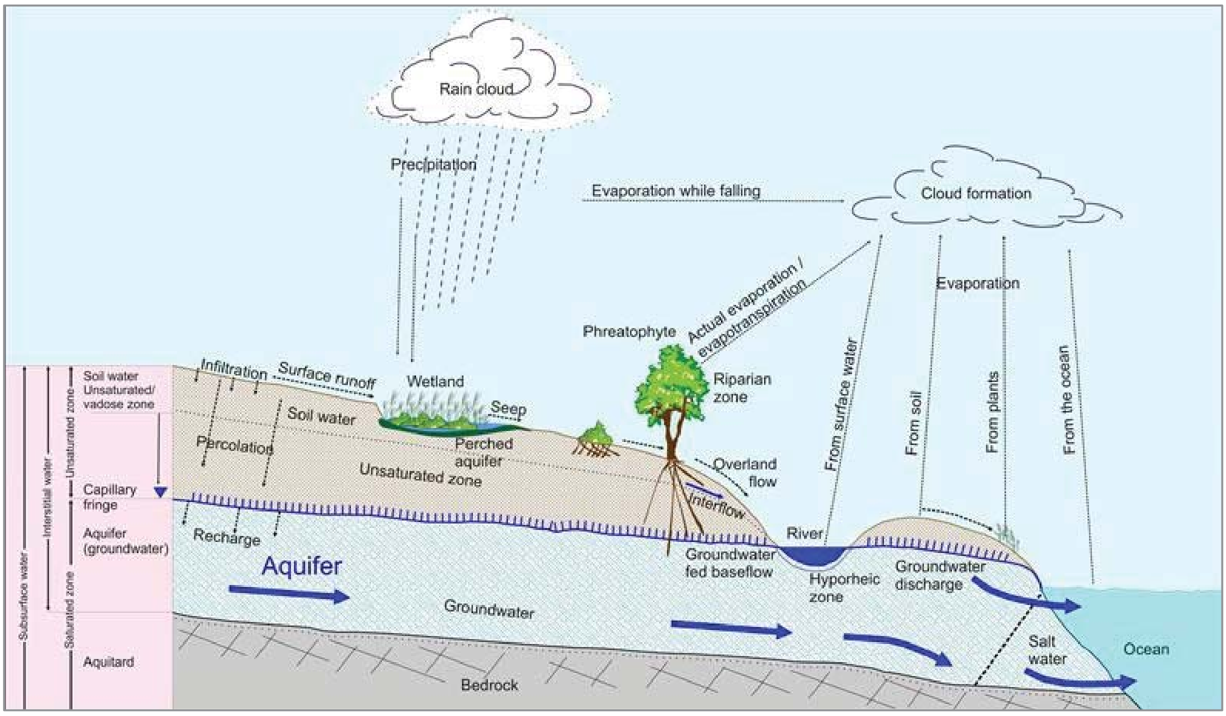

Figure 30: The water cycle illustrating surface water-groundwater connections and flows with the example of an unconfined aquifer underlain by impermeable bedrock (Credited to CSIR 2004 in http://www.limpopo.riverawarenesskit.org)

Land management practices and land cover changes, even well away from any obvious body of water, can have effects elsewhere and, potentially, 100s of kilometres away (Dabrowski et al., 2013; McDonald et al., 2016; Scanlon et al., 2007, 2005). The Orange River is a good example. Much of the water that is transferred from dams in Lesotho to Gauteng, is not available to towns and farming communities downstream on the Orange River. Similarly, sediment or chemicals released into a river at one point can affect all the people downstream.

5.3 Potential human impacts on water quantity and quality

This section is not intended to provide an exhaustive description of human impacts but identifies key impacts associated with land-cover and the related land-use practices as background for Section 7 of the report on impacts and threats to water source areas.

5.3.1 Land cover and water quantity

The amount of rainwater which becomes stream flows or groundwater recharge depends on several factors, including the characteristics of the land and the vegetation growing on it because they affect evaporation (including transpiration) and infiltration (Brauman et al., 2007; Calder, 2005; Postel and Thompson Jr., 2005). Generally, tall, evergreen trees use more water than seasonal grasslands, particularly because they continue using water when the grasses are dormant (Everson et al., 2011; Zhang et al., 2001). All the widely planted forest plantation species in South Africa are evergreen, and the additional water they use is the reason why afforestation is regulated as a stream-flow reduction activity under the national Water Act (Bosch and Von Gadow, 1990; Dye and Versfeld, 2007). Many of these plantation trees species have become invaders, together with a range of other species, and these invasions are resulting in significant reductions in the mean annual runoff (MAR) (Le Maitre et al., 2016, 2015).

A number of crop species in dryland agriculture have been evaluated as potential stream-flow reduction activities (e.g. sugar cane) but none have been shown to significantly reduce the MAR from planted lands. Most dryland crop species have shorter growing seasons than the natural vegetation and almost certainly use less water than the native vegetation, so dryland cultivation tends to increase the MAR. Irrigated agriculture typically increases the water-use per unit area because the farmers typically maintain the soil moisture as levels which are optimal, or even exceed optimal, for crop growth (DWAF, 2010; Singels et al., 2008). This water is typically supplied by dams or by pumping directly from river systems and so results in reduced river flows downstream. Overall, irrigated agriculture accounts for about 60% of all the available water in South Africa (DWAF, 2013; Van Rooyen and Versfeld, 2010) but it also produces food crops which are essential for food security and significant earners of foreign exchange (Blignaut et al., 2015; Stuart-Hill and Schulze, 2015; Swilling et al., 2016; Wenhold et al., 2007). Nevertheless, the large volumes used provide a strong motivation for investing in water-use efficient irrigation systems (Brauman et al., 2013).

5.3.2 Land cover and water quality

Impacts on water quality can be grouped into three broad classes: those involving the addition of chemical compounds and elements, those involving increases in suspended and transported sediments, and those involving living organisms (water-borne diseases, parasites and pathogens). The chemical additions can, in turn, be divided into those which are key nutrients that enhance the growth of organisms (e.g. nitrogen, phosphorus) and others which have varying effects on the health of organisms and people using the water (e.g. are toxic, alter hormone production) (Genthe et al., 2013). In addition there is pollution with solid waste, such as plastics, but this falls largely outside the scope of this study except to note that it is largely associated with urban areas, especially those lacking effective waste disposal systems.

The quality of the water in South Africa’s river systems has been deteriorating for a long time, but has been exacerbated by the failure of many municipalities to maintain or upgrade their water-water treatments plants, stormwater management systems and regulate other point-sources of pollutants (CSIR, 2011; NPC, 2011; Sershen et al., 2016). The focus of this study is mainly on the many other linkages between land-cover and land-use management practices and diffuse sources of factors that alter water quality, the main one being agricultural chemicals (Falkenmark and Galaz, 2007; Scanlon et al., 2007).

Dryland agriculture typically is characterised by low profit margins and, thus, by limited use of fertilisers and agrochemicals so the main impacts on water quality are through soil loss associated with poor tillage practices (Le Roux et al., 2007; Love et al., 2006). Nevertheless, there is evidence that some of these chemicals could be harmful (Dabrowski, 2015). Where the geology and hence groundwater underlying the area has naturally higher levels of salts, this salinity can be enhanced by the dryland cultivation and management practices. The removal of naturally deeper rooted and evergreen vegetation can cause a rise in groundwater levels which mobilises salts stored in the unsaturated zone (De Clercq et al., 2010; Flugel, 1991; Kamish, 2008). This in turn allows the saline water to discharge as interflow (which seeps through the unsaturated zone), or as baseflow into rivers, increasing their salinity.

Irrigated agriculture is typically much more intensive than dryland agriculture, and involves agro-chemicals for controlling weeds and pests as well as fertilisation (Ashton and Dabrowski, 2011; CSIR, 2011; Dabrowski et al., 2013; Dabrowski, 2015; Scanlon et al., 2007; Twomlow et al., 2008; Van Rooyen and Versfeld, 2010). Pollution of neighbouring water bodies and water courses by overspray and through sub-surface water return flows are the main ways in which irrigated agriculture affects water quality in rivers and in groundwater. Long-term crops like vineyards and orchards typically require less intensive inputs than short-term crops like vegetables but some deciduous fruits (e.g. apples) may require intensive pest control. Growing pressure from consumers, environmental bodies and regulatory organisations, as well as increasing costs, are resulting in reduced agrochemical inputs, but irrigated agriculture is still a key source of water pollution through return flows (CSIR, 2011; Lemley et al., 2014). Increased nutrient levels in rivers and other water bodies can lead to algal blooms which can become toxic if cyanobacteria are involved (CSIR, 2011; Oberholster and Botha, 2011). Elevated nitrate concentrations, for example in groundwater surrounding agricultural areas, are a well-known phenomenon. At the same time, groundwater and surface water extraction for irrigation tends to reduce the flow in the rivers downstream and so the reduced flows may not dilute the pollutants sufficiently to achieve the limits specified for acceptable water quality for different purposes. One study found that the volumes of water needed to obtain adequate dilution of return flows can exceed the quantity of water applied during the irrigation (Dabrowski et al., 2009).

Mining can also have significant impacts on water quality, through unmanaged point discharges (e.g. from tailings dams) and through various groundwater impacts, particularly the generation of acid mine drainage (AMD) (Ashton and Dabrowski, 2011; Dabrowski et al., 2015; McCarthy, 2011; Oberholster et al., 2016). The dewatering of mines, and the disturbance of the rock formations, exposes rocks to the atmosphere enabling oxidation of minerals (particularly iron sulphides and pyrites). On cessation or reduction in pumping, groundwater tables rise, and groundwater flows through the acidic rock and so generating acidic water. The acidity in the AMD increases the solubility of aluminium and heavy metals and this polluted water may decant to, or is discharged into, surface waters where it can have significant impacts on human and aquatic ecosystem health as well as being very expensive to treat (McCarthy, 2011; Naidoo, 2015). Where this water is already polluted with nutrients and other compounds, the effects of the combinations of these chemical and compounds on ecosystems and on human health can be severe (Genthe et al., 2013; John et al., 2014). Furthermore there is a risk that discharges of AMD will reach the karst groundwater systems in the Gauteng region, thus endangering the water quality in the most significant aquifer systems in South Africa, in terms of human dependence (Hobbs 2015).

Increases in the sediment levels in water bodies due to land degradation or poor cultivation and road construction and design also affect water quality, increase turbidity and can result in sedimentation and the loss of storage capacity in dams (Laker, 2004; Le Roux et al., 2008; Msadala et al., 2010; Owens, 2005). Sediments are a normal and integral part of riverine ecosystems and these ecosystems are adapted to ranges of spatial and temporal sediment dynamics. When increases exceed these levels then they will have adverse impacts on these ecosystems as well as increasing the cost of water treatment and filling dams

(Collins et al., 2011; Dabrowski et al., 2013; Jeleni et al., 2013; Owens, 2005). Soil losses as a result of vegetation degradation have had significant adverse impacts on land productivity and society (Beinart, 1984; Hoffman and Todd, 2000).

Forest plantations can experience high sediment losses during tree harvesting as well as from poorly designed roads (Scott et al., 1998), but these factors can be mitigated by adherence to environmental guidelines and road construction standards (Forestry Industry Environmental Committee, 2002). There are also best practice manuals and guidelines for minimising soil loss from cultivated lands and rangelands which can be recommended under South African conditions (Coetzee, 2005; Esler et al., 2010; Tainton, 1999). Soil conservation practices can often be combined with water harvesting to increase crop productivity, reduce drought risk and increase food security (Rockström et al., 2009).

The sensitivity of water bodies to impacts also varies across South Africa due to the nature of the geological formations and the soils that are formed from them, particularly in the natural levels of nutrients and fine sediments (Dallas and Day, 1993; Malan and Day, 2012, 2005). The dark, brown waters produced by the sandstones of the Table Mountain Group, are very low in nutrients (Midgley and Schafer, 1992) and typically lack, or have very low levels of, fine sediments. This means that they have very limited capacity to absorb or buffer nutrients, quickly reaching levels which result in algal blooms (Oberholster et al., 2013). The basement rocks (e.g. granites, basalts) tend to be low in dissolved ions but can have fine sediments (Dallas and Day, 1993). The Karoo rocks were formed from fine sediments, often from marine origin, and tend to have higher salt and nutrient contents as well as producing fine sediments which provide a greater buffering capacity. Waters from the dolomites are typically alkaline with high concentrations magnesium and carbonates. Extra care needs to be taken in the sensitive environments such as the Table Mountain Group sandstones to ensure that impacts on water quality are minimised.

6. LINKING STRATEGIC WATER SOURCE AREAS TO BENEFICIARIES

6.1 Surface water as a beneficiary of groundwater discharge

All of the SWSA-sw coincide with either a SWSA-gw, or at least areas meeting criteria 1 or 2 (high groundwater recharge) (Figure 31). Rainfall is the dominant controlling factor in the recharge dataset used, and rainfall is the dominant control on runoff, so the co-occurrence of high recharge and SWSA-sw is to be expected. The SWSA-sw are all located where baseflow is at least 11-25 mm/a, indicating an enhanced link between groundwater and surface water at the SWSA-sw. Therefore it is safe to assume that aquifers in areas of high groundwater recharge are providing (some) discharge to surface water within their vicinity, contributing to runoff and, thus to relatively high MAR in surface water source areas, and especially to dry season flows.

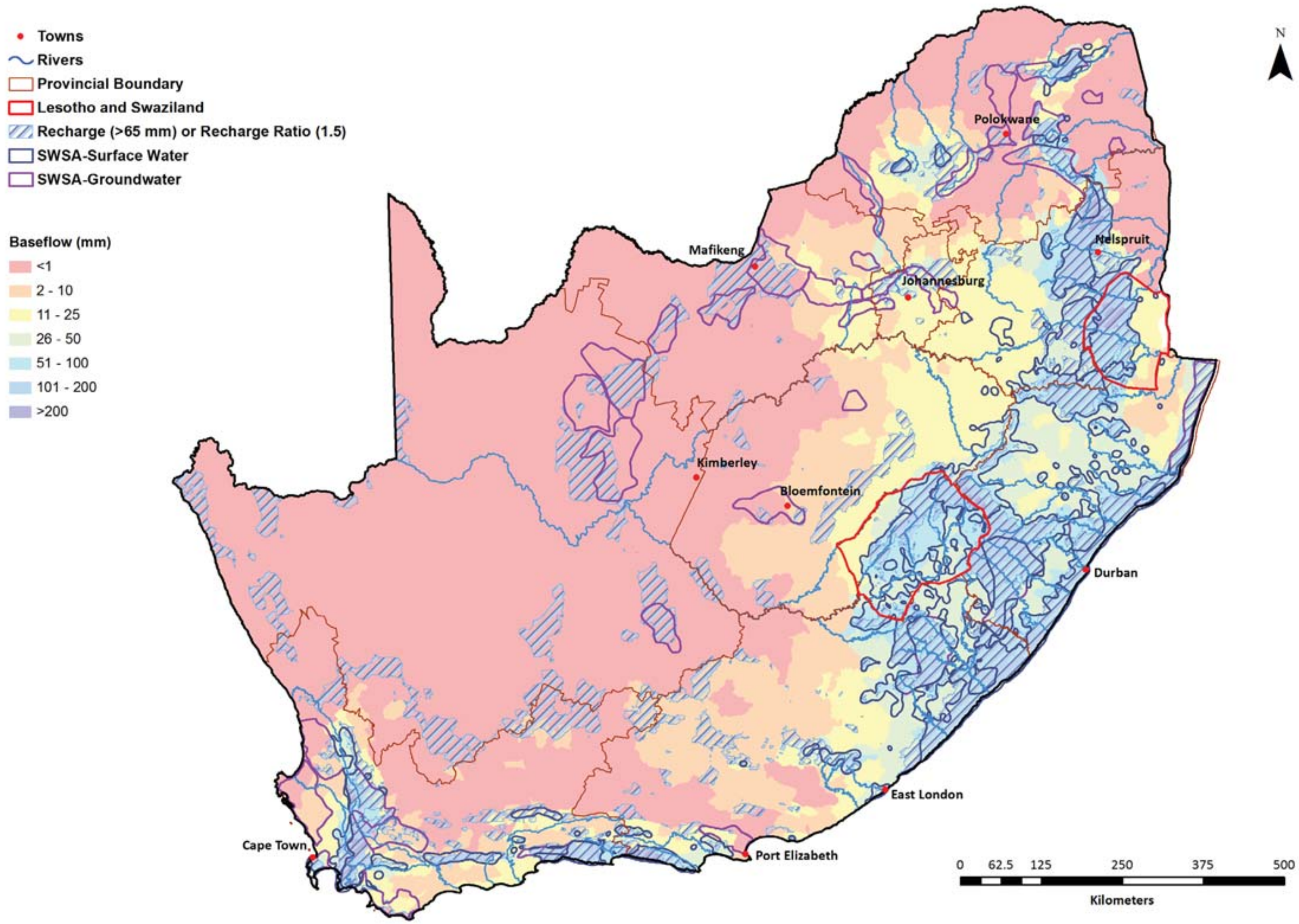

Figure 31: The relationship between Strategic Water Source Areas for groundwater and river baseflow (Vegter, 1995)

To assess the degree to which each of the SWSA-sw receives its runoff from baseflow, as an indicator of benefits to SWSA-sw from groundwater, the sum of baseflow was compared to the sum of runoff as a percent, in each SWSA-sw (Table 11). This analysis is highly simplified, as runoff within a SWSA-sw may include significant baseflow from upstream of the area which is not part of this calculation. Baseflow also contains a portion derived from interflow, and a portion from groundwater. Nevertheless, the data suggests a potentially significant contribution from groundwater to SWSA-sw:

- Sixteen (out of 22) of the SWSA-sw derive >10% of their water from groundwater
- The highest contribution (21%) is reached in Mpumalanga Drakensberg

Although groundwater contribution to baseflow can be theoretically distinguished from surface water derived from interflow and runoff, in practice, they are simply different pathways by which river flows are generated. Groundwater is generally the source of all rivers (springs) and maintains the flows during the dry season so protection of surface water requires some protection of the groundwater contribution to baseflow. Given this, SWSA-sw should be considered as areas within which both the surface water and groundwater contribution to baseflow should be protected.

Table 11: Groundwater contribution to the SWSA-sw (through analysis of baseflow as a % runoff)

SWSA-sw	Baseflow/MAR %
Mpumalanga Drakensberg	20.6%
Upper Usutu	18.9%
Outeniqua	18.9%
Wolkberg	17.9%
Mbabane Hills	17.6%
Tsitsikamma	16.2%
Enkangala Grassland	14.9%
Langeberg	14.4%
Maloti Drakensberg	13.9%
Southern Drakensberg	13.4%
Eastern Cape Drakensberg	12.7%
Soutpansberg	12.7%
Waterberg	12.4%
Boland	12.1%
Northern Drakensberg	12.1%
Mfolozi Headwaters	10.9%
Amatole	9.7%
Table Mountain	9.4%
Groot Winterhoek	7.4%
Upper Vaal	7.4%
Kouga	6.1%
Swartberg	3.7%

Most of the SWSA-gw do not overlap SWSA-sw because their delineation is based on the coincidence of high recharge and high groundwater use, not based on high recharge only. This illustrates the importance of regional groundwater recharge (a proxy for groundwater availability), and the lack of other water sources, as relevant factors in determining where groundwater use is significant. Nevertheless, these SWSA-gw will still be supporting surface water through natural discharge. The baseflow generated within each SWSA-gw amounts to an appreciable percentage of the mean annual runoff within the SWSA-gw (Table 12). This analysis may underestimate the contribution to surface water because aquifers within the SWSA-gw may discharge to surface water outside of the SWSA-gw. There also are significant simplifications in the quaternary catchment level baseflow data available for analysis. Nevertheless, it does provide a useful indication of the contribution. In certain areas, where there is significant groundwater discharge to baseflow even though the rainfall and runoff are not particularly high, the resulting percentage contribution is high: for example the Far West Karst Region, Kroondal/Marikana and Westrand Karst Belt (all above 20% baseflow/MAR). Each of these groundwater source areas is associated with karstic aquifers and, thus, significant recharge. Low percentage contributions arise in dry parts of the country where baseflow is considered to be zero or very low and rivers flow seasonally or ephemerally (i.e. much of the Karoo).

Table 12: Groundwater contribution from SWSA-gw to surface water (through analysis of baseflow as a % runoff)

SWSA-gw	Baseflow/MAR %
Far West Karst Region	42.0%
Kroondal/Marikana	25.7%
Westrand Karst Belt	21.8%
Eastern Karst Belt	19.1%
Northern Lowveld Escarpment	18.5%
Ventersdorp/Schoonspruit Karst Belt	16.0%
Zululand Coastal Plain	15.7%
George and Outeniqua	15.6%
Richards Bay GW Fed Lakes	15.2%
Transkei Middleveld	15.1%
Ixopo/Kokstad	14.9%
KwaDukuza	14.8%
Letaba Escarpment	14.5%
Soutpansberg	14.4%
Nyl and Dorps River Valley	13.5%
Southwestern Cape Ranges	11.7%
Northwestern Cape Ranges	11.5%
Tulbagh-Ashton Valley	11.4%
Overberg Region	11.1%
Kroonstad	9.8%
West Coast Aquifer	9.1%
Crocodile River Valley	8.9%
Sandveld	8.0%
Coega TMG Aquifer	7.8%
Cape Peninsula and Cape Flats	7.3%
Bo-Molopo Karst Belt	5.3%
Eastern Kalahari A	2.7%
Central Pan Belt	1.8%
Southern Ghaap Plateau	0.6%
Eastern Kalahari B	0.6%
Vivo-Dendron	0.5%
Northern Ghaap Plateau	0.4%
Upper Sand (Polokwane) Aquifer System	0.4%
De Aar Region	0.0%
Giyani	0.0%
Phalaborwa	0.0%
Sishen/Kathu	0.0%

6.2 SWSA-gw serving urban and domestic use

Within the primary catchments, a river will have headwaters in the SWSA-sw of the upper catchment where runoff is high, which is generally dammed at some point, and used at significant distance downstream in urban areas, or even in a neighbouring catchment where inter-basin transfers occur. For surface water, the beneficiary and source can therefore be significantly disconnected, as is the case with Gauteng using water taken from Lesotho and Cape Town, which is in the Berg River catchment, using water which is transferred in from the Breede River catchment.

Most aquifers are not laterally extensive on a scale greater than a primary catchment, with hydraulic barriers such as dykes, faults, or less permeable formations forming a boundaries between one groundwater flow system and another. This means that groundwater use occurs mainly in the vicinity of the groundwater resource unit. In some cases though, aquifers are extensive and devoid of such barriers (i.e. parts of the Karoo). Even in these cases however, as groundwater travel time is long, and propagation of impact from abstraction is slow (propagation is dependent on aquifer diffusivity and duration of abstraction, not volume pumped), for planning purposes (within perhaps a 200 year period), the users can be presumed to be sourcing water relatively close to (on a national scale) the abstraction point. As people's use of groundwater has been included in the delineation of source areas, it is acceptable to assume that, in most cases, these areas are already linked to human users within them. Human use (i.e. beneficiaries) of the SWSA-gw was assessed via two means:

a) Assessing the ***population of towns that have sole***[3] ***groundwater municipal supply*** within the SWSA-gw boundaries (Table 13).

b) Determining the water supply in each of the 26 areas of national economic importance in the NWRS (DWAF, 2013), and calculating the portion derived from a SWSA, including groundwater and surface water (presented in Section 6.3 below). Conversely to a) above, this analysis includes all groundwater use by areas of national economic importance, not only sole supply (>50%).

Population data were taken from the All Towns dataset (DWA, 2012a) (Section 2.1.3) which were therein derived from census information and provided for a mix of 2013, 2014 and 2015 populations. The population data have several gaps, and the list of sole source towns also has great uncertainty, so the ***population figures should be seen as an approximation***.

Table 13: Municipal sole groundwater supply towns within SWSA-gw (SWSA-gw with no sole supply groundwater settlements are excluded in this list)

SWSA-gw	Study_Name[*1]	Population per town	Population per SWSA-gw
Bo-Molopo Karst Belt	Shiela Water Supply Scheme	57 783	327 125
	Wondermere-Slurry Water Supply Scheme Cluster	4 586	
	Boikhutso Base Supply Scheme	25 017	
	Dinokana Water Supply Scheme	49 570	
	Mafikeng Water Supply Scheme Cluster	167 470	
	Matikiring-Carlisonia Cluster	1 914	
	Zeerust Water Supply Area	20 785	

[3] Sole supply settlements are defined as those receiving >50% of their supply from groundwater

SWSA-gw	Study_Name[*1]	Population per town	Population per SWSA-gw
Central Pan Belt	Petrusburg Town Area	7 014	7 014
De Aar Region	De Aar Town	26 445	30 257
	Hanover Town	3 812	
Eastern Kalahari A	Tlhakgameng Cluster	18 488	18 488
Eastern Kalahari B	Atamelang Cluster	20 738	162 535
	Mofufutso Cluster	14 605	
	Driehoek-South Supply Scheme Cluster	55 186	
	Stella Town	5 202	
	Maipeng Cluster	8 785	
	Motsitlane Cluster	29 346	
	Old Kraaipan Cluster	9 974	
	Setlagoli Cluster	18 699	
Eastern Karst Belt	Delmas/Botleng and Eloff Sundra Cluster	48 868	48 868
Ixopo/Kokstad	Bulwer Donnybrook Water Supply Area	n/av	43 549
	Ixopo/Carisbrooke Water Supply Area	8433	
	Mahehle-Ncakubana Water Supply Area	n/av	
	Pakkies Water Supply Area	n/av	
	Pitela Water Supply Area	n/av	
	Kwanovuka Water Supply Area	n/av	
	Richmond Water Supply Scheme	35 116	
KwaDukuza	Hlimbitwa Water Supply Area	n/av	n/av
	Masibambisane Water Supply Area	n/av	
	Mushane Water Supply Area	n/av	
	Ozwathini Water Supply Area	n/av	
	Hlatikhulu Water Supply Area	n/av	
	Masihambisane Water Supply Area	n/av	
	Ntanzi Water Supply Area	n/av	
Letaba Escarpment	Sekgopo Groundwater Supply Scheme	25 638	25 638
Northern Ghaap Plateau	Kagung Cluster	5 141	106 559
	Kuruman Cluster	18 985	
	Sedibeng Cluster	6 218	
	Batlharos Cluster in the Lower Vaal	23 476	
	Moshaweng Ward 11	2 402	
	Moshaweng Ward 3	8 241	
	Moshaweng Ward 4	5 047	
	Moshaweng Ward 6	5 376	
	Moshaweng Ward 7	5 125	
	Moshaweng Ward 8	7 673	
	Mothibistad Cluster	18 875	
Northern Lowveld Escarpment	Mafefe Individual GWS Cluster	9 049	62 252
	Mathabatha Individual GWS Cluster	8 318	
	Blyde Local Sources Water Supply Scheme	17 530	
	Penge Water Scheme	6 396	
	Calais RWS Cluster	3 027	
	Lebalelo North Water Supply Scheme	7 893	
	Moremela Water Supply Scheme	10 039	
Northwestern Cape Ranges	Op Die Berg	1 049	5 185
	Prince Alfred Hamlet	4 136	

SWSA-gw	Study_Name[*1]	Population per town	Population per SWSA-gw
Nyl and Dorps River Valley	Mookgopong Regional Water Scheme	30 450	30 450
Overberg Region	Hermanus	53 936	78 429
	Stanford	5 083	
	Wolvengat	149	
	Bredasdorp	13 760	
	Elim	1 444	
	Napier	4 057	
Sandveld	Citrusdal	5 389	16 876
	Elandsbaai	1 782	
	Graafwater	1 969	
	Lamberts Bay	5 489	
	Leipoltdville	306	
	Eendekuil	1 055	
	Redelinghuys	886	
Sishen/Kathu	Dibeng in the Lower Vaal	7 538	24 711
	Kathu Town in the Lower Vaal	17 173	
Southern Ghaap Plateau	Campbell	1 662	44 149
	Griekwastad Town	5 604	
	Postmasburg Cluster	25 114	
	Danielskuil Town	11 769	
Soutpansberg	Matshavhawe Kunda Water Supply Area	n/av	n/av
	Mutale Main Water Supply Scheme Area	n/av	
	Nzhelele Makhado Regional Water Supply Scheme Area	n/av	
	Sinthumule Kutama Regional Water Supply Scheme Area	n/av	
	Valdezia Regional Water Supply Scheme Area	n/av	
	Vhembe Individual Water Supply Scheme Areas	n/av	
Transkei Middleveld	Engobo & Cluster 7 Villages	44 660	397 697
	Chris Hani Cluster 6 Villages	34 760	
	Elundini Rural 2	32 307	
	Elundini Rural 1	42 710	
	WSU 4a Tsolo, Qumbu and Villages	225 707	
	Alfred Nzo Cluster 3 Villages	17 553	
Tulbagh-Ashton Valley	Rawsonville	2 204	2 204
Upper Sand (Polokwane) Aquifer System	Moletje South Individual Groundwater Supply Scheme	12 442	12 442
Ventersdorp/Schoonspruit Karst Belt	Grootpan Water Supply Scheme	1 669	1 669
Vivo-Dendron	Buysdorp	1 687	1 687
West Coast Aquifer	Aurora	443	
	Atlantis	66 488	66 931
Zululand Coastal Plain	Mseleni Water Supply Area	19 500	43 211
	Mbazwana Water Supply Area	23 711	

[*1] Towns name refers to the name of the reconciliation strategy developed for this area under the DWS All Towns Reconciliation Strategy Study, hence in some areas is a name given to a cluster of villages or a rural scheme

Table 14: Summary of sole groundwater source (>50% supply) towns and population within SWSA-gw and nationally

Item	Count	Population
Sole GW source settlements within SWSA-gw	94 (24% of all sole GW source settlements, or 10% of all settlements)	1 127 042 (17% of the population within sole GW source settlements, or 2% of all South Africans)
All sole GW source settlements (Figure 15)	394 (41% of all settlements)	6 726 172 (12% of South Africans)
All South Africa[4]	966	54 000 000

Based on this analysis (Table 13 and Table 14):

- 12% of South Africa's population reside within sole groundwater supply towns or settlements
- 24% of these sole groundwater supply settlements lie within SWSA-gw areas (which increases to 32% if the sub-national WSA-gw are also included, statistics for which are shown in the Appendix 2 Section 10)

A number of patterns emerge from this analysis:

- Many settlements with sole groundwater supply are rural village clusters or small towns. Only 24% of these fall within SWSA-gw because the remainder do not coincide with areas of high groundwater availability.
- None of the 11 metropolitan municipalities have >50% groundwater supply (Table 2), hence the population within sole groundwater supply settlements is only a small proportion of the total population (12%)

The total population supported by groundwater to some degree, although <50% of the supply, is clearly significantly higher than the numbers shown in Table 13, and would include parts of several metropolitan areas (Cape Town, Port Elizabeth, Gauteng/ Pretoria).

This assessment includes municipal supply only, and a larger population would be incorporated if "off grid" private abstraction for domestic use within the SWSA-gw (and indeed across South Africa) was included. The Schedule 1 use, as registered in WARMS, was assessed to determine if (through application of a typical domestic use rate in l/capita/day) this could be translated to off-grid population supported. However the Schedule 1 registrations are not accurate enough to reflect domestic off-grid groundwater use; zero Schedule 1 registrations are recorded in some areas known for rural farmsteads with wind pump groundwater abstraction for domestic use. Conversely very high total volumes are listed under Schedule 1 in some other agricultural areas, where the use cannot be solely attributable to domestic use.

Areas where the assumptions regarding the groundwater source being local to position of use do not apply, include the karstic dolomites where travel times can be quick, and in the TMG where confined flow paths can be long. The karstic dolomite aquifer boundaries are well understood (DWA, 2009b), and where the SWSA-gw are associated with dolomite, aquifer compartments have been taken into account in the delineation. It was recognised at proposal stage that not all SWSA-gw could be linked to users, and not all

[4] South African population listed for 2014, in line with the data available for population per town (All Towns data, a mix of 2013, 2014 and 2015).

groundwater use could be linked to a source area that follows a groundwater resource unit, in a national scale mapping project. The proposed approach was to determine this link for “key areas”. The 26 areas of national economic importance (DWAF, 2013) were selected as key areas, and for each of these the groundwater resource unit supplying the town has been included as a SWSA-gw, so that use is linked to source area for these areas.

6.3 SWSA serving domestic and industrial water use in major urban centres

6.3.1 Introduction

From a planning perspective, it is essential to understand SWSAs and their associated water supply in the context of access and use of water for current and potential downstream beneficiaries. Here, beneficiaries are defined primarily as the people, or economic sectors, that access the supply of water from the water source areas via their Water Supply Scheme (WSS). In this section, domestic use includes use by all those connected to the urban water supply system, i.e. primarily by households, service providers (e.g. schools, businesses) and light to medium industry, but also includes heavy industry in some locations.

The relationship between SWSAs, current water supply access via engineered infrastructure, and potential future access and use provides valuable information for planning. Using such information, the social-economic impact of different catchment development futures can be explored, or returns on different catchment management investments can be assessed. In this section the water-use at major urban centres is explicitly linked to their respective SWSA, providing easy to understand schematics of water-flow pathways from source to tap. The tabulated information shown here has also been provided in spreadsheet format (to go on a CD). The values given are based on various sources which introduces some differences. But it is important to recognise that, for example, water transfers into the Vaal system from the Tugela depend on the availability of water in both systems compared with the demand. When the Vaal dam is full, transfers from the Tugela will be minimized and *vice versa*. Thus the volumes reported here are means or estimates of the means and not necessarily the amounts in a given year.

6.3.2 Major urban centres and their populations and GVA

The urban centres were selected based on the 26 areas of national economic importance ((DWAF, 2013), Figure 32). Seventeen of the urban centres were identified for the assessment of flows to urban beneficiaries, based on a number of factors including their populations and level of economic activity (Table 15). A new evaluation of the potential for economic development is underway which uses a typology linked to population, service levels and economic activities (Van Huyssteen, 2016). These analyses have identified a number of regional centres which are not included in the set identified here, including Dennilton/Siyabuswa, Port Shepstone/Margate and Stanger. We have used the centres considered in the 2013 National Water Resources Strategy but recommend that this analysis is updated once the economic development centres have been officially adopted by the National Spatial Development Framework.

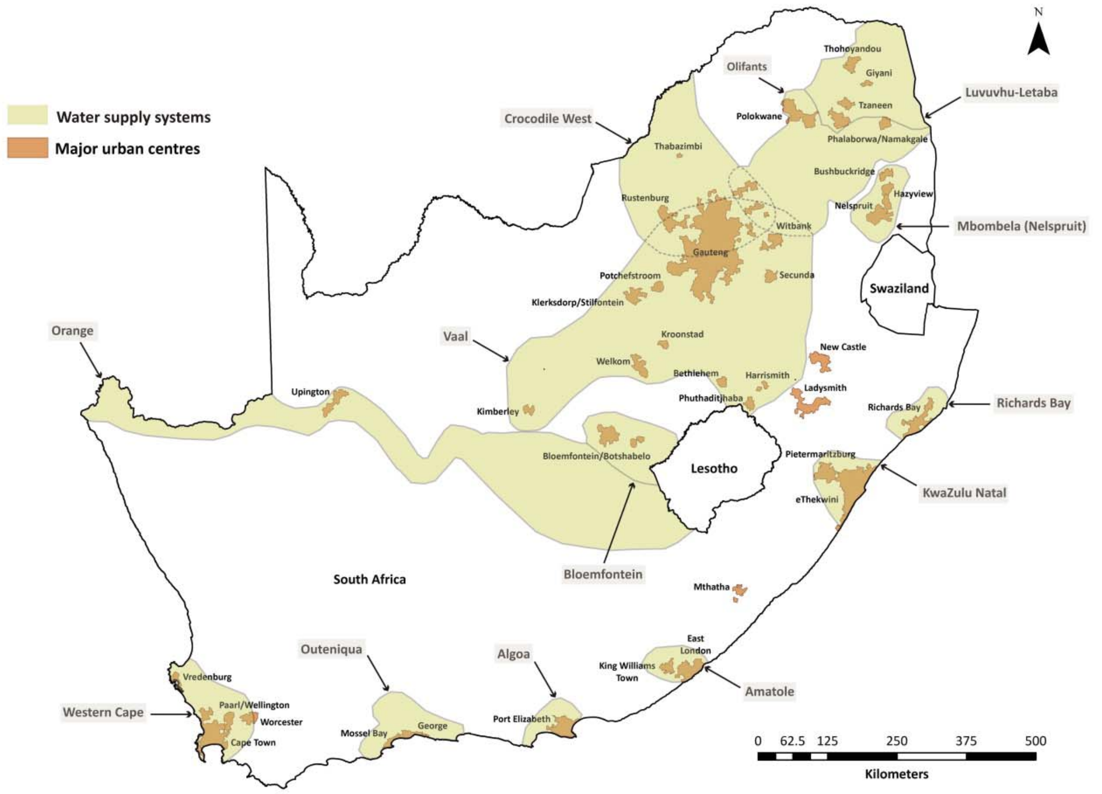

Figure 32: Large water supply schemes and towns identified in the National Water Resource Strategy (After Figure 6 in DWA, 2013).

The urban centres that were examined included 60% of the population in 2011 and accounted for about 75% of the national GVA (Table 5). Even if we are conservative, the SWSA-sw supply all or most of the water for more than 50% of the population and more than 70% of the GVA. The role of ground water supply systems is discussed in Section 3.2.

Table 15: Major urban centres in South Africa (DWA, 2013), selected for analysis of benefit flows through water supply schemes (Figure 32). Population and GVA data from the CSIR Geospatial Analysis Platform (GAP) database available from stepSA (http://stepsa.org/map_space.html).

Reconciliation Strategy Area	Area of National Economic Significance/Urban Centre	Estimated Population (Census 2011)	% national population	Total GVA (R million 2011)	% national GVA
Vaal and Crocodile West	Gauteng	13 187 338	25.48	586 594	36.07
Western Cape	Cape Town-Worcester area	4 220 550	8.15	195 498	12.02
	Saldanha area	75 743	0.15	2 189	0.13
KwaZulu-Natal Coastal Metropolitan Area	Durban-Pietermaritzburg area	4 365 310	8.43	174 221	10.71

Reconciliation Strategy Area	Area of National Economic Significance/Urban Centre	Estimated Population (Census 2011)	% national population	Total GVA (R million 2011)	% national GVA
Vaal-Olifants	Witbank-Secunda area	531 163	1.03	20 835	1.28
Algoa	Port Elizabeth area	1 149 873	2.22	40 270	2.48
Vaal	Rustenburg area	495 324	0.96	24 259	1.49
Richards Bay	Richards bay area	437 356	0.85	14 216	0.87
Bloemfontein/ Mangaung	Bloemfontein	729 419	1.41	24 522	1.51
Amatole	East London area	686 524	1.33	24 926	1.53
Vaal	Potchefstroom-Klerksdorp area	511 141	0.99	14 088	0.87
Outeniqua	George-Mosselbay area	263 792	0.51	9 423	0.58
Mbombela	Nelspruit-Bosbokrand area	772 924	1.49	13 840	0.85
Vaal	Welkom-Kroonstad area	440 253	0.85	11 611	0.71
Vaal	Kimberley area	228 884	0.44	6 943	0.43
Mafikeng WSS Cluster (gw)	Mafikeng-Lichtenburg area	259 279	0.50	7 292	0.45
Luvuvhu Letaba	Thohoyandou-Giyani area	324 490	0.63	8 614	0.53
Olifants (gw)	Polokwane area	516 386	1.00	14 372	0.88
Newcastle	Newcastle area	427 034	0.83	6 970	0.43
Mthatha	Mthatha area	211 896	0.41	5 108	0.31
Olifants	Phalaborwa area	131 858	0.25	4 535	0.28
Crocodile West	Thabazimbi area	28 403	0.05	1 918	0.12
Vaal	Bethlehem-Harrismith-Phuthadithjaba area	400 367	0.77	7 469	0.46
Luvuvhu Letaba	Tzaneen area	369 967	0.71	5 414	0.33
Orange River	Upington area	109 611	0.21	2 727	0.17
Ladysmith	Ladysmith area	286 232	0.55	5 245	0.32
Total		31 161 117	60.21	1 233 099	75.82
National Total		51 755 034		1 626 410	

6.3.3 Collating information on water use in major urban centres

Urban benefit flows were analysed by examining the connections engineered infrastructure provides between the major urban centres covered by the reconciliation strategies (Table 15) and their water sources. Large dams and transfer schemes are the main types of engineered infrastructure that allow access to surface water supply, and through which benefit flows can be explicitly assessed.

For several of the urban centres, information on water sources (which includes dams and inter-basin transfers) was obtained from the original reconciliation strategies. Current water use and predicted water demand was generally obtained from more recent documents such as updated progress reports, and steering committee meeting presentations. The data on the water supply systems (WSS) from these sources, particularly the original Reconciliation Strategy Studies, were used to calculate the yields. The WSSs included dams, inter basin transfers, groundwater and re-use figures. In more detail:

- We distinguished between yield and capacity and used the "1:50 year yield or existing allocation/use". The Historic Firm Yield was used if no other information was available. In some instances the yield information was only available for groups of dams so their total yield or existing allocation/use was included. It is important to note that although the updated progress reports contained updated use values, these were often summarised for the reconciliation strategy area and not linked back to the individual water sources as contained in the original reconciliation strategy reports.

- Using Google Earth, the positions of the dams were identified and the connectivity to an upstream Strategic Water Source Area was documented. Google Earth was used because the dams were easily located in the database.

- The river system supplying each dam was identified in GIS.

- We used current use and future requirements as per the latest information available on the Department of Water and Sanitation Website: https://www.dwa.gov.za/projects.aspx. The original use figures from the Reconciliation Strategy Studies were not used because they were outdated. For each urban centre the date of the current use was documented and the future growth graphs were captured from the source material. The latter sometimes included the original reconciliation strategy documents. Where possible, the current use was for 2015 and the future use was for 2035.

We summarised the information sources used for each area and made notes of some of the issues/challenges we had in compiling it. This dataset was used to tabulate the data for each urban centre with the water yields, requirements and future demand for the different water reconciliation areas (Table 16). Graphical summaries of the reconciliation strategies developed for each urban centre are given in Appendix 2.

Table 16: Summary of the water yields, requirements and future demand for the different water reconciliation strategies for the major water schemes in the NWRS2 (DWAF, 2013). Negative values for the balance indicate a deficit.

Supply System	Current available water resource yield (2012)	2012 Total water requirements	2012 balance	2035 High water requirement scenario
Western Cape	580	513	67	950
Algoa	170	170	-	240
Amatole	108	85	23	120
KZN Coastal Metropolitan Area.	375	440	-65	600
Vaal River	3 000	3 000	-	3 229
Crocodile West	1 090	1 045	45	1 405
Olifants River	1 023	1 036	-13	1 179
Mangaung	84	84	-	168

6.3.4 Linking urban centres with their strategic surface water source areas

6.3.4.1 City of Cape Town

The Western Cape WSS supplies the City of Cape Town (CoCT) metropole and the surrounding towns and irrigation areas with water. The large dams that supply the bulk of the water are Theewaterskloof, Berg River Dam, Wemmershoek, Voëlvlei and Upper and Lower Steenbras (Table 17) (DWS, 2014b; Riemann et al., 2015). As of 2015, the system had a yield of 582 million m^3/a, with a revised domestic allocation of 392.9 million m^3/a and agricultural allocation of 216.2 million m^3/a, a total allocation of 609.1 million m^3/a, which exceeds the yield. Most of the water is allocated to the CoCT (357.9 million m^3/a), with the next largest allocation being the West Coast District Municipality which receives 22.8 million m^3/a. Overberg Water receives 4 million m^3/a, and Stellenbosch Local Municipality receives 3 million m^3/a. Drakenstein Local Municipality receives 1.2 million m^3/a, and Piketberg & PPC receive 2.9 million m^3/a.

Theewaterskloof supplies the most water to the CoCT (30%, Figure 33), followed by the Berg River Dam (20%) and Voëlvlei Dam (18%). Wemmershoek Dam supplies 14% and the Steenbras Upper and Lower Dams supply 10%. The Table Mountain dams only supply 1% of CoCT's water.

City of Cape Town receives a total of 98% of its water from SWSA-sw (Table 17). The three SWSA-sw which supply the dams are the Boland, which supply 79% of the water, Groot Winterhoek which supplies about 18% and Table Mountain, which supplies 1% of the water. In addition, CoCT makes use of several groundwater sources including the Albion Spring and the Atlantis aquifer system which supply a combined total of 2%, with the yields of these sources in Table 17 based on their licensed abstraction rates. The Albion springs are sustained by groundwater discharge, and that groundwater is recharged in the Peninsula Formation aquifer of the Cape Peninsula and Cape Flats SWSA-gw (which overlaps with the Table Mountain SWSA-sw). The Atlantis aquifer forms part of the West Coast SWSA-gw. The therefore CoCT derives 100% of its water from SWSAs.

CoCT also has boreholes along the Lourens Rivers in Somerset West (CCT, 2017), however no information is available on their yields for inclusion in this assessment. Although groundwater sources could supply over 2% of CoCT's use, the actual use from groundwater sources ranged from 0.3 to 0.5% of the total raw water supplied in FY13/14 to FY15/16 (CCT, 2016). The importance of groundwater as a supply source is set to increase in future, particularly accelerated by the current drought. Groundwater is expected to make up 25% of the “new” (non-surface) water resources for the CoCT, with planned abstraction from the TMG aquifer in the Hottentots Holland Mountains and in the Cape Peninsula, planned increased abstraction at Atlantis, and planned abstraction from the Cape Flats aquifer. All of these resources lie within SWSA-gw.

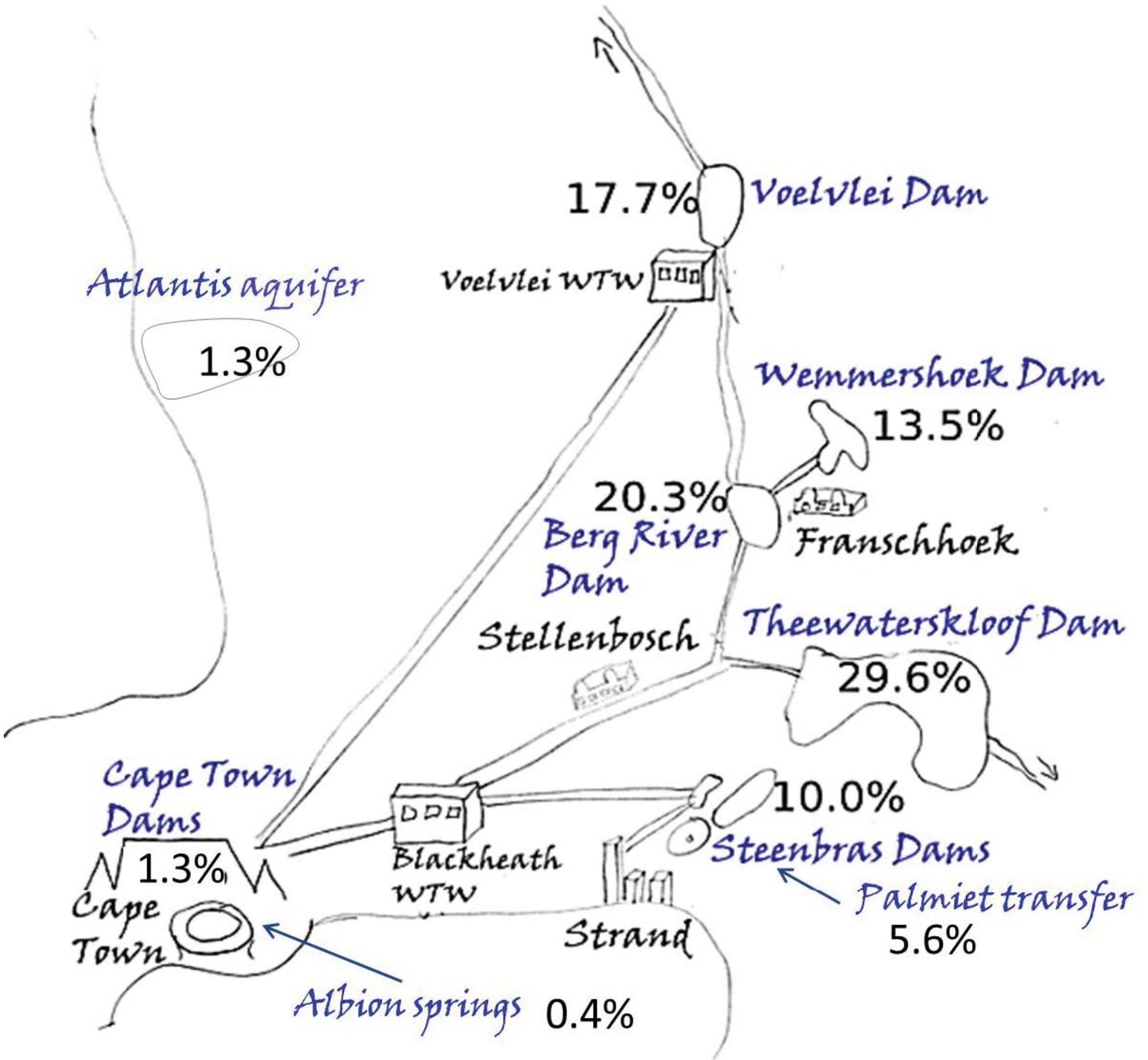

Figure 33: Schematic showing the main dams and aquifers which currently supply CoCT with water and the percentage of the total supply

Table 17: Benefit Shed for City of Cape Town showing the SWSA and river system in which the dam is located (DWS, 2014b; Riemann et al., 2015).

Urban Centre	Dam or aquifer associated with urban town	Long-term (1 in 50) annual water yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Cape Town	Berg River	81.0	20.3	Boland	Berg River
Cape Town	Theewaterskloof	118.0	29.6	Boland	Bree (Breede)
Cape Town	Voëlvlei	70.4	17.7	Boland & Groot Winterhoek	Klein Berg River, 24 Rivers & Berg River
Cape Town	Wemmershoek	54.0	13.6	Boland	Berg River
Cape Town	Steenbras Upper	40.0	10.0	Boland	Steenbras
Cape Town	Steenbras Lower			Boland	Steenbras
Cape Town	Palmiet River (Rockview and Kogelberg Dams)	22.5	5.6	Boland	Palmiet
Cape Town	Land en Zeezicht	0.6	0.2	Boland	Lourens
Cape Town	Kleinplaats	1.9	0.5	Table Mountain	Else
Cape Town	Lewis Gay	0.2	0.1	Table Mountain	Else
Cape Town	Woodhead	1.3	0.3	Table Mountain	Disa
Cape Town	Hely Hutchinson	1.3	0.3	Table Mountain	Disa
Cape Town	Victoria	0.1	<0.1	Table Mountain	Disa
Cape Town	Alexandra	0.1	<0.1	Table Mountain	Disa
Cape Town	De Villiers	0.3	0.1	Table Mountain	Disa
Cape Town	Groundwater: Albion Springs	1.5	0.4	Table Mountain	n/a
Cape Town	Groundwater: Atlantis	5.0	1.3	West Coast Aquifer	n/a

6.3.4.2 Durban and Pietermaritzburg

The reconciliation strategy for the KZN Coastal Metropolitan Area (AECOM SA, 2015; DWAF, 2007b) covers the eThekwini Metropolitan Municipality (MM), Msunduzi Local Municipality as well as portions of the uMgungundlovu, iLembi and Ugu District Municipalities. The study area includes the Mooi-Mgeni Transfer Scheme, MMTS) with Mearns Weir (Phase 1) and the Spring Grove Dam (Phase 2), as well as linkages between the Northern and Western Aqueducts and the South Coast Augmentation (SCA) and Lower Thukela Bulk Water Supply Scheme (LTBWSS) conveyance infrastructure (Figure 34). The volumes also include the proposed transfer from the uMkhomazi catchment to the Mgeni catchment via the uMkhomazi Water Project Phase 1 (uMWP-1). The newly built Spring Grove Dam, which is part of the Mooi-Mgeni Trans Scheme (MMTS in Figure 34) contributes about 14% to the total volume (Figure 35, Table 18). The combined dams on the Mgeni River (Midmar, Albert Falls, Nagle, Henley and Inanda) supply 84% of the total of the Mgeni WSS. Hazelmere Dam, located on the Mdloti River contributes 2% although this volume will change once the raising of the dam wall is completed in 2018. Although it contribution a small percentage, the Hazelmere dam is responsible for supplying the suburbs in Northern eThekwini which are under severe water restrictions because of the low water level in the dam.

In summary eThekwini and Pietermaritzburg receive 98% of their water from the Southern Drakensberg SWSA-sw with the balance from the Zululand Coast sub-national WSA-sw.

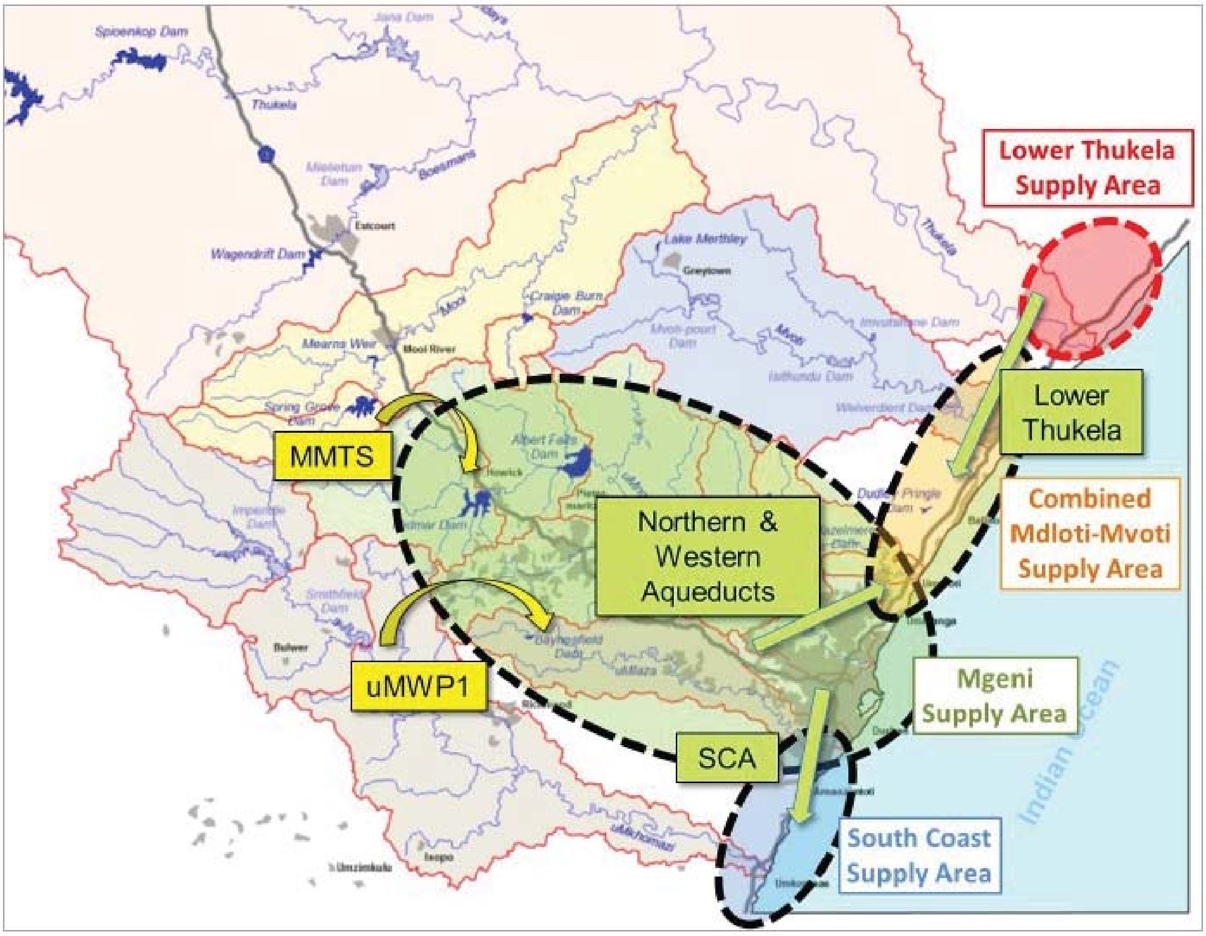

Figure 34: Study area of the KZN Coastal Metropolitan Area Reconciliation Study (DWS, 2015c).

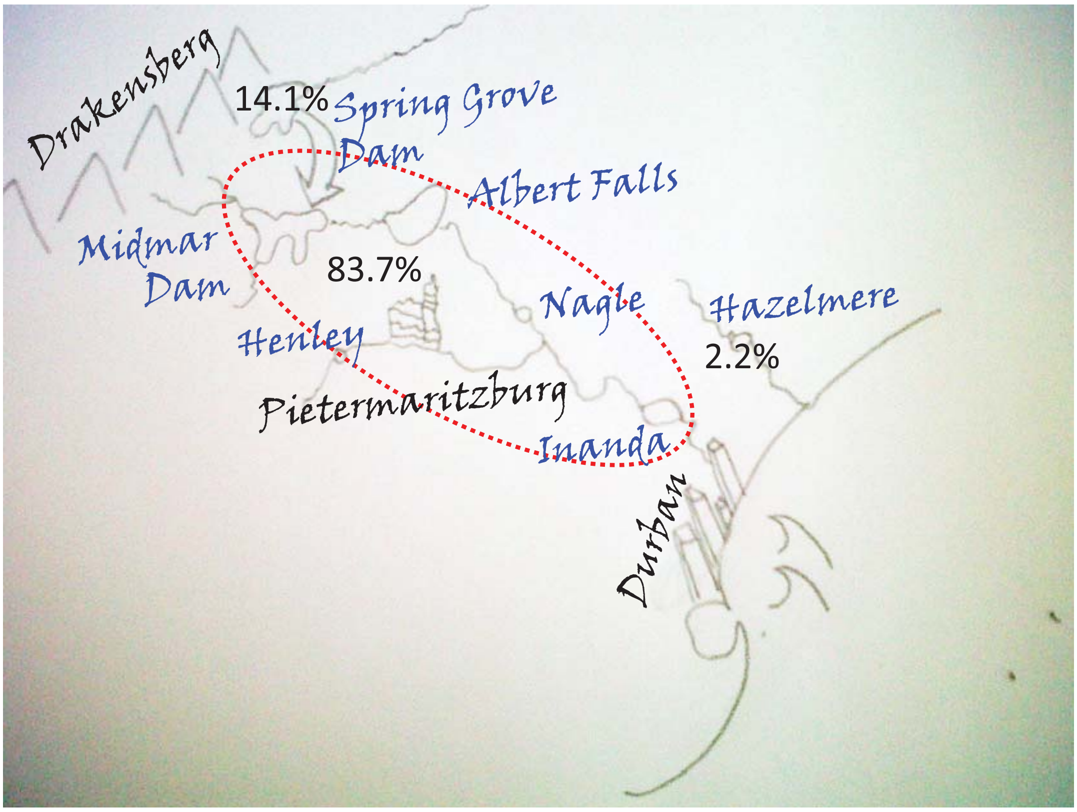

Figure 35: Schematic showing the KZN Coastal Metropolitan Area source dams and the transfer from the Spring Grove Dam.

Table 18: Benefit shed for the urban centres of eThekwini and Pietermaritzburg on the Mgeni WSS, showing the yields and percentage of the various dams in the supply system and the Strategic Water Source Area in which they are located.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
eThekwini Pietermaritzburg	Albert Falls Dam	282.8	83.7	Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Inanda Dam			Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Mearns Dam			Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Nagle Dam			Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Dudley Pringle Dam			Southern Drakensberg	Tongati River
eThekwini Pietermaritzburg	Henley Dam			Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Midmar Dam			Southern Drakensberg	Mgeni River System
eThekwini Pietermaritzburg	Spring Grove			Southern Drakensberg	Mooi River System
eThekwini Pietermaritzburg	Hazelmere Dam	6. 3	2.2	Zululand Coast sub-national	Mdloti River System

6.3.4.3 Vaal Water Supply System (Rand water supply area)

The Vaal Water Supply System supplies the Pretoria-Witwatersrand-Vereeniging industrial and urban complex, including Rustenburg and Sasol, as well as transferring water to the Olifants and Inkomati catchments. This is the most complicated WSS in the country, consisting of a series of interlinked dams and interbasin transfers into and out of the Upper Vaal Catchment as well as transfers to the Crocodile (West) WSS for Rustenburg, Pretoria, northern Johannesburg and Midrand (see Figure 36) (DWAF, 2009, 2007c, 2004) (Figure 36). The naturalised MAR of the Vaal and Wilge River systems upstream of the Vaal Dam is about 2032 million m^3/a with 29% of that coming from the SWSA-sw in these catchments (Table 19), mainly the Northern Drakensberg SWSA-sw in the Wilge River catchment. The firm yield of the Vaal Dam, including the Vaal Barrage, is about 941 million m^3/a (DWA, 1986) and the Vaal Dam on its own about 831 million m^3/a (DWAF, 2002). Given that 29% of the naturalised MAR is from areas identified as SWSA-sw in this report, about 170 million m^3/a of that yield would come from the SWSA-sw linked to the river systems above the Vaal Dam.

The Lesotho Highlands Water Project Phase I currently transfers about 780 million m^3/a from the Senqu to the Vaal system and has a maximum capacity of 808 million m^3/a (ORASECOM, 2014a). The Senqu gets its water from the Maloti Drakensberg SWSA-sw. These transfers affect the availability of water to the Orange River system downstream, and this impact will increase following the development of Phase II of the Lesotho Highlands Water Project which will transfer an additional 471 million m^3/a into the Vaal River system (DWA, 2014a). Although the Vaal River is a tributary of the Orange River, the degree of water-use use in the Vaal system itself is such that there is little inflow to the Orange from the Vaal River under normal conditions. So the transfers represent a net reduction in flows to the lower middle and lower Orange River (DWAF, 2009; ORASECOM, 2014a, 2014b).

The Thukela-Vaal transfer scheme which transfers water from the Driel Barrage, Woodstock and Spioenkop Dams to the Sterkfontein dam has a maximum capacity of 630 million m^3/a, but currently transfers about 430 million m^3/a to meet demand in the Vaal catchment (DWAF, 2013, 2009, 2004). The Thukela-Vaal transfer from the Zaaihoek Dam via the Majuba Power Station to Grootdraai Dam has a maximum capacity of 63 million m^3/a, and currently transfers about 55 million m^3/a, some of which goes to Secunda. About 25 million m^3/a of this is used by the Majuba power station (Eskom, 2012). The transfer from the Heyshope Dam in the Usutu catchment to the Grootdraai Dam in the Upper Vaal comes to about 63 million m^3/a (Table 19) (ORASECOM, 2014b) some of which is then transferred to Eskom power stations in the Olifants River catchment (Jeleni and Mare, 2007). Water is also transferred from the Heyshope Dam to supplement water transfers from the Morgenstond, Jericho and Westoe Dams to Camden Power Station in the Vaal catchment, and then onwards to the other power stations in the Olifants River catchment (Jeleni and Mare, 2007). The current transfers from the Vaal into the Olifants River system come to about 36 million m^3/a and could be increased to about 250 million m^3/a (ORASECOM, 2014a).

The net result of all these transfers, and the flow generated within the system, is that the total Vaal WSS yield is about 1 927 million m^3/a (DWAF, 2009). The volume of water transferred to the Crocodile West WSS for urban (domestic) purposes is about 524 million m^3/a. This comes from the Vaal Dam and Barrage and so is comprised of a mixture of internally generated flows and transfers. The abstractions reduce the total volume available in the WSS and downstream. Assuming the mixture comes proportionally from all sources, the transfers will not affect the relative importance of the inflows from each of the sources Table 19). The transfer of 36 million m^3/a to the Olifants system comes from the Grootdraai Dam and so does reduce the proportions coming from upstream of the Grootdraai Dam and the Thukela(Tugela)-Vaal transfers (Zaaihoek and Heyshope Dams). However the water from these dams in the Thukela comes from the Upper Usutu SWSA-sw and so does not really affect how much water is contributed by SWSA-sw. Based on these values and estimates, about 100% of all the water flowing in and into the Vaal WSS is linked to SWSA-sw. If the runoff from the Vaal is limited to just that from its SWSA-sw, the total from SWSA-sw is still 71%.

Groundwater from dolomitic systems was historically an important source of water in the Vaal WSS. The initial source of water for Johannesburg was at Zuurbekom between Soweto and Westonaria. This is located in the West Rand Karst Belt SWSA-gw and supplied about 9.0 million m^3/a. It is mentioned as a source of water for Johannesburg (DWA, 1986) but it is apparently no longer used as it is not mentioned in more recent reports or as a water source by Rand Water (possibly because of water contamination issues). Pumping and treating AMD commenced in 2012 and will process about 76[5] million m^3/a from the Western, Central and Eastern basins (Bobbins, 2015; CoJ, 2012). At least some of this water will flow into rivers in the Crocodile West catchment rather than the Vaal River catchment. We could get confirmation on whether or how much of the treated water is actually being used for industrial or municipal supply and so have not included the AMD in the water balance at this stage.

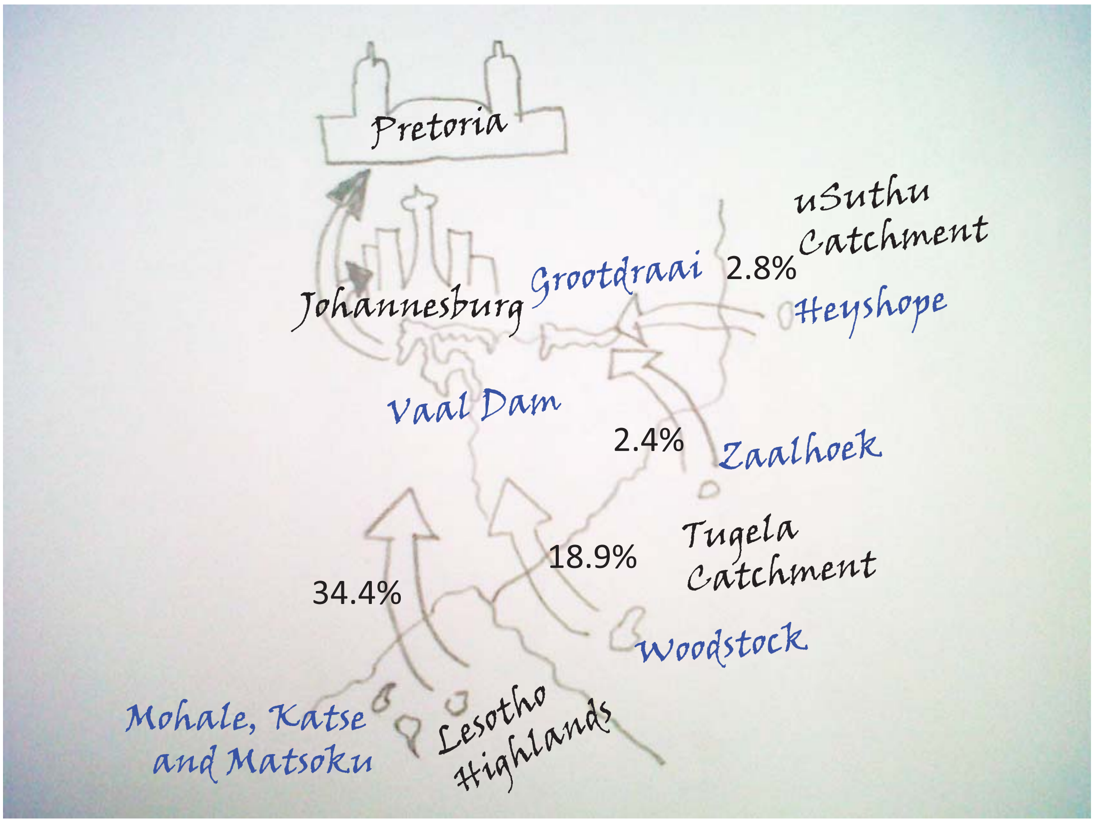

Figure 36: Schematic of the Vaal WSS showing the relative contributions of the interbasin transfers into the system (Table 19). Essentially all the water transferred originates in SWSA-sw.

[5] Final AMD treatment capacity 88 million m^3/a based on figures in Engineering News 18 May 2016. Minister launches long-term acid mine water solution. http://www.engineeringnews.co.za/article/water-minister-launches-long-term-acid-mine-drainage-solution-2016-05-18

Table 19: Yields and of the dams and interbasin transfers which supply the Vaal WSS (DWAF, 2013, 2009, 2007c; ORASECOM, 2014a). Upper Vaal here refers to the entire catchment upstream of the Vaal Dam. Volumes transferred from the Lesotho Highlands Development Authority (http://www.lhda.org.ls/Phase1/Reports/PDF/12/WaterSales2016.pdf)

Urban Centre	Dam associated with WSS	Long-term (1 in 50) water yield or transfer (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Vaal – Lesotho Highlands	Mohale	780.0 (2006-2015 mean 783.4)	34.5	Maloti Drakensberg	Senqu (transfer via As and Liebenbergsvlei Rivers into Vaal)
	Katse				
	Matsoku weir				
Vaal – Tugela	Woodstock	431.0	18.9	Northern Drakensberg	Thukela
	Zaaihoek	55.0	2.4	Northern Drakensberg	Thukela
Vaal – Usutu	Heyshope	63.0	2.8	Upper Usutu	Usutu
Vaal – from Upper Vaal linked SWSAs	Vaal	162.0[1]	12.0	Upper Vaal, Upper Usutu, Northern Drakensberg	Vaal
Vaal – from balance of Upper Vaal	Vaal	772.0	29.3	Upper Vaal, Upper Usutu, Northern Drakensberg	Vaal

1: Based on a firm yield of 941 million m^3/a for the Vaal Dam and Barrage (DWA, 1986) and 29% of the MAR at dam being from SWSA-sw upstream

6.3.4.4 Crocodile West (Johannesburg, Pretoria and Rustenburg)

The Crocodile West WSS is very closely linked to the Vaal WSS because large volumes are transferred from the Vaal WSS. These transfers are linked dynamically to the demand and water availability in the Crocodile system, and so will vary depending on factors such as rainfall in the catchments and demand. The total volume of water transferred into the WMA from the Vaal WSS came to 651.1 million m^3/a in 2000 (Table 20) (DWAF, 2008a). Urban water requirements in 2000 came to 528 million m^3/a, rural to 25.7 million m^3/a, irrigation 417.5 million m^3/a, and power generation, mining and bulk industrial to 148 million m^3/a. The domestic requirement closely matches the most recent reconciliation report (DWA, 2012b) which gives the current transfer (2010) for domestic water as 523 million m^3/a, rising to 524 million m^3/a in 2015 and to about 725 million m^3/a in 2035. No data were given in this report for transfers for industrial, power generation and mining water, presumably because these are linked into local supply sources as well. However, in 2000 the transfers were estimated to amount to 49% of the utilisable water in the catchment (DWAF, 2008a). The domestic demand for 2015 for the Crocodile West River catchment is estimated as 694 million m^3/a while 268 million m^3/a is required for agriculture and 116 million m^3/a for mining, power generation and bulk industry (DWA, 2012b). The volume of return flows in the river systems for 2015 is modelled at 321 million m^3/a, and is projected to increase to 428 million m^3/a by 2035 (Table 21) (DWA, 2012c).

The 2015 transfer of 524 million m^3/a from the Vaal River system for domestic purposes therefore accounts for 76% of the domestic water demand in the Crocodile West Catchment (Figure 37 and Table 20), and 49% of the total water supply in the catchment. Almost 50% of domestic water is discharged back into the system as return flows. The municipality also gets 7.7 million m^3/a from the local Rietvlei Dam. Some of the streams that flow into this dam are fed by dolomitic springs.

Groundwater is also an important supply source to Tshwane. 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 or target the karstic aquifer formed by the dolomites of the Malmani Subgroup of the Chuniespoort Group (Transvaal Supergroup) (DWA, 2010b). The total groundwater yield available to Tshwane is 13.1 million m^3/a, 6% of the 2015 water requirements for Tshwane metropolitan municipality (TMM, 2014).

Based on an estimate that 71% of the water from the Vaal WSS originates in SWSA-sw (see Section 6.3.4.3), the transfer of SWSA-sw water to the Crocodile WSS is about 344 million m^3/a, or about 45% of the water available in the WSS. The proportion of the 82 million m^3/a of groundwater which comes from the Eastern Karst Belt SWSA-gw has not been estimated but is probably high, so that more than 50% of the water in the Crocodile WSS is from SWSA.

Table 20: Water sources and supplies in in the Crocodile West WMA (DWA, 1986; DWAF, 2008a, 2008b).

Urban Centre	Dam associated with WSS	Local yield and transfers (million m^3/a)	Percentage of total[1]	Strategic Water Source Area	River System
Transfers in to Johannesburg north (Upper Crocodile)	Vaal	352.0 (in 2000)	68.9	See Vaal WSS	Vaal
Transfers in to Pretoria (Apies-Pienaars)	Vaal	230.0 (in 2000)		See Vaal WSS	Vaal
Transfers in to Rustenberg (Elands)	Vaal	69.1 (in 2000, 19.7 for urban use)		See Vaal WSS	Vaal
From the Crocodile catchment (surface water)	Including Hartebeespoort, Roodekopjes, Roodepoort & Rietvlei	155.0	20.8	(Eastern Karst Belt)[2]	Crocodile, Elands, Apies-Pienaars
From the Crocodile catchment (groundwater) including The Fountains in Pretoria		13.1	2.8	Eastern Karst Belt	

1: Assuming 524 million m^3/a transfer from Vaal for urban use (DWA, 2012b)

2: Springs are the source of many rivers and streams in the Crocodile West catchment

Table 21: Domestic water requirements for the municipalities in the Crocodile West Catchment (DWA, 2012b). The full domestic water requirement for the City of Johannesburg is in the order of 500 million m^3/a. The figures in the table only represent the volumes supplied by Rand Water and do not take into account municipal owned supply.

Municipality	Domestic Water Requirements (million m^3)	
	2015	2035
City of Tshwane MM	287.7	395.3
City of Johannesburg MM	188.2	247.7
Ekurhuleni MM	89.7	118.2
Rustenburg LM	39.5	56.3

Figure 37: Schematic showing the interbasin transfers into the Crocodile West Catchment from the Vaal River System. This accounts for 75.5% of domestic water use, and 48.6% of total water use. The return flows are shown in shaded arrows. Return flows account for 29% of the water balance for the catchment.

Randwater supplies 100% of the water for the City of Johannesburg from various sources and 81% of the water for the City of Tshwane (which gets the balance from Rietvlei, boreholes and springs). Rustenburg receives water from Rand Water and Bospoort Dam, with 19.8 million m^3/a supplied by Rand Water from the Vaal Barrage (DWA, 2008). Thabazimbi receives its water from Magalies Water with the source being Vaalkop Dam. The planned transfers to the Lephalale area to support power generation and mining are expected to be between 45 and 80 million m^3/a which could lead to water shortages in the WMA (DWA, 2012b).

6.3.4.5 Greater Bloemfontein

Bloemfontein receives most of its water from the Maloti-Drakensberg SWSA-sw via the Caledon River. The three main transfer water supply schemes are the Caledon-Bloemfontein Transfer Scheme, the Maselspoort Scheme (approximately 25% of Bloemfontein's water), and the Caledon-Modder/Novo Transfer Scheme (Figure 38) (DWA, 2012d).

The Caledon-Bloemfontein Transfer Scheme supplies potable water from Welbedacht Dam on the Caledon River. The yield from Welbedacht Dam has decreased due to siltation from 115 million m^3/a to 15.5 million m^3/a. It has been replaced by the Knellpoort off-channel storage dam on the Rietspruit, a tributary of the Caledon which supplies the Welbedacht Water Treatment Works, which has a capacity of 145 Ml/day. The Maselspoort Scheme includes the Maselspoort WTW (110 Ml/day) and Maselspoort Weir, located on the Modder River, downstream of Mockes Dam and supplies approximately 25% of Bloemfontein's water needs. The Novo Transfer scheme operates from the Caledon River into the off-channel Knellpoort Dam which is then transferred to the Modder River, upstream of Rustfontein and Mockes Dam. The operating rules are that it maintains a water level of 60% of full supply in Rustfontein Dam, which means it has run almost continuously since December 2008.

Nearly 70% of the surface water runoff originates in Lesotho, with just more than 30% from the Upper Orange Catchment within South Africa (DWA, 2012d) (Figure 39). Only the Lesotho portion of the headwaters of the Caledon River is located in a SWSA-sw, which means that this SWSA-sw is responsible for about 70% of the water supply to Bloemfontein WSS (Figure 38, Table 22).

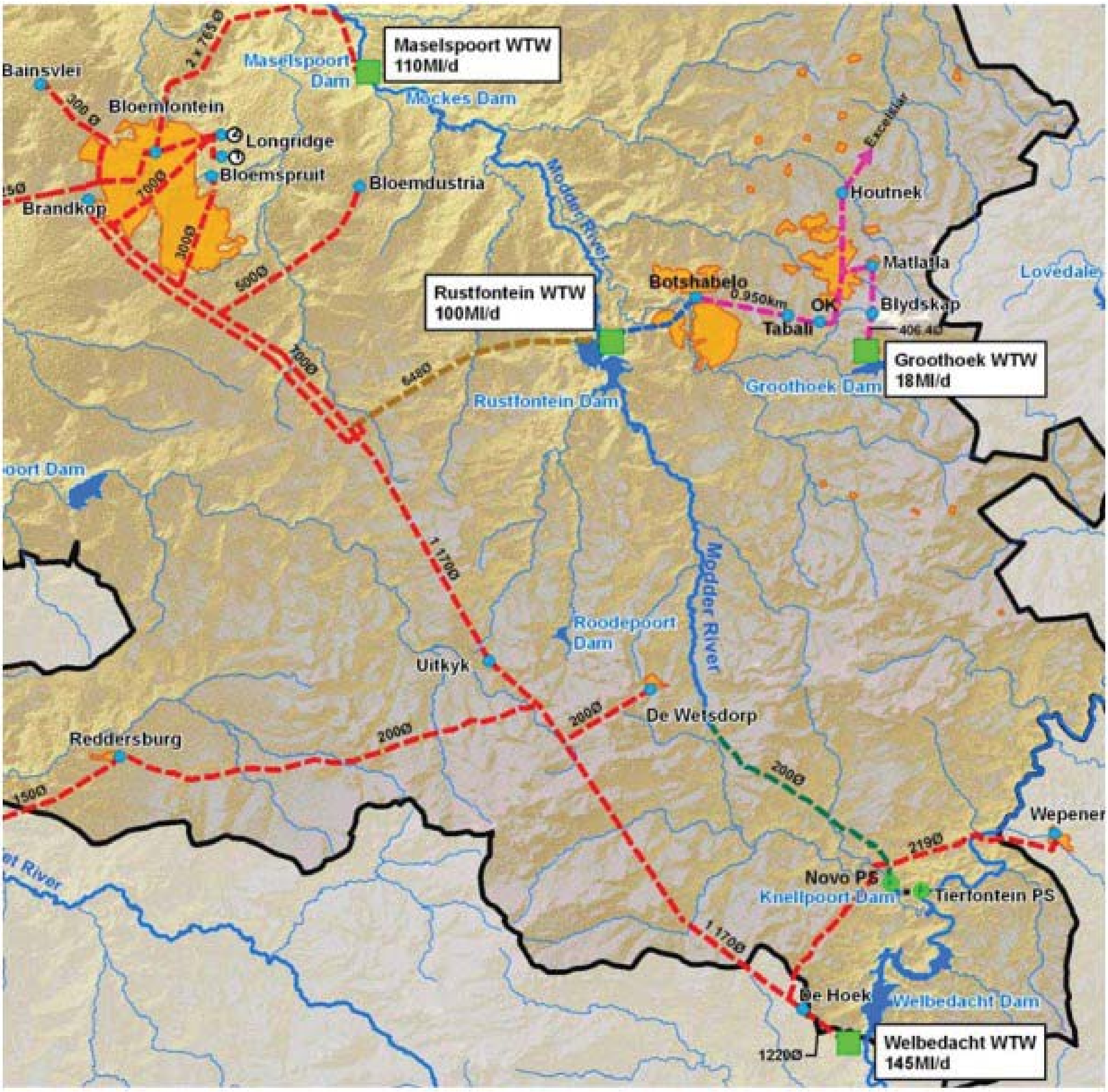

Figure 38: Greater Bloemfontein WSS (DWA, 2012d)

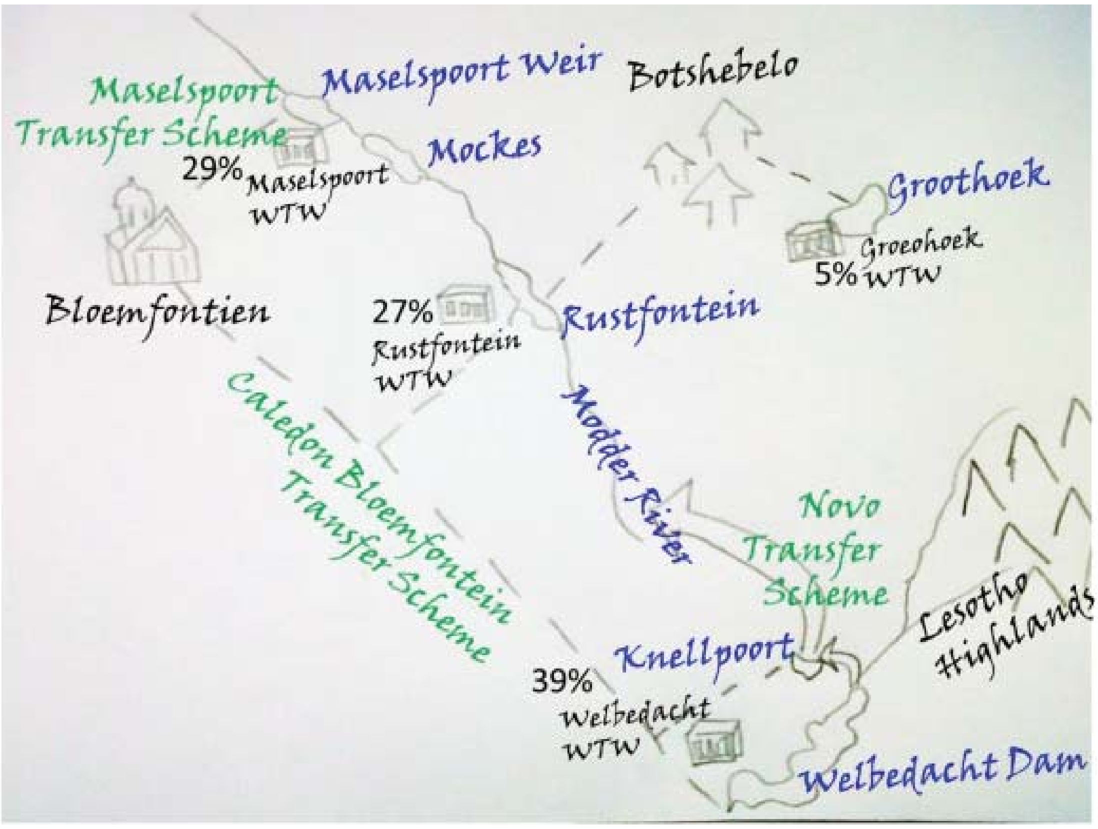

Figure 39: Schematic for the Greater Bloemfontein WSS showing the three transfer schemes in green and the percentage each Water Treatment Works supplies. All the water originates from the Caledon River with transfers into the Modder River.

Table 22: Water sources and yields for the Bloemfontein WSS (DWA, 2012d).

Water Supply System	Urban Water Scheme	Long-term 1:50 year water yields (million m^3/a)	% Yield per urban water scheme	Associated Strategic Water Source Area	% Yield per Strategic Water Source Area
Bloemfontein	Welbedacht	85.00	70.2	Maloti Drakensberg	70.3
Bloemfontein	Knellpoort				
Bloemfontein	Rustfontein	8.00	6.6	None	
Bloemfontein	Maselspoort				
Bloemfontein	Groothoek				
Bloemfontein	Local yield (other)	28.00	23.2	None	

6.3.4.6 Richards Bay WSS

Richards Bay receives its water from a series of lakes and transfer schemes (Figure 40, Table 23) (DWS, 2015b). The three lakes which supply Richards Bay are Lake Nsezi, Lake Chuba and Lake Msingazi which are characterised by strong groundwater surface water interactions, and it is estimated that 6% of the yield of the lakes is derived from groundwater contribution (DWS, 2015b). The catchment area of the Lakes falls within the Richards Bay GW-fed Lakes SWSA-gw. There is a transfer scheme from the Mfolozi to Lake Nhlabane which is allocated to Richards Bay Minerals.

There is an additional transfer from the Thukela River into Goedertrouw Dam. The transfer point is located in the lower reaches of the Thukela River, about 100 km from the river mouth. If river flows are low then dam releases from Spioenkop Dam, located in the Northern Drakensberg SWSA-sw can be used if needed.

The Mfolozi Headwaters SWSA-sw supplies 29% and the transfer from the Thukela relies on both runoff from the Northern Drakensberg SWSA-sw and from the rest of the Thukela upstream. The chronic water shortages that have been experienced in the area led to the commissioning of a desalination plant, the importance of which has been diminished by the high rainfall during the past summer. Provided it is properly maintained, it will be important for ensuring water security during future droughts.

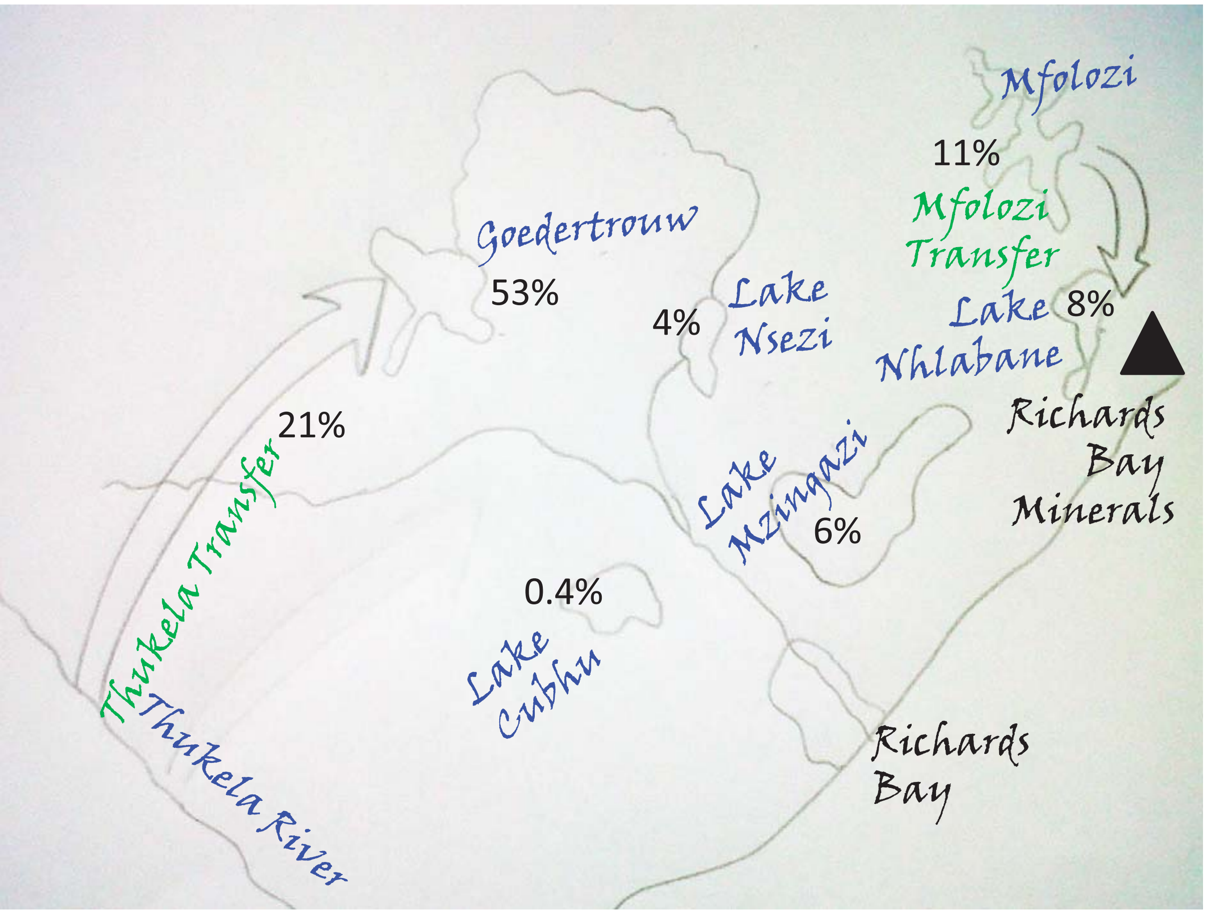

Figure 40: Schematic showing the Richards Bay WSS and the various yields as a percentage from the different water sources.

Table 23: Benefit shed for Richards Bay showing the water source, the yield (and as a percentage), the strategic water source area associated with the water source and the river system the water source is located on (DWS, 2015b).

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Richards Bay WSS	Lake Nsezi	6. 6	4.0%	Richards Bay Groundwater-fed lakes	Nsezi
Richards Bay WSS	Lake Mzingazi	10.5	6.4%	Richards Bay Groundwater-fed lakes	
Richards Bay WSS	Lake Chubu	0.4	0.2%	Richards Bay Groundwater-fed lakes	
Richards Bay WSS	Goedertrouw Dam (excluding Thukela water transfer)	86.6	52.8%	None	Mhlatuze
Richards Bay WSS	Thukela water transfer to Goedertrouw Dam	34.0	20.7%	Northern Drakensberg	From Thukela River
Richards Bay WSS	Mfolozi support to Lake Nhlabane	18.0	11.0%	Mfolozi Headwaters	Mfolozi
Richards Bay WSS	Lake Nhlabane: with no support from Mfolozi	7.9	4.8%	Richards Bay Groundwater-fed lakes	

6.3.4.7 Amatole – East London

The Amatole WSS is responsible for supplying East London, King Williams Town and Bisho with water (Figure 41, Table 24) (DWA, 2012e; DWAF, 2006b). The Maden and Rooikranz Dams supply King Williams Town and Bisho with water, as well as via the Wriggleswade Transfer from Wriggleswade Dam on the Kubusi River to the Buffalo River upstream of Laing Dam. Bridledrift Dam on the Buffalo River and Nahoon Dam on the Nahoon River supply East London with water.

The Amatole SWSA-sw is responsible for supplying 93% of the water to the dams in the Amatole WSS. The only dam which is not located within or downstream of the Amatole SWSA-sw is the Nahoon Dam.

Figure 41: Benefit shed for the Amatole WSS showing the main dams which supply the scheme and the Wriggleswade transfer scheme. The percentages represent the various yields of the dams and include the transfer losses from Wriggleswade Dam.

Table 24: Summary of the benefit shed for Amatole showing the yield (DWA, 2012e) and relative importance of each dam in the Amatole WSS and the SWSA-sw associated with each dam.

Urban Centre	Dam associated with urban town	Yield (million m³/a)	Percentage of total	Strategic Water Source Area	River System
Amatole WSS	Maden Dam	4.18	5.1%	Amatole	Buffalo River
Amatole WSS	Rooikrantz Dam			Amatole	
Amatole WSS	Laing Dam	16.51	20.1%	Amatole	
Amatole WSS	Bridledrift Dam	29.41	35.7%	Amatole	
Amatole WSS	Gubu Dam	2.22	2.7%	Amatole	Gubu River
Amatole WSS	Wriggleswade Dam	23.79	28.9%	Amatole	Kubusi River
Amatole WSS	Nahoon Dam	6.15	7.5%	None	Nahoon River

6.3.4.8 Algoa WSS

The Algoa WSS supplies water to the Nelson Mandela Bay Municipality (NMBM) and consists of a Western, Eastern and Central System (Figure 42) (DWA, 2011b). The Western System supplies water to NMBM from the Churchill and Impofu Dams on Kromme River, from the Kouga Dam on the Kouga River and the Loerie Balancing Dam on the Loeriespruit. The Loerie Balancing Dam is fed by an irrigation canal from Kouga Dam. The Eastern System consists of an inter-basin transfer from the Gariep Dam on the Orange River via the Orange-Fish Tunnel, the Fish River, the Fish-Sundays Canal, Skoenmakers River and Darlington Dam. The Lower Sundays River Water User Association receives its water from the same transfer scheme and does not receive water from the Algoa WSS. The Central System consists of the older NMBM dams on the Sand, Bulk, Van Stadens and Kwa Zunga Rivers and groundwater from the Uitenhage Springs. The Groendal Dam forms part of the Central System. The transfer from the Gariep Dam for domestic use, including Algoa, amounts to 42.4 million m^3/a (DWA, 2014a).

The Tsitsikamma SWSA-sw supplies 41% and the Kouga SWSA-sw supplies 22% of the water to Algoa WSS (Table 25). The Sundays River Government Water Scheme supplies 25% of the water which it receives from the Gariep Dam, located downstream of the Maloti Drakensberg SWSA-sw. In total SWSA-sw are responsible for 89% of the water used in the Algoa WSS. The groundwater resource unit responsible for the Uitenhage Springs is incorporated within the Coega TMG aquifer SWSA-gw and supplies 2%. Supply to NMBM from this SWSA-gw will increase in future with additional groundwater development currently underway.

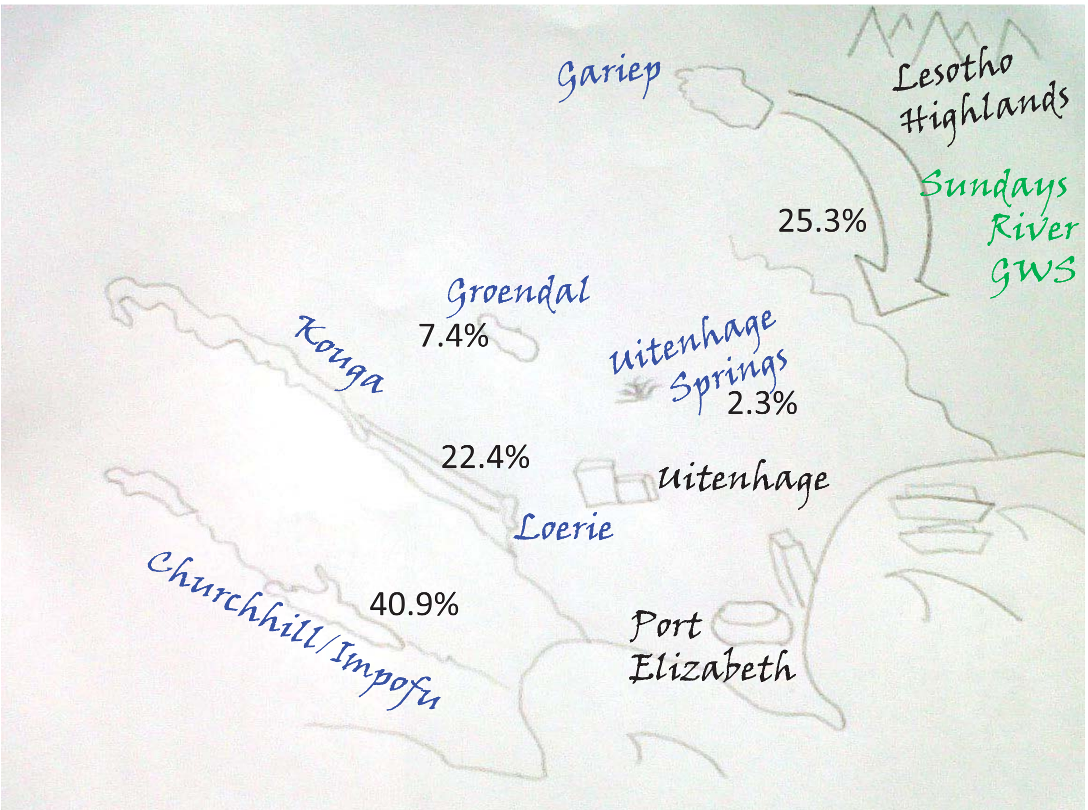

Figure 42: Schematic of the Algoa WSS showing the main water sources and the yield from each resource

Table 25: Benefit shed of the Algoa WSS showing the water sources and the percentage yield from each resource and the associated SWSA and river system

Urban Centre	Water source associated with urban town	Yield	Percentage of total	Strategic Water Source Area	River System
Algoa WSS	NMBM older dams	7.6	7.4	None	Minor Rivers
Algoa WSS	Groendal Dam			Linked to Coega TMG Aquifer	Kwa Zungu
Algoa WSS	Churchill/Impofu Dams	42.0	40.9	Tsitsikamma	Kromme River
Algoa WSS	Kouga Dam	23.0	22.4	Kouga	Kouga River
Algoa WSS	Loerie Dam			Kouga	Loeriespruit (Gamtoos)
Algoa WSS	Sundays River GWS	26.0	25.3	Maloti Drakensberg	Orange River (Gariep Dam)
Algoa WSS	Uitenhage Springs	2.4	2.3	Coega TMG Aquifer	n/a
Algoa WSS	Re-use	1.7	1.6	None	n/a

6.3.4.9 Mosselbay

The Mosselbay Regional WSS was described in the Outeniqua Reconciliation Strategy and comprises three WSSs (Figure 43, Table 26) (DWAF, 2007d). The Mosselbay WSS supplies the town and nearby resort towns in the area between the Klein Brak River in the east and Vleesbaai in the west, as well as the industrial requirements for PetroSA. The supply comes from the Wolwedans Dam on the Great Brak River and the Klipheuwel off-channel storage dam located close to the Moordkuil River. The Hartbeeskuil Dam is also located in this area, but is currently not being used because of low yield and poor water quality. PetroSA, the only large-scale industrial user in the study area, has a licensed allocation of 5.6 million m^3/a, at a 99.5% assurance of supply.

The Klein/Mid-Brak RWSS supplies the area between the Klein Brak and the Great Brak rivers, including the resorts of Klein Brak, Tergniet and Rheebok from the Ernest Robertson Dam on the Great Brak River and the Kleinbos Weir on the Beneke River.

The Great Brak RWSS supplies the town of Great Brak and nearby resorts including Glentana from the Great Brak River via the Searles Furrow run-of-river scheme.

The only dam not located in or downstream of the Outeniqua SWSA-sw is the Hartbeeskuil so the Outeniqua SWSA-sw is the source of 94% of the water supplied to the Mosselbay RWSS.

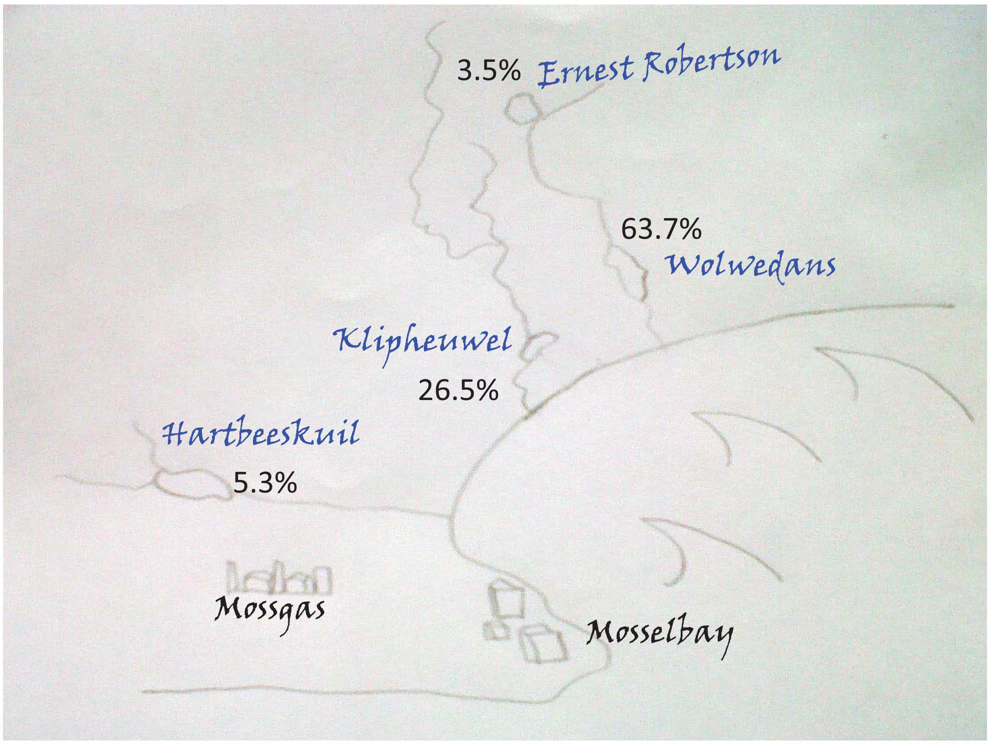

Figure 43: Schematic showing the main dams which supply Mosselbay WSS and the dam yield as a percentage of the Mosselbay WSS yield.

Table 26: Benefit shed for Mosselbay indicating the historic firm yields, percentage yield from each dam in the system and the SWSA which supplies the dam.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Mosselbay RWSS	Hartbeeskuil	1.2	5.3	No	Hartenbos
	Wolwedans Dam	14.4	63.7	Outeniqua	Great Brak River
	Klipheuwel Off channel Dam	6.0	26.5	Outeniqua	Moordkuil/ Klein Brak
	Ernest Robertson Dam	0.8	3.5	Outeniqua	Great Brak River
	Kleinbos Weir	0.2[1]	0.9	Outeniqua	Beneke River

1: Permitted allocation

6.3.4.10 George

George Municipality is supplied by the George RWSS which includes the town of Wilderness. George receives its water from the Garden Route Dam (Figure 44) (Table 27). Historically George also received water from the Swart River Dam but the pump scheme is not operational at present and has been excluded from this assessment. The Kaaimans River Weir was recommissioned to begin operation in 2007, however we could not find recent information on the yield and use of this system. The town of Wilderness receives its water from the local run-of-river of the Touw River Weir as well as augmentation from the George RWSS when necessary. During the past few years George has experienced severe water shortages and a number of emergency schemes and water supply augmentation options are under consideration. Several boreholes were drilled, however these have not (yet) been brought into full-time supply and are considered as a backup supply only. The groundwater resource unit supplying the current (and potential future) boreholes is incorporated in the George and Outeniqua SWSA-gw.

The Outeniqua SWSA-sw supplies 100% of the current water supply for George, via the Garden Route Dam, and Wilderness via the Touw River Weir.

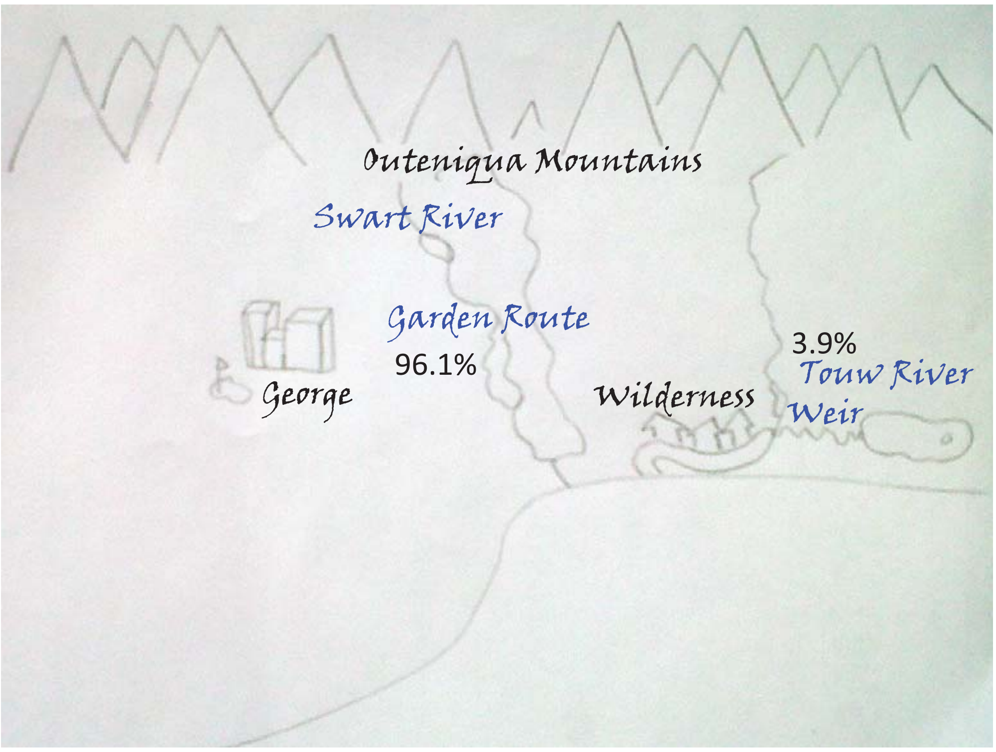

Figure 44: Schematic showing the water sources for George and Wilderness.

Table 27: Benefit shed for George Municipality showing the supply dams and weirs, yields (at 98% assurance of supply) and the associated SWSA and river system (DWAF, 2007d).

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Outeniqua WSS - George RWSS	Garden Route Dam	10.5[1]	96.1	Outeniqua	Swart/Kaaimans
	Touw River Weir (Wilderness)	0.43	3.9	Outeniqua	Touw River
	*Swart River Dam	2.3		Outeniqua	Swart River
	#Kaaimans River Weir	unknown		Outeniqua	Kaaimans

1: Excluding ecological water requirements; permitted abstraction 10.5 million m^3/a; *: not currently in use due to poor condition; #: being refurbished in 2007

6.3.4.11 Mthatha

The most recent assessment of the situation for towns in the DWS southern planning region was produced in 2015 (DWS, 2015d). Mthatha town itself is considered to have sufficient water available from the Mthatha Dam (Table 28) (capacity 254 million m^3) for the next 40 years (Table 29 for 2030) but the regional scheme, which includes 147 villages, is considered likely to experience water availability shortfalls within 5-10 years. The town currently uses about 21.9 million m^3/a (DWA, 2011c). One of the key issues is that water security is compromised by substantial water losses between the water treatment works and the users. The dam also supplies Eskom's First and Second Fall hydro-power stations with about 2.0 million m^3/a.

All the water comes from the Mthatha River which has its source in the Eastern Cape Drakensberg SWSA-sw.

Table 28: Benefit shed for Mthatha showing the supply dam yield (DWA, 2011c) and the associated SWSA and river system.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage from SWSA	Strategic Water Source Area	River System
Mthatha	Mthatha Dam	145	100	Eastern Cape Drakensberg	Mthatha River

Table 29: Current and modelled future use (million m^3/a) for Mthatha (DWA, 2011c)

Urban Centre	Current Use (2007)	Future Use (High) (2030)	Future Use (Low) (2030)
Mthatha	22.10	26.04	22.10

6.3.4.12 Upington

Although the Orange River system supplies a large area of the Northern Cape with water, as well as transferring water to the Eastern Cape (Figure 45), only Upington is included in the assessment as an urban centre. Upington was included in the Lower Orange River Management Study with an allowance of 21.4 million m^3/a for 2010 increasing to 23.1 million m^3/a by 2025 (DWA, 2011d). The report notes that although Upington has the highest urban demand along the Orange River, this demand is still relatively small compared with the total demand. Upington has a WARMS registered use of 25 million m^3/a, but actual water usage for Upington in 2008 was 12.80 million m^3 (Jeleni and Mare, 2007). Upington receives its water directly from the Orange River and predicted future use indicates a substantial increase (Table 30).

Table 30: Current and modelled future use (million m^3/a) for Upington

Urban Centre	Current Use (2008)	Future Use (High) (2030)	Future Use (Low) (2030)
Upington	12.30	19	17

Most of the present day runoff of the Orange River is generated in Lesotho with very little coming from the Upper and Middle Vaal (Figure 46) due to high use in the Vaal system. It is unlikely that the water used by Upington in the middle reaches of the Orange River is directly supplied the Maloti, Northern, Southern and

Eastern Cape Drakensberg SWSA-sw, which are located far from the abstraction point. It is impossible to separate the SWSA-sw sourced water from the return flows from the irrigated areas and urban and industrial centres upstream. So, although it is clear that the SWSA-sw in upper Orange, Vaal and Tugela River catchments are the ultimate sources of the water for Upington, we have not identified them as contributing directly to its water supply (Table 31).

Figure 45: Schematic showing the area supplied by the Orange River, including the inter-basin transfers to the Eastern Cape rivers.

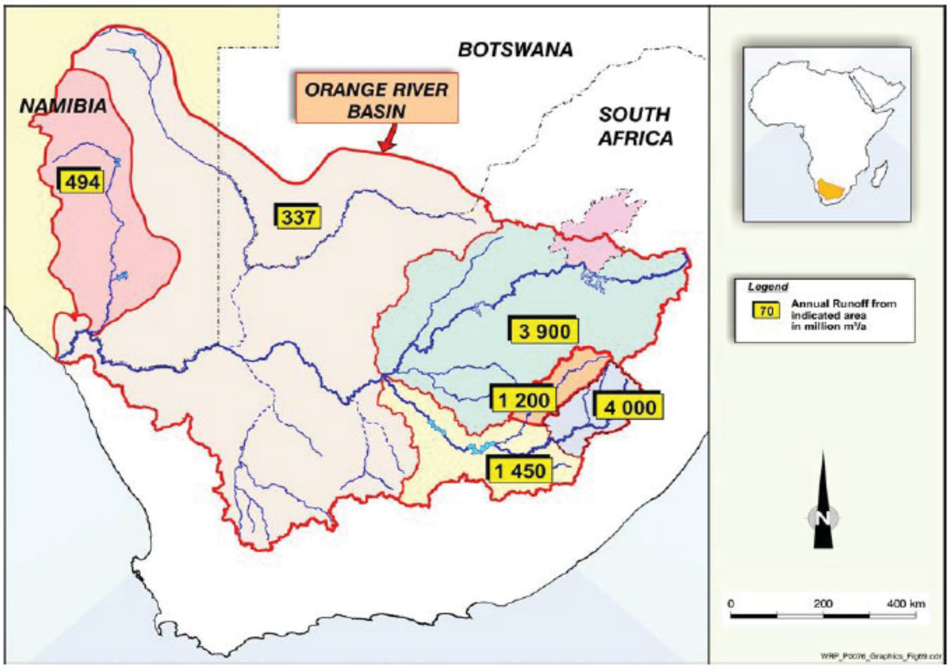

Figure 46: Diagram showing the relative runoff for the different catchments in the Orange-Senqu Basin, from Jeleni and Mare (2007).

Table 31: Benefit shed spreadsheet for Upington showing the Orange River as the only source of water for the urban centre.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage from source	Strategic Water Source Area	River System
Upington	Orange Run-of-river	25.0	100%	None	Orange River

6.3.4.13 Ladysmith

The Ladysmith Water Supply Scheme is located in the Thukela River Catchment and Thukela Water Management Area. The WSS includes the town itself and surrounding areas and villages that can be supplied from the scheme, such as Steadville (DWA, 2011e). Economic activities in the area include manufacturing, agriculture and tourism, the latter being expected to develop rapidly in the future.

The WSS obtains its raw water from the Klip River, Tugela River and Spioenkop Dam with a registered use of 5.9 million m^3/a from the Klip River (direct abstraction), Spioenkop Dam (pipeline) and a link between the Ezakheni and Ladysmith schemes which can deliver 1.8 million m^3/a. The current use exceeds the agreed allocation (Table 32). The scheme was in surplus in 2008 based on unallocated water in the Tugela system, but additional supplies will be required by 2025 which will require water trading and reductions in water losses. The Spioenkop Dam is part of the scheme which transfers water to the Vaal River system and could be used as the source for additional water requirements. All the water for Ladysmith is sourced from the Tugela catchment's portion of the Northern Drakensberg SWSA-sw.

Table 32: Current and modelled future use (million m^3/a) for Ladysmith (DWA, 2011e)

Urban Centre	Current Use (2008)	Future Use (High)	Future Use (Low)

		(2030)	(2030)
Ladysmith	9.27	21.89	13.13

6.3.4.14 Newcastle

The town of Newcastle is situated in the Amajuba District Municipality in KwaZulu-Natal and includes the Newcastle, Dannhauser and eMadlangeni Local Municipalities. The Newcastle LM is characterised by the well-developed town of Newcastle, mining and large industries, including steelworks and synthetic rubber, and nearly 90% of the population live in Newcastle (DWA, 2011f). In addition to supplying the domestic and industrial water to the town, the Newcastle water supply scheme also supplies the Buhlebomzinyathi tribal area which includes Madadeni and Osizweni.

The Ngagane WTW obtains its water from three sources (a) Ntshingwayo Dam on the Ngagane River (storage capacity 194.6 million m^3), (b) abstraction works in the Ngagane River, downstream of the dam; and (c) the Buffalo River abstraction works at Schurvepoort. In 2008 raw water abstraction at the WTW was 40.66 million m^3/a, with high raw water losses (estimated to be 20%) attributed mainly to leaks in the main pipeline. The water demand is projected to increase rapidly due to rapid population growth and economic development and supplementary water supplies to the nearby towns of Dannhauser and Durnacol which were self-sufficient in 2011 (Table 33). The total registered water use is 55 million m^3/a: 33.0 million m^3/a from Ntshingwayo Dam, 11.0 million m^3/a from the Ngagane and 11.0 million m^3/a from the Buffalo River. The supply from the Buffalo River was added in 1992 as an emergency drought measure but has been in operation since then. The Buffalo River also supplies the town of Utrecht (1.36 million m^3/a), irrigated agriculture (26.47 million m^3/a) and Arcelor Mittal Steel (7.05 million m^3/a). The Ntshingwayo Dam also stores water for the towns of Glencoe and Dundee downstream. The Slang and Buffalo Rivers also supply 15.98 million m^3/a to Majuba Power Station from the Zaaihoek Dam. The Zaaihoek (capacity 184.63 million m^3) and Ntshingwayo Dams contribute 173 million m^3/a to the total system yield of the upstream catchments.

Table 33: Current and projected future use (million m^3/a) for Newcastle (DWA, 2011f).

Urban Centre	Current Use (2008)	Future Use (High) (2030)	Future Use (Low) (2030)
Newcastle scheme	40.66	126.22	63.07

Although the water scheme can currently meet demand, meeting the projected demand will require water conservation and demand management (notably water loss reduction), water trading with irrigation, and waste water re-use.

The water for the WSS is primarily supplied by the Northern Drakensberg SWSA-sw, which supplies the Ngagane River and the Ntshingwayo Dam, and the Enkangala Drakensberg SWSA-sw which sustains the Slang, Buffalo (incl. Zaaihoek Dam) and Klip Rivers. Thus the Northern Drakensberg provides 44 million m^3/a (80%) and the Enkangala Drakensberg 11 million m^3/a (20%) of the current registered use.

6.3.4.15 Mbombela-Nelspruit

The natural MAR for the Crocodile Catchment is in the order of 1 136 million m^3 but the capacity of the dams in the catchment comes to just 199.8 million m^3 (DWA, 2014b), which means that much of the runoff in the catchment remains in the streams and rivers and is not captured by dams. However, large volumes are abstracted for irrigation, about 408 million m³/a in the Crocodile River system alone, 209 million m³/a upstream of or within the Mbombela municipality. The water use for the Mbombela study area is summarised in Table 34 and includes the source of the water for each of the local water supply systems.

The main dams which supply Mbombela are shown in Figure 47 with the yield of each dam as a percentage of the total system yield (Table 35). The Kwena Dam, which is not directly supplying any settlements, has a historic firm yield of 83.2 Million m³/a, and plays an important role in supplying irrigation water. As mentioned above, much of the runoff remains in the rivers, as illustrated by Nelspruit which receives its water from a diversion weir on the Crocodile River and not from a dam. All of the dams are located within the Mpumalanga Drakensberg SWSA-sw which supplies 100% of the water for Mbombela dams as well as the runoff in the rivers.

Table 34: Current (2014) and future use for the different areas within the Mbombela Reconciliation Strategy (DWA, 2014b).

Urban Centre and Use	2014 use (million m³/a)	2030 low growth (million m³/a)	2030 high growth (million m³/a)	Dam or Source Name
Nelspruit Domestic	9.07	13.48	15.05	Diversion weir on the Crocodile River
Nelspruit Industrial		6.3	7.03	
White River: Domestic	2.77	3.47	6.78	Witklip Dam Longmere & Klipkopje Dams Borehole
White River: Industrial	6.6	0.86	1.81	
Karino/Plaston Corridor: Domestic		3.09	3.57	Primkop Dam Direct abstraction from Crocodile River
Karino/Plaston Corridor: Industrial		0.46	0.52	Crocodile River offtake
Nsikasi South: Domestic	19.00	20.46	21.88	Crocodile River offtake
Nsikasi South: Industrial	0.29	0.29	0.29	Crocodile River offtake
Matsulu: Domestic		7.68	7.99	Crocodile River offtake
Nsikasi North: Domestic	10.72	12.52	13.26	Sabie River offtake
Hazyview: Domestic	1.39	1.65	1.71	Sabie River offtake
Elandshoek: Domestic:	54.12	0.04		Direct from local stream
Ngodwana: Domestic:	0.50	0.50		Ngodwana Dam
Kaapsehoop: Domestic	0.03	0.03		Boreholes
Ngodwana: Industrial Sappi	14.00	14.00	14.00	Ngodwana Dam

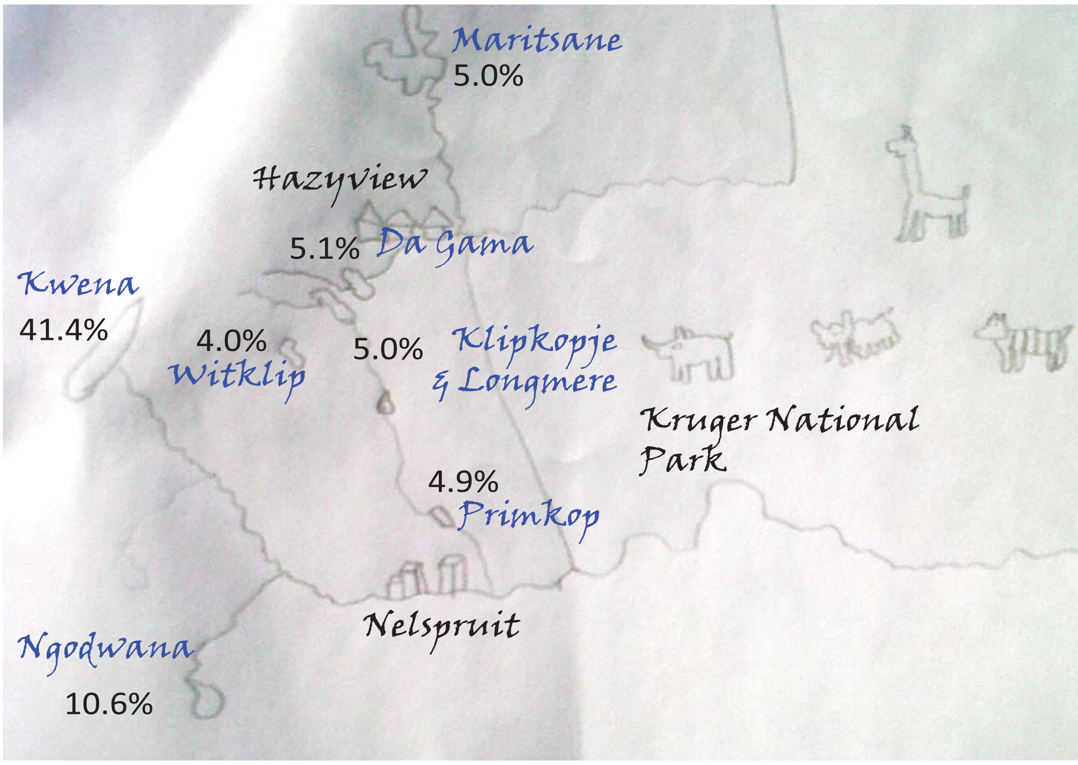

Figure 47: Schematic of the major dams which supply the Mbombela area with the 1 in 50 failure of supply yield as a percentage of the total yield. Nelspruit receives its water directly from the Crocodile River.

Table 35: Benefit shed table for the Mbombela Study Area showing the 1 in 50 failure of supply yields and as a percentage of the total yield.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage	Strategic Water Source Area	River System
Mbombela: Crocodile	Kwena Dam	87.5	41.4	Mpumalanga Drakensberg	Crocodile
Mbombela: Crocodile	Witklip Dam	8.5	4.0	Mpumalanga Drakensberg	Sand
Mbombela: Crocodile	Klipkopje Dam	10.6	5.0	Mpumalanga Drakensberg	Crocodile
Mbombela: Crocodile	Longmere Dam			Mpumalanga Drakensberg	White River
Mbombela: Crocodile	Primkop Dam	10.3	4.9	Mpumalanga Drakensberg	Crocodile
Mbombela: Crocodile	Ngodwana Dam	22.4	10.6	Mpumalanga Drakensberg	Crocodile
Mbombela: Sabie	Inyaka Dam	50.7	24.0	Mpumalanga Drakensberg	Sabie
Mbombela: Sabie	Da Gama Dam	10.8	5.1	Mpumalanga Drakensberg	Sabie
Mbombela: Sabie	Maritsane Dam	10.5	5.0	Mpumalanga Drakensberg	Sabie

6.3.4.16 Luvuvhu-Letaba

The Luvuvhu/Letaba Reconciliation Study Area includes Tzaneen and the growing towns of Giyani and Thohoyando (DWA, 2014c, 2012f, 2012g). There are two transfers out of the catchment (Figure 48): The first transfer is from Albasini Dam to Makhado (2.4 million m^3/a) and the second transfer is from Ebenezer and Dap Naudé Dams to Polokwane (±20.2 million m^3/a). There is an intra-basin transfer from Nandoni Dam to Nsami Dam to augment the water supply to Giyani and a canal from Middle Letaba to Nsami Dam. The water balances and flows in these catchments are very complicated because of the large Rural Water Supply schemes and transfers between them and the various storage dams. In many cases groundwater supply schemes augment the supplies in this largely rural area.

Figure 48: Schematic showing the main dams in the Luvuvhu-Letaba catchment and the transfer schemes.

The recently completed Luvuvhu-Letaba Reconciliation Study provided data on the yields of the dams in the system and the urban centres they supply (DWA, 2014c), and groundwater yields were assumed from DWS All Towns Reconciliation project data (Table 36). The estimated urban/industrial and rural demand for 2012 within the different sub-catchments (million m^3/a from surface water) was:

- Letaba: Groot Letaba 27.80, transfers to Polokwane 20.17, Middle Letaba 18.37;
- Luvuvhu & Shingwedzi 33.77
- Mutale 2.41

These systems are generally under stress from over-allocation and a number of new dams and transfer schemes are being considered in addition to the expansion of groundwater schemes in some areas. Thohoyandou is situated within the Soutpansberg SWSA-sw as well as being within the Soutpansberg SWSA-gw. The Giyani SWSA-gw is situated in the central Letaba and the source of the Letaba River, and most of its tributaries, is located in the Letaba Escarpment SWSA-gw as well as the Wolkberg SWSA-sw.

Table 36: Benefit Shed for the urban centres in the Luvuvhu-Letaba catchment completed with data on the main dams from the yield study and the reconciliation study, excluding the transfers out (DWA, 2014c, 2014d).

Urban Centre	Source associated with urban town	Historic firm yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Giyani	Middle Letaba	18.0	9.4	Wolkberg and Soutpansberg	Little Letaba
Giyani	Nsami	0.2	0.1	None	Little Letaba
Giyani	Groundwater	3.6	1.9	Giyana	n/a
Thohoyandou	Vondo	16.8	8.8	Soutpansberg	Luvuvhu
Thohoyandou	Albasini (excl. groundwater)	1.4	0.7	Soutpansberg	Luvuvhu
Thohoyandou	Nandoni	62.0	32.4	Soutpansberg	Luvuvhu
Tzaneen	Tzaneen Dam	45.0	23.5	Wolkberg	Groot Letaba
Tzaneen	Ebenezer & Dap Naudé	36.2	18.9	Wolkberg	Groot Letaba
Politsi, Duiwelskloof & GaKgapane	Magoebaskloof & Vergelegen	8.1	4.2	Wolkberg	Groot Letaba

6.3.4.17 Olifants

The Olifants River Reconciliation Strategy is separated into the Upper Olifants (which includes Emalahleni and Middelburg), the Middle Olifants (which includes Lydenburg) and the Lower Olifants (which includes Phalaborwa) (Figure 49) (Table 37) (DWA, 2011g). The water requirements for the power generation in the Upper Olifants are fully met by inter-basin transfers from the Upper Vaal and the Upper Komati Catchments, with no return flows into the Olifants River. The benefit shed spreadsheet for the Upper, Middle and Lower Vaal and includes the dams which transfer water to Mokopane and Polokwane (Table 38).

The Dap Naudé and the Ebenezer Dams are located in the Wolkberg SWSA-sw and contribute 1% to the total yield of all the dams in the Olifants catchment (Table 37). The Phalaborwa Barrage (6%) is located downstream of the Wolkberg SWSA-sw. The Mpumalanga Drakensberg SWSA-sw contributes 41% to the dams in the Middle and Lower Olifants. In total, SWSAs contribute 48% to the total yield of the dams in the Olifants Catchment. None of the towns in the in the Emalahleni Municipality in the Upper Olifants catchment obtain their water from SWSA-sw. The MAR in the Upper Olifants Catchment is relatively low and very evenly distributed, with only the area near Bethal coming close to meeting the requirements for an SWSA-sw.

The Wilge River and some of its tributaries (e.g. Bronkhorstspruit) have their sources in the Eastern Kart Belt SWSA-gw and the Northern Highveld SWSA-gw is linked to the Olifants River tributaries to the east of Loskop Dam. The Northern Lowveld Escarpment SWSA-gw extends from Chuniespoort across a portion of the Olifants River and much of the Blyde River tributary’s catchment. The Phalaborwa SWSA-gw is found around the town of Phalaborwa and includes the confluence of the Olifants and Ga-Selati Rivers.

Table 37: Summary of water requirements for the Upper, Middle and Lower Olifants

Management Zone	Irrigation	Urban	Rural	Industrial	Mining	Power Generation	Total
Upper Olifants	249	93	4	9	26	228	**609**
Middle Olifants	81	56	22	0	28	0	**187**
Lower Olifants	156	29	3	0	32	0	**220**
Total	**486**	**178**	**29**	**9**	**86**	**0**	**1016**

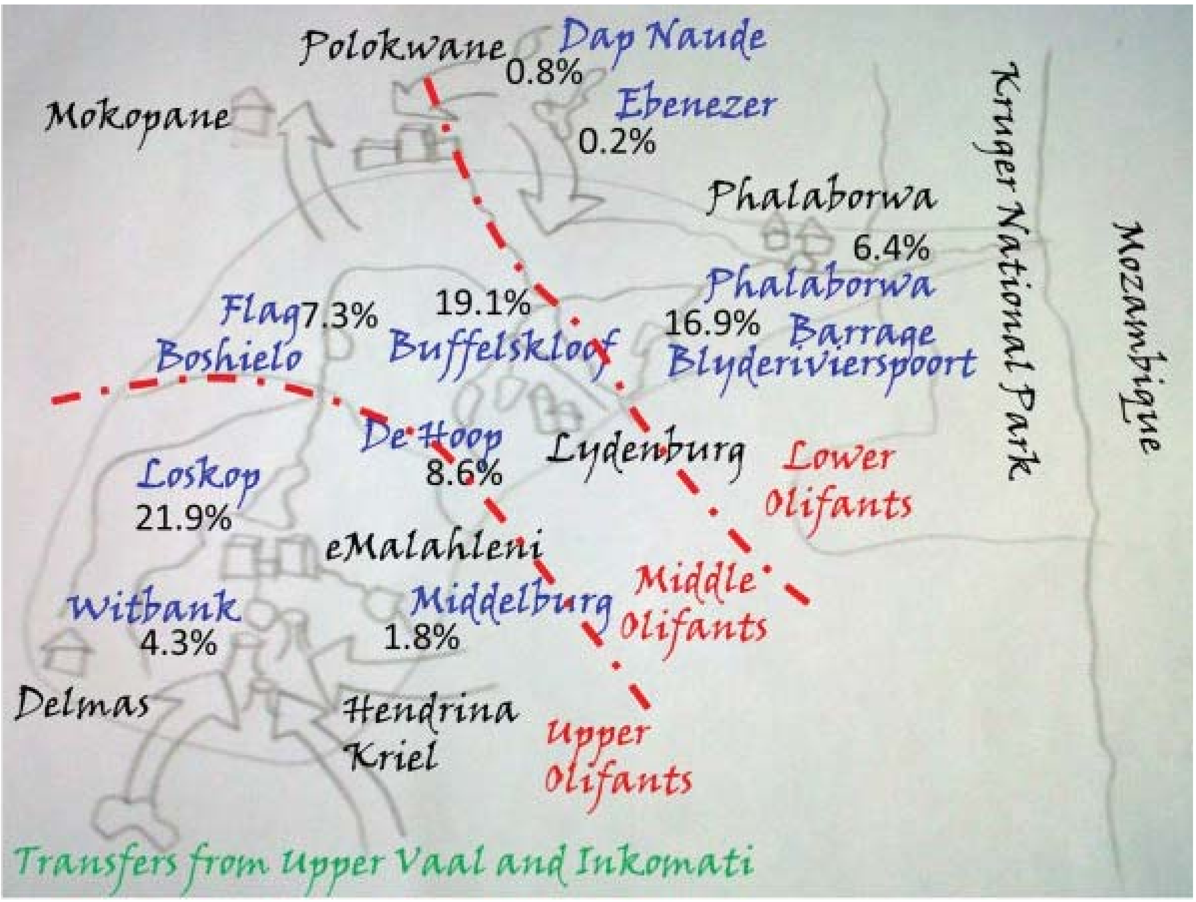

Figure 49: Schematic of the Olifants River Catchment, showing the Upper, Middle and Olifants management areas. Only the main dams and the percentage yield of the total dam supply to the catchment are shown.

Table 38: Benefit shed for the Olifants catchment summarising the main dams and their yields.

Urban Centre	Dam associated with urban town	Yield (million m^3/a)	Percentage of total	Strategic Water Source Area	River System
Olifants transfer: Polokwane	Dap Naudé Dam	6.2	0.8	Wolkberg	Great Letaba
Olifants transfer: Polokwane	Ebenezer Dam	1.2	0.2	Wolkberg	Great Letaba
Olifants transfer: Mokopane	Doorndraai Dam	4.4	0.6	None	Mogalakwena
Olifants Upper	Bronkhorstspruit	23.5	3.1	None	Wilge
Olifants Upper	Middelburg Dam	14.0	1.8	None	Klein Olifants
Olifants Upper	Wilge Dam	8.0	1.0	None	Wilge
Olifants Upper	Witbank Dam	33.0	4.3	None	Olifants
Olifants Upper	Loskop Dam	168.0	21.9	None	Olifants
Olifants Upper	Rust de Winter Dam	11.7	1.5	None	Elands
Olifants Upper	Mkombo with Weltevreden weir	14.0	1.8	None	
Olifants Middle	Flag Boshielo	56.0	7.3	None	Olifants
Olifants Middle	De Hoop	66.0	8.6	None	Steelpoort
Olifants Middle	Buffelskloof	147.0	19.1	Mpumalanga Drakensberg	Spekboom
Olifants Middle	Der Brochen	8.3	1.1	Mpumalanga Drakensberg	Dwars (Steelpoort)
Olifants Middle	Belfast	5.7	0.7	Mpumalanga Drakensberg	Langspruit (Steelpoort)
Olifants Middle	Lydenburg	2.5	0.3	Mpumalanga Drakensberg	Sterk (Dorps, Steelpoort)
Olifants Lower	Ohrigstad	19.8	2.6	Mpumalanga Drakensberg	Ohrigstad
Olifants Lower	Blyderivierspoort	130.0	16.9	Mpumalanga Drakensberg	Blyde
Olifants Lower	Phalaborwa Barrage	49.0	6.4	Wolkberg	Olifants

6.3.4.18 Polokwane

As described in Section 6.3.4.17, Polokwane is supplied with water from the Olifants River system through transfers from the Ebenezer Dam, Dap Naudé Dam and the Olifantspoort Weir (Table 39)(Figure 50) (DWS, 2016b). About 55% of the water requirements come from the Great Letaba River system which is linked to the Wolkberg SWSA-sw and the balance from the middle Olifants River which has a small contribution from

SWSA-sw along the Drakensberg escarpment. In addition, the town's supply is supplemented with 3.68 million m^3/a (11%) of groundwater from the Upper Sand (Polokwane) Aquifer System SWSA-gw.

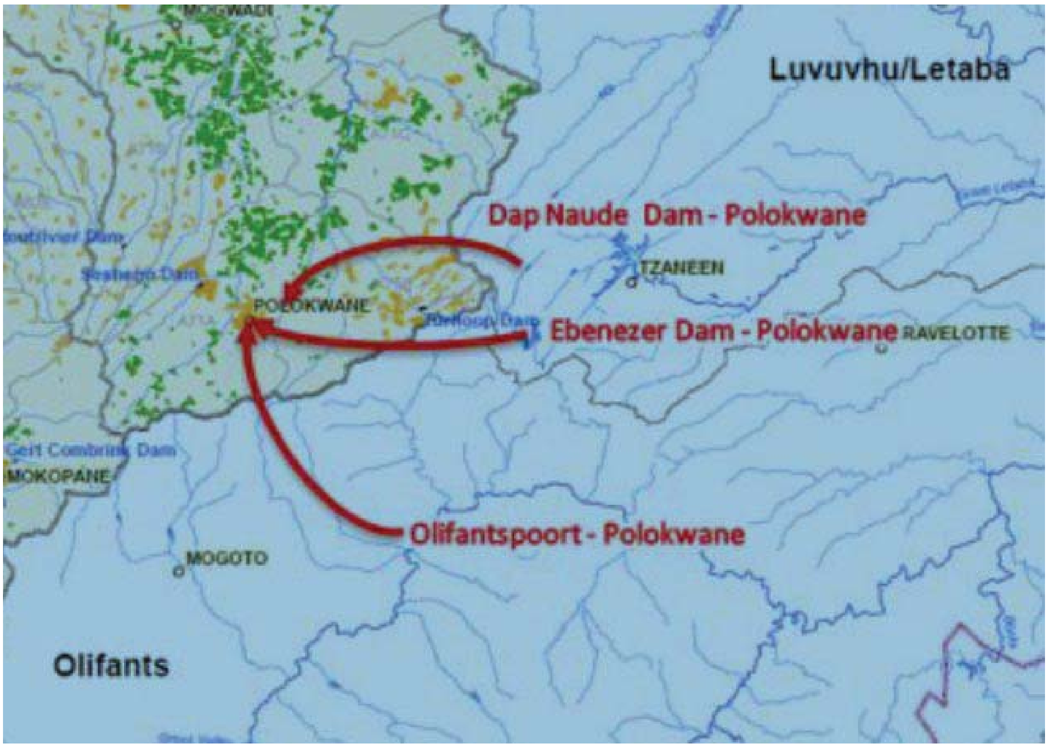

Figure 50: Transfers to Polokwane from the Great Letaba and Olifants River systems (DWS, 2016b).

Table 39: Benefit shed for Polokwane showing the transfers, the groundwater (not included in the percentages) (DWS, 2016b) (DWA, 2011c)and the associated SWSA and river system.

Urban Centre	**Water source associated with urban town**	**Transfer or yield (million m^3/a)**	**Percentage**	**Strategic Water Source Area**	**River System**
Polokwane	Ebenezer Dam	12.0	35.8	Wolkberg	Great Letaba
	Dap Naudé Dam	6.5	19.4	Wolkberg	Great Letaba
	Olifantspoort Weir (Flag Boshielo Dam)	11.3	33.8	None	Olifants River
	Groundwater	3.68	11.0	Upper Sand (Polokwane) Aquifer System	None

The domestic water requirements in the Sand catchment, where Polokwane is situated, were 38.7 million m^3/a of surface water and 17.1 million m^3/a of groundwater in 2011, and they are expected to increase to a total of 69.4 million m^3/a by 2030 (DWS, 2016b). The mining and industrial requirements were 10.8 million m^3/a in 2011 and are expected to increase to 56.0 million m^3/a by 2030. Meeting these requirements will require upgrades to the existing system, recycling, additional transfers from other WMAs, notably Crocodile West, and clearing of invasive alien plants.

6.3.5 Summary of linkages between urban centres and Strategic Water Source Areas

The major urban centres generally source a high percentage water of their water from the SWSA-sw (Table 40). In the case of the Vaal WSS, if the yield from the portion of the Vaal catchment outside the catchment's SWSA-sw is excluded, 67% of the water is from SWSA-sw. The lowest is the Olifants regional WSS which gets less than half of its water from SWSA-sw. In some cases, notably Pretoria, Richards Bay and Polokwane, a fair proportion of the urban centre's water is obtained from SWSA-gw (Table 40).

Table 40: Summary of urban centres and the percentage of their water supply which is linked to Strategic Water Source Areas.

Water supply scheme	Urban centre	Percentage linked to SWSAs	Strategic Water Source Areas
Vaal	Pretoria, Johannesburg, Vereeniging	70.6	Maloti Drakensberg 34.5%, Northern Drakensberg, Upper Vaal, Enkangala, Upper Usuthu 36.5%
Crocodile West	Johannesburg, Pretoria	>50.0	Including transfer from Vaal WSS and Eastern Karst Belt
Western Cape	Cape Town	100.0	Boland & Groot Winterhoek 96.8%, Table Mountain 1.6%; Atlantis 1.3%, Albion Springs 0.4%
KwaZulu-Natal	Durban, Pietermaritzburg	97.8	Southern Drakensberg 97.8%
Algoa	Port Elizabeth	91.0	Tsitsikamma 40.9%, Kouga 22.4%, Maloti Drakensberg 25.3%; Uitenhage Springs 2.3%
Bloemfontein	Bloemfontein	70.3	Maloti Drakensberg 70.3%
Amatole	East London, King Williams Town	92.5	Amatole 91.1%
Polokwane	Polokwane	66.3	Wolkberg 55.3%; Upper Sand (Polokwane) Aquifer System 11.0%
Richards Bay	Richards Bay	47.4	Mfolozi Headwaters 11.0%; Northern Drakensberg 20.7%; Richards Bay groundwater-fed lakes 15.7%
Luvuvhu-Letaba	Thohoyandou, Giyani, Tzaneen	100.0	Soutpansberg 41.9%; Wolkberg 56.1%; Giyana 1.9%
Mbombela	Nelspruit, White River, Hazyview	100.0	Mpumalanga Drakensberg 100%
Mosselbay	Mossel Bay	94.7	Outeniqua 94.7%
George and Wilderness	George	100.0	Outeniqua 100%
Mthatha	Mthatha	100.0	Eastern Cape Drakensberg 100.0%
Ladysmith	Ladysmith	100.0	Northern Drakensberg 100.0%
Newcastle	Newcastle	100.0	Northern Drakensberg 80.0%; Enkangala Drakensberg 20.0%
Olifants	Witbank, Groblersdal, Phalaborwa	48.1	Mpumalanga Drakensberg 40.7%, Wolkberg 7.4%

6.4 Agricultural benefit flows from Strategic Water Source Areas

6.4.1 Introduction

More than half the country has an annual rainfall of less than 500 mm which means that it is generally unsuitable for crop cultivation unless it is irrigated. Almost all of the land assessed as having a high agricultural capability (i.e. both suitable for cultivation and with a suitable climate (Laker, 2004; Schoeman et al., 2002)) is already under cultivation. The actual extent varies with economic and climatic conditions and how they influence farmers to increase or decrease the areas they till in a given period (Biggs, 2002). This leaves little land for additional cultivation. The current drought in the winter-rainfall region, and recent drought in the summer rainfall region, have highlighted the growing water and food security problems, especially the shortages of important dryland crops such as maize and wheat. There are ambitious plans to expand irrigated agriculture by about 50% (or at least 800 km^2) to meet food security requirements, but most of the utilisable water is already allocated, leaving very little for such expansion, so that water use efficiency will have to be increased significantly (DWAF, 2013).

The agricultural survey of 1996 found that the total area of farmland was 1 006 558 km^2 (82% of the total area of the country) of which 167 377 km^2 is considered potentially arable. Most of the arable land is cultivated, and 14 340 km^2 are under commercial forest plantations (DAFF 2016). In 1993 about 95 283 km^2 were under field crops and 38 985 km^2 under horticultural crops (orchards, vines, vegetables) on commercial farms although other sources give 13 541 km^2 under irrigation on commercial farms (Development Bank of Southern Africa, 1991 in (DAFF, 2016)). No data were provided for farms in the former homelands. Irrigated agriculture currently requires about 7 920 million m^3/a of water, which is about 60% of the national annual water requirements, but about 35-45% of that water is lost before it is applied to the crop (DWAF, 2010, 2004). Irrigated agriculture is also an important source of pollution through its return flows, i.e. surplus water that drains back to rivers (CSIR, 2011; DWAF, 2013). On the other hand, irrigated agriculture accounts for almost all the vegetable and fruit production in the country which makes it critical for meeting people's nutritional requirements.

About 8.5 million people are directly or indirectly dependent on agriculture for employment and income (DWAF, 2013). The sector contributes about 3% to the national GDP and provides about 7% of the formal employment but its real importance is far greater because failing to ensure that people have sufficient, affordable food can threaten national security. An analysis of the 2011 Census data found that 2.9 million households (20% of the total) were involved in agriculture, with the percentage involvement ranging from 25% in KwaZulu-Natal, 21% in the Eastern Cape to 3% in the Western Cape and 2% in Northern Cape (Statistics South Africa, 2013).

Different methods were applied in analysing the agricultural benefit sheds for SWSA-sw and for SWSA-gw. For SWSA-sw, major areas of irrigated agriculture were identified, estimates of the surface water allocated to each area were sourced, and were related back to the SWSA-sw, as well as quantifying their contribution to the economy. This approach is necessary for surface water because of the location of the source can be a long way from the point of use. In the case of the Orange-Vaal system the return flows from various water-users can be re-used several times which makes the quantifying the sources a study on its own. The analysis was therefore focussed at a high level to try to capture the essential details and avoided getting involved in detailed accounting. Conversely, with some exceptions, groundwater used for irrigation is mostly sourced from groundwater resources close to or at the point of abstraction. It is generally not sourced from large-scale groundwater-fed schemes which transport groundwater significant distances, or abstracted from aquifers with recharge zones very distant from the point of use (described more fully in Section 6.2 and

Section 2.2.2). This is why groundwater use for agriculture within a given SWSA-gw was summed to provide an indication of the agricultural beneficiaries of that SWSA-gw.

6.4.2 Agricultural (and industrial) benefits from SWSA-sw

6.4.2.1 Data sources and selection

The primary sources of information on agriculture are the databases on agricultural statistics maintained by the Department of Agriculture, Forestry and Fisheries (DAFF)[6] and Statistics South Africa[7]. Water requirements for irrigation are described in the national water resources strategy (DWAF, 2013) and other strategic planning documents held by the Department of Water and Sanitation. The most recent statistics available for agriculture are for 2015 and are summarised in the annual abstracts (DAFF, 2016). However the key statistics on cultivated areas in these abstracts date from 1996 and irrigation data were from 1991. The statistics are also only available at the provincial level which is not suitable for identifying where the main irrigated areas are located.

The National Water Accounts provide information on areas of irrigated land, water allocations and economic contributions for each of the water management areas (Statistics South Africa, 2010). The statistics on areas under agricultural land are from 2002 and information is provided on areas and production of field crops and horticultural crops, in tons and Rand, in each of the 19 Water Management Areas as originally defined for South Africa (DWAF, 2004). The assessments also provide an estimated average water allocation (m^3/ha/year), water use (m^3/year), volume purchased, cost (cents/m^3) and production (Rand per m^3). The data identify the WMAs where there are large irrigated areas and there is a high water allocation, as well as the value of the produce.

However, these data are still relatively coarse and more than 10 years old. An update is under way as part of a Water Research Commission project (W. Nomquphu, personal communication, July 2016), but the results are not available yet. The Water Resources 2005 (Middleton and Bailey, 2008) and 2012 studies (Bailey and Pitman, 2015b) provide information on irrigated areas and allocations for each quaternary catchment in South Africa. However, the information on the areas under irrigation is based on the 1996 land cover (Fairbanks et al., 2001) which is out-of-date, and there only seem to be estimates of allocations where these are documented, leaving many gaps. Estimates of water allocations are made by the Pitman models used in these water resource assessments, but the allocations are contained in the model parameter files and outputs (A.K. Bailey personal communication June 2016) and are not easily extracted.

The 1996 land cover explicitly distinguished between irrigated (including pastures) and dryland cultivation and between perennial and short-lived crops (Fairbanks et al., 2001). This is generally regarded as a high-quality dataset with extensive ground-truthing and aerial photograph verification. A land cover dataset was produced for 2000 (Van den Berg et al., 2008) but the classes do not explicitly distinguish between irrigated and non-irrigated field crops, whether under commercial of subsistence farming systems. Although some horticultural crops are grown on drylands, the vast majority are grown under irrigation so it is acceptable to assume that they are all irrigated. The same issues apply to the 2013-14 land cover (GTI, 2015), but it does provide information on the crop vigour in each class for field crops. Since irrigated crops typically grow more vigorously than dryland crops it would be acceptable to assume that the high vigour class fields are irrigated. However, these fields comprise a relatively small component, so we excluded them and used the 2014 data for the classes including pivots, orchards, vines, pineapples and sugar cane to represent the current irrigated areas. Sugar cane is grown both in dryland and irrigated systems, with most of the sugar cane in KwaZulu-

[6] http://www.daff.gov.za/daffweb3/Branches/Administration/Statistics-and-Economic-analysis/Publication
[7] http://www.statssa.gov.za/?page_id=735&id=4

Natal being dryland and most in Mpumalanga being under irrigation (Jarmain et al., 2014). However, detailed data on where irrigation was applied were not readily available so sugar cane has been treated as an irrigated crop in this assessment.

The Department of Agriculture, Fisheries and Forestry has created datasets for all the cultivated fields in each province in South Africa based on SPOT imagery, the most recent version being for the year 2013 (DAFF, 2015). The classes are very similar to the 2013-14 national land cover (GTI 2015) and include annual crops or pastures, horticulture or viticulture and pivots. Although additional crop data (e.g. pulses) are available for some provinces, they are not available for all provinces. Visual inspection shows that these datasets are spatially very similar to the national land cover, so we chose to use the national land cover as this is the same dataset we have used for the analysis of the state of the SWSAs in this report (see Section 7.1).

The irrigation requirement data for the 2004 NWRS are provided per WMA, but we wished to obtain data per secondary catchment to align the results better with the data for water transfers for meeting domestic and industrial water requirements. We used the national land cover to get data on the area of irrigated land in each of the WMAs and then calculated the proportion of the total irrigated land in each quaternary catchment in the respective WMA. This proportion was used to estimate the proportion of the WMA irrigation requirement in each quaternary. The quaternary data were then summed to obtain the irrigation water requirement per secondary catchment. This approach does not allow for increases in the requirements based on expansion in the irrigated area from 1996 to 2014 but to make these adjustments we would need data on the crops involved and suitable data are not available at present.

There are various sources of information on the economics of agriculture in South Africa, including the Statistics South Africa and DAFF (http://www.statssa.gov.za/?s=agriculture; http://www.daff.gov.za/daffweb3/Branches/Administration/Statistics-and-Economic-analysis/Publication). These sources provide details on the economic performance of different components of the agricultural sector, but typically for administrative units such as provinces. The National Water Accounts (Statistics South Africa, 2010) do provide information by WMA but that is still relatively coarse for our purposes and the data are out of date. The CSIR has been producing disaggregated economic data for small spatial units, defined largely by administrative boundaries and land-cover information for several years (Naudé et al., 2007; Van Huyssteen et al., 2009). The disaggregation process uses well-defined rules to distribute economic activity to mesozones – spatial units of about 7x5 km. Each mesozone unit was assigned quaternary catchments by using the centroid of the mesozone to identify which catchment it fell in. The Gross Value Added (GVA), is a measure of the monetary value added by a sector (e.g. agricultural producers) including employee compensation and operating surpluses, and is a sound measure of economic activity (EUROSTAT, 2008). However, it also includes the value added by fisheries and forestry, as well as the primary and secondary processors where they are directly involved in, for example food packing or wine production. This gives very high GVA values in some areas, typically those including processing industries so the GVA is inflated without necessarily taking into account the water used which may come from water service providers such as municipalities. Except for the secondary catchments along the Orange River, the GVA data includes dryland cultivation and livestock production. It is not possible to exclude the dryland GVA at this stage but, since irrigated agriculture tends to produce higher value crops, this probably does not bias this analysis significantly. The GVA of the dairy industry is included, which is appropriate given that almost all dairy farming is based on irrigated pastures. Disaggregating the farm GVA from the other agricultural sector GVA activities would require detailed analysis so we have used the GVA as provided. The Rand values per mesozone and sector are available from 1996 to 2013. The 2013 data were used in this analysis and the data were aggregated to a secondary catchment level for comparison with the irrigation requirements.

6.4.2.2 Results

6.4.2.2.1 Irrigation requirements

Irrigated areas are distributed broadly across South Africa, but are mainly found in more humid eastern and south-western parts of South Africa, except for the Orange and Vaal River systems in the centre of the country (Figure 51). Sugar cane is found mainly in KwaZulu-Natal and the Mpumalanga Lowveld and vineyards in the Western Cape and along the Orange River, while orchards and pivots are widespread.

The total area of the irrigated classes in the 1996 land cover came to 17 060 km^2 which is less than the 2013-14 total for pivots, orchards, vineyards, sugar cane and pineapple of 17 645 km^2. Given that it is likely that some of the field crop classes include irrigated land, the increase is probably greater than is indicated by these values. In addition, a comparison of the 2013-14 area under pivots with that under pivots in 1990 shows that there has been an increase of 200% in pivot irrigation, 16% in vineyards and 11% in orchards during this period.

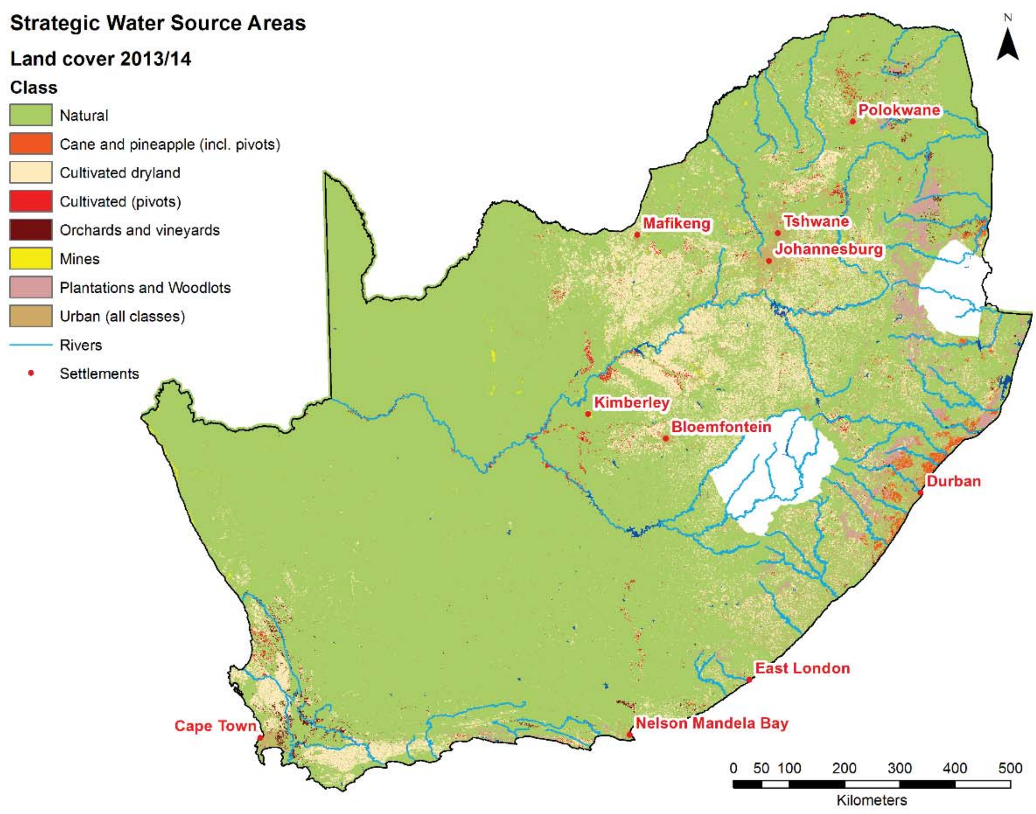

Figure 51: The distribution of the main classes of cultivated agriculture in South Africa based on the national land cover dataset from 2013-14 (GTI 2015). Cultivated fields (commercial or subsistence) were classed as dryland agriculture and the other classes were grouped as irrigated in this assessment.

The summary of irrigation water requirements by sub-WMA for the National Water Resource Strategy (DWAF 2004) shows that by far the largest irrigation requirement is the 916 million m^3/a for the Lower Orange sub-WMA (Figure 52). Large irrigation requirements of 250-500 million m^3/a were also allowed for in the Harts, Upper Orange, Riet-Modder, Vanderkloof, Mgeni, Middle Olifants, Crocodile, Fish and Upper Breede sub-WMAs. When these requirements are recalculated to the secondary catchment level, the middle-Orange (between the Vaal-Orange confluence and the Hartbees) still has the greatest requirement of about 746 million m^3/a (Figure 53) but there are some changes elsewhere. A number of secondary catchments have requirements between 250 and 500 million m^3/a, including the Crocodile, Middle Olifants, Crocodile (West), Harts, Riet-Modder and Orange River (Gariep Dam to Vaal confluence). If the most important areas are those that account for 50% of all the water used for irrigation nationally, then this list should be extended to include the: Mgeni (U2), Lower Orange (D8), lower Sundays (N4), Berg (G1), upper Breede (H1) and central Breede (H4) (Table 41). The total irrigation demand of the top 15 secondary catchments was estimated to be 4155 million m^3/a, 51% of the national total, based on data from the 2004 National Water Resource Strategy (DWAF 2004). These top 15 areas only account for 33% of the total irrigated area, with the top 25 areas accounting for 53% of the total irrigated area and about 66% of the total irrigation water requirement. If a threshold for main irrigation areas is set at 75% of the irrigation requirement, this includes the top 35 secondary catchments and 62% of the irrigation water requirement.

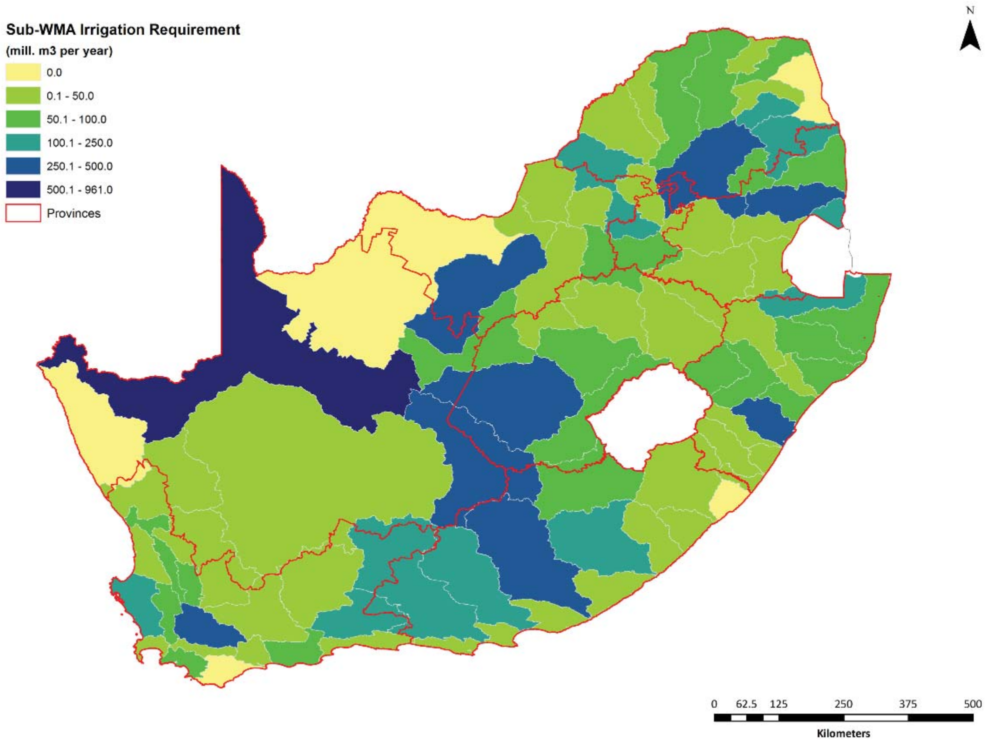

Figure 52: Irrigation water requirements for each sub-Water Management Area based on data from the National Water Resource Strategy of 2004 (DWAF 2004).

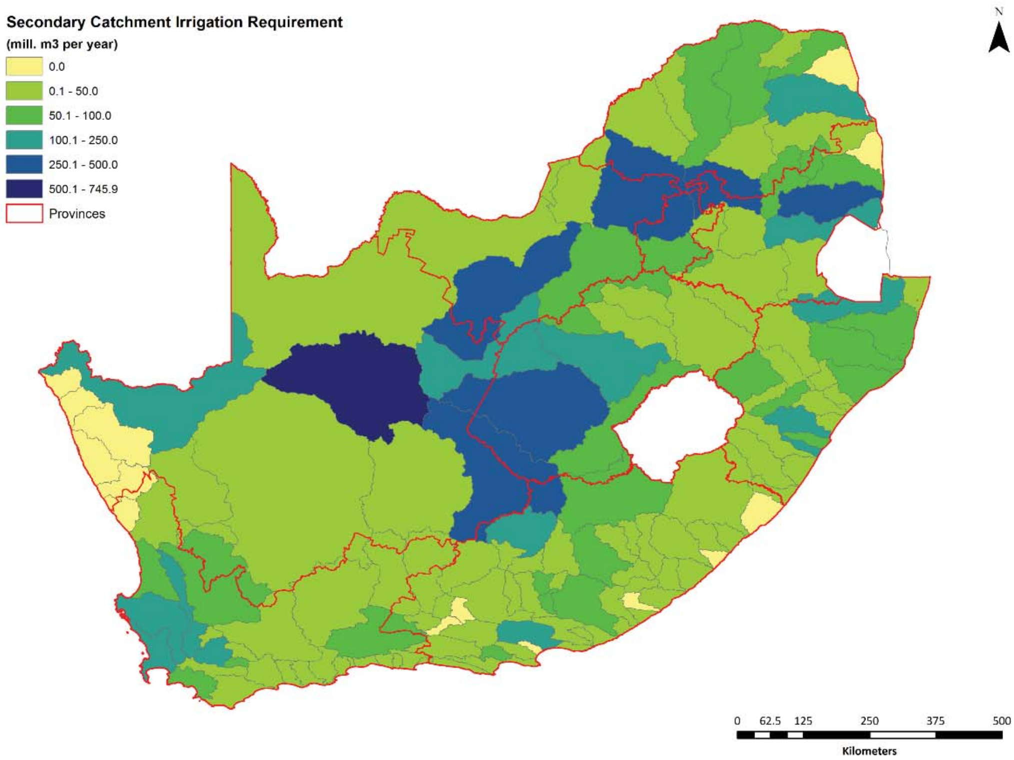

Figure 53: Irrigation water requirements for each secondary catchment based on data on requirements from the National Water Resource Strategy of 2004 (DWAF 2004) and estimates of the area under irrigation in each of the respective quaternaries from the 2013-14 land cover (GTI 2015).

Table 41: The irrigation requirements of the top 20 secondary catchments arranged in descending order based on their estimated requirements. Irrigation requirements recalculated from data in the NWRS 2004 (DWAF 2004) and irrigated areas from the 2013-14 land cover (GTI 2015).

Secondary catchment code and description		**Irrigation requirement (million m^3/a)**	**Irrigated area (ha)**	**Cumulative percentage of national total**
D7	Orange River (Vaal confluence to Hartbees)	745.9	40325.9	9.18
C3	Harts River	453.1	47568.9	14.75
A2	Crocodile (West)	408.9	48384.4	19.78
D3	Orange River (Gariep Dam to Vaal confluence)	336.0	39729.3	23.92
B3	Middle Olifants	273.0	44670.9	27.27
X2	Crocodile	257.0	44067.4	30.44
C5	Riet-Modder	252.0	56159.4	33.54
X1	Komati	236.0	52989.9	36.44
W4	Pongola	213.0	28491.9	39.06
U2	Mgeni	184.0	40641.4	41.32
D8	Lower Orange River	173.2	9359.7	43.45
N4	Lower Sundays River	158.6	14905.7	45.41
G1	Berg River	156.4	51988.4	47.33
H1	Upper Breede River	155.7	29329.0	49.25
H4	Central Breede River	152.3	28679.9	51.12

Secondary catchment code and description		Irrigation requirement (million m^3/a)	Irrigated area (ha)	Cumulative percentage of national total
B8	Letaba	151.0	42099.7	52.98
E1	Olifants River (Olifants-Doring)	149.0	27976.5	54.81
Q1	Headwater Fish River	146.9	8343.0	56.62
G2	Greater Cape Town	144.6	32238.9	58.40
C9	Lower Vaal River	114.8	54070.3	59.81

These findings show that about 15% of all the irrigation requirements are for areas connected directly to the Orange River and fed by the Maloti, Northern, Southern and Eastern Cape Drakensberg (SWSA-sw) located within Lesotho (transboundary) and the Caledon River basin. The Harts (6%) and Riet-Modder (3%) are not directly linked to any SWSA-sw but the Harts is supplemented with about 18 million m^3/a from the Orange River (DWAF 2004). In addition, about 571 million m^3/a is transferred from the Orange River to the Fish, about 117 million m^3/a of which is then transferred to the Sundays River to support irrigation and supply the Nelson Mandela Bay Metropol. The Vaal River is also supplemented with about 413 million m^3/a transferred from the Tugela (Southern and Northern Drakensberg SWSA-sw) and 600 million m^3/a from Lesotho's portions of the Maloti, Northern and Southern Drakensberg SWSA-sw. Most of these transfers are for urban and industrial use in the Gauteng region but some, including return flows, augment the flows downstream. Some of the water transferred from the Vaal to Tshwane is returned to the Crocodile (West). This supplements this river system's flows, some of which are used for irrigation.

The Middle Olifants irrigation requirements are also not linked to an SWSA-sw except for limited overflows from transfers from the Usutu catchment to power stations in the Olifants catchment. The Crocodile and Komati irrigation requirements are provided by the Mpumalanga Drakensberg and Mbabane Hills SWSA-sw and the Pongola by the Enkangala SWSA-sw. The Mgeni is linked the Southern Drakensberg SWSA-sw, and the flows are supplemented by a transfer from the Tugela catchment (Mooi River) which is fed by the Southern Drakensberg SWSA-sw.

The important irrigation areas in the Breede and Berg River systems are supplied by the Boland and Groot Winterhoek SWSA-sw as well as the Hex and western Langeberg, which were not specifically identified in the original analysis but are included in this one. The northern part of the Groot Winterhoek SWSA-sw (i.e. Witzenberg and Kouebokkeveld) supplies the Olifants (E1) which falls just outside the top 15. Also just outside the top 15 is the Letaba (B8) which is supplied by the Wolkberg SWSA-sw.

One of the issues with using the NWRS 2004 data for irrigation requirements is that the area under irrigation has increased since 2000 and includes some new catchments which had no irrigation in 2000. Correcting these deficiencies falls outside the scope of this assessment but could be addressed in updates.

6.4.2.2.2 Gross Value Added

The total agricultural GVA in 2013 was R42.5 billion rand based on the mesozone dataset and its contribution to GDP was estimated at R57.9 billion (DAFF, 2014). The gross income from field crops (12.18 million ha) was some R47.7 billion and from horticultural crops (17 066 km^2) was R47.8 billion, reflecting the high GVA per ha generated by irrigated agriculture. The total gross value (production x average prices) for 2013 was estimated at R187.68 billion with horticultural production contributing 26% of the total compared with animal products at 47%. The most valuable horticultural crops were: deciduous fruit R12.81 billion, vegetables R15.92 billion, viticulture R4.35 billion, citrus R9.56 billion and sub-tropical fruit R2.56 billion. By comparison, milk producers earned R12.43 billion.

The GVA by the agricultural sector is concentrated in KwaZulu-Natal, Western Cape, Gauteng, parts of Mpumalanga, and along the Orange River (Figure 54), areas with extensive irrigation (Figure 51). The relatively high GVA of the Kalahari region (secondary D4) is the result of it including both the relatively high GVA areas in the north-east, including irrigation, and near the Orange River in the west, which is in contrast to the relatively low irrigation requirement (Figure 53). The GVA per mesozone data are highly skewed, with low GVA found mainly in the Karoo and Kalahari (the low values in the north-east are mainly in the Kruger National Park) and very high GVA in or near metropoles and industrial towns. The concentration of the very high GVA mesozones in industrial areas is indicative of the strong vertical integration of primary producers and processors in this sector. The data therefore include industrial GVA but not necessarily the water used by these industries which may come from other sources. At the secondary catchment level the GVA does not align with the irrigation requirements (Figure 55 versus Figure 53).

The GVA for the top 15 secondary catchments in terms of water requirements (up to H4 in Table 41) is only 28% of the total GVA compared with 51% of the water and 33% of the irrigated area. Half of the total GVA is from the top 26 secondary catchments in terms of water requirements, and accounts for 53% of the irrigated area. The High GVA generated in the Berg River and Greater Cape Town catchments is sustained directly by the Boland and southern Groot Wintershoek SWSA-sw, and the Mhlatuze by the sub-national Zululand Coast WSA-sw (Figure 55). The High GVAs generated in the Middle Vaal River and in the Crocodile (West) are partially supported by the transfers from the Maloti, Northern and Southern Drakensberg SWSA-sw. The Mgeni has source areas with a mean annual runoff >135 mm and is directly linked to the Southern Drakensberg SWSA-sw, including the transfers from the Mooi River.

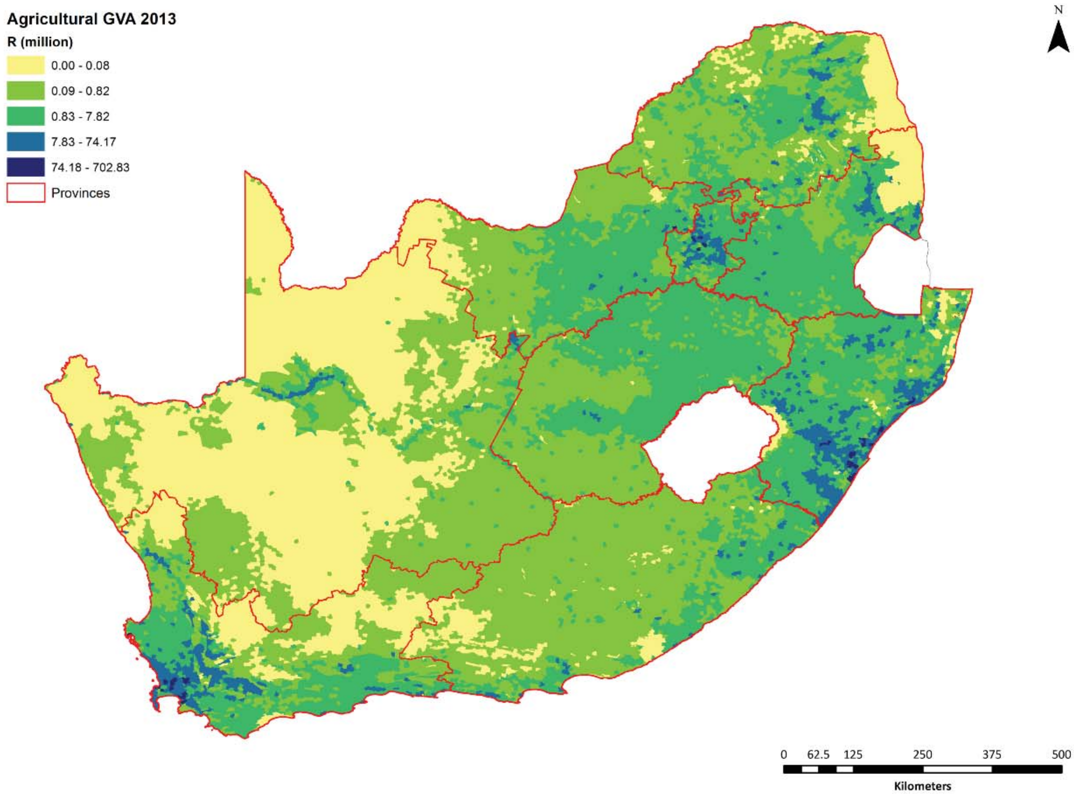

Figure 54: Agricultural GVA shown at the mesozone level for South Africa based on disaggregated economic data generated by the CSIR (Naudé et al., 2007). A geometric scale was used for the values to highlight the low end of the range as the median was R0.28 million, the mean 1.70 and only 30 of the 25 000 mesozones had a GVA exceeding R74.1 million.

One of the issues in using the agricultural sector GVA is that it includes commercial forestry and also the fishing industry. This could bias the data, especially for parts of KwaZulu-Natal (e.g. the Midlands and Zululand coast), and the Drakensberg escarpment in Mpumalanga and Limpopo as well as for the coastal regions. Irrigation is also important in the same areas of these provinces, and irrigated and afforested areas often form a land-use mosaic, making it very difficult to separate them even at the mesozone level. Unfortunately the disaggregated data are not available at a fine spatial resolution so we have kept to the sectoral data as we believe the overall picture is still accurate enough for the purposes of this report.

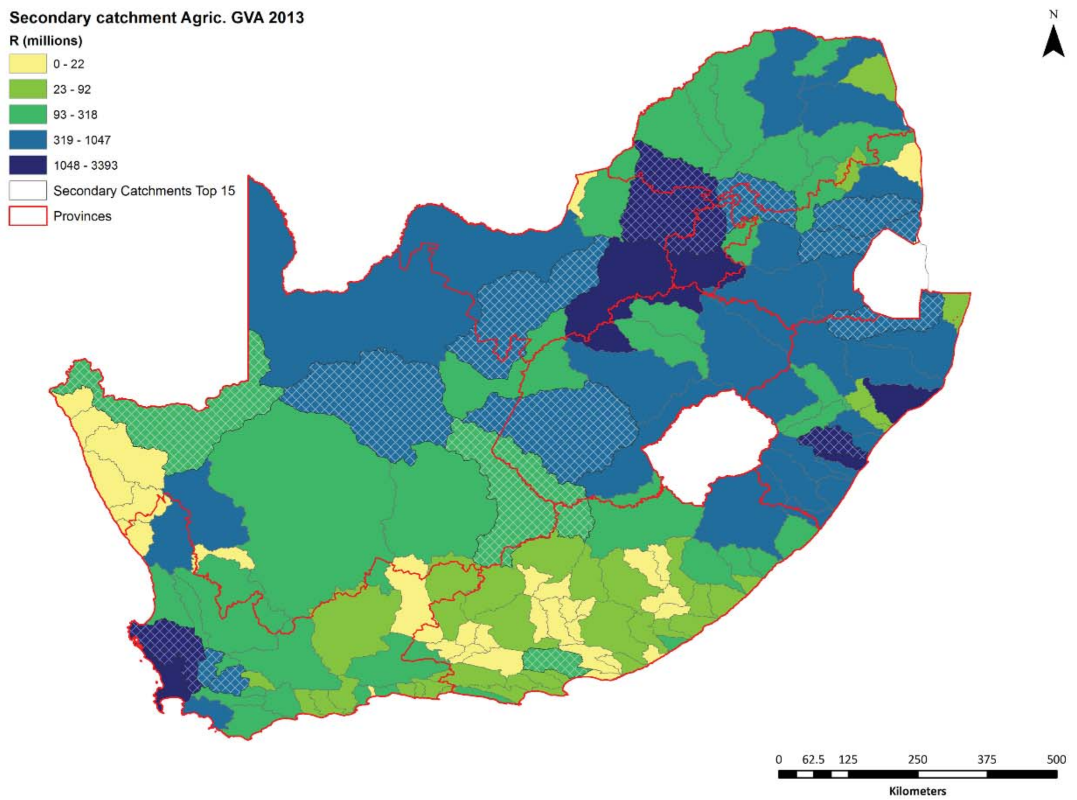

Figure 55: Agricultural GVA shown at the secondary catchment level for South Africa based on the economic data shown in Figure 54. Also shown in cross hatching are the top 15 secondary catchments in terms of their irrigation requirements (see Figure 53).

6.4.2.2.3 Conclusions

The data are estimates rather than being based on verified use, but they do show that irrigation in the secondary catchments which have the greatest irrigation requirements can be linked either directly, or indirectly, to SWSA-sw in South Africa. The most important water source areas by volume are those that supply the water to the Orange and Vaal River systems, including the large transfers from the Maloti, Northern and Southern Drakensberg SWSA-sw. The top 15, those that require about half the total irrigation requirement, only account for 26% of the agricultural GVA, largely because the areas with the highest GVA are those which include primary agricultural processing and not just crop production values. This means that industrial GVA is included in these estimates but not necessarily the water they use which may come from municipal supply systems. The Western Cape Mountains, the Drakensberg and KwaZulu-Natal coast all include primary processing which substantially increases and inflates their GVA so the data must be interpreted and used with care.

6.4.3 Agricultural (and industrial) benefits from SWSA-gw

Groundwater abstraction for agricultural and industrial use has been summed (m^3/a) per SWSA-gw. This is compared to the total registered (groundwater and surface water) agricultural and industrial use per SWSA-gw, to provide a perspective on the relative contribution of GW (compared to SW) for agricultural production and industrial activity per SWSA-gw, i.e. as a % of the total water use (Table 42). It is assumed that this % split translates directly to a % split of economic value (i.e. 1 litre of groundwater generates the same benefit as 1 litre of surface water), and hence, agricultural GVA derived from groundwater per SWSA-gw is also provided.

Table 42: Agriculture and industry supported by groundwater per SWSA-gw, as water volume, and for agriculture as GVA[8]

SWSA-gw Name	Registered Agricultural GW Use (WARMS, m^3/a)	Registered Industrial GW Use (WARMS, m^3/a)	Agricultural GW use as a % total water use by agriculture within SWSA-gw	Industrial GW use as a % total water use by industry within SWSA-gw	Agricultural GW contribution to GVA (R millions)
Bo-Molopo Karst Belt	57 456 576	6 079 594	96.1	43.2	165.54
Cape Peninsula and Cape Flats	7 288 953	3 933 035	87.5	13.1	271.64
Central Pan Belt	45 413 462	367 754	92.0	96.5	271.84
Coega TMG Aquifer	1 194 351	110 701	7.9	100.0	5.13
Crocodile River Valley	45 104 312	8 758 051	54.1	64.2	17.51
De Aar Region	739 240	25 100	68.0	100.0	20.16
Eastern Kalahari A	38 535 000	5 785	100.0	100.0	12.01
Eastern Kalahari B	8 993 859	0	100.0	n/a	66.82
Eastern Karst Belt	34 345 284	4 230 719	72.6	47.6	289.32
Far West Karst Region	3 517 369	36 896 954	20.6	90.8	12.15
George and Outeniqua	1 432 934	0	9.5	0.0	7.01
Giyani	473 851	8 876	11.1	100.0	1.77
Ixopo/Kokstad	365 289	95 186	0.5	38.9	2.88
Kroondal/Marikana	9 636 706	3 953 091	42.9	35.1	33.65
Kroonstad	481 473	30 000	9.3	14.0	2.25
KwaDukuza	0	2 350	0.0	6.7	0.00
Letaba Escarpment	21 426 589	96 160	11.2	11.9	43.06
Northern Ghaap Plateau	2 055 665	345 600	100.0	100.0	17.92
Northern Lowveld Escarpment	16 346 841	3 576	13.0	0.7	14.21
Northwestern Cape Ranges	70 604 359	1 438 539	33.5	74.7	216.06
Nyl and Dorps River Valley	12 701 324	817 307	80.2	42.6	34.59
Overberg Region	5 249 163	75 031	27.0	100.0	22.27
Phalaborwa	68 400	3 132 837	38.1	83.5	0.17
Richards Bay GW Fed Estuary	489 600	0	3.9	0.0	10.84
Sandveld	67 171 107	129 372	77.7	100.0	146.70
Sishen/Kathu	358 088	43 166 139	100.0	100.0	13.02
Southern Ghaap Plateau	2 697 692	9 655 152	0.8	42.0	0.15
Southwestern Cape Ranges	16 744 620	837 653	6.5	1.1	63.14
Soutpansberg	32 914 452	89 469	42.1	81.7	114.52
Transkei Middleveld	0	7 300	0.0	13.1	0.00
Tulbagh-Ashton Valley	64 985 065	720 596	28.5	9.3	194.27
Upper Sand (Polokwane) Aquifer System	13 118 709	5 479 424	82.4	88.2	36.27
Ventersdorp/Schoonspruit Karst Belt	54 299 293	1 147 977	96.9	98.1	98.57

[8] n/a in % column reflect no registered (surface or groundwater) use for agriculture within SWSA-gw. Conversely a 0% indicates there is some surface water use registered, yet zero registered groundwater use, hence groundwater forms 0%.

SWSA-gw Name	Registered Agricultural GW Use (WARMS, m^3/a)	Registered Industrial GW Use (WARMS, m^3/a)	Agricultural GW use as a % total water use by agriculture within SWSA-gw	Industrial GW use as a % total water use by industry within SWSA-gw	Agricultural GW contribution to GVA (R millions)
Vivo-Dendron	42 961 207	18 576	88.8	100.0	49.56
West Coast Aquifer	12 260 265	848 676	84.1	100.0	351.90
Westrand Karst Belt	41 255 096	82 415	85.3	67.3	36.76
Zululand Coastal Plain	107 826	0	1.5	0.0	2.88

Table 43: Summary of agriculture and industry supported by groundwater from SWSA-gw

Item	Agricultural GW Use (WARMS, million m^3/a)	Industrial GW Use (WARMS, million m^3/a)	Agricultural GW use as a % total	Industrial GW use as a % total
SWSA-gw	732	133	31	34
All South Africa	1609	283	14	10

The data in Table 42 and Table 43 show that while groundwater abstraction makes up only 14% of water abstracted nationally for agricultural purposes (the remainder made up by surface water), 46% (732/1609 in Table 43) of the groundwater abstraction for agriculture comes from within SWSA-gws (which only cover 11% of the land surface). Groundwater in South Africa accounts for an agricultural GVA of R6 135 million, which is 14% of the national agricultural GVA, and GWSAs contribute R2 647 million, or 43% of the GVA. This highlights the importance of the SWSA-gw to agriculture. These figures suggest that agriculture realises substantial benefits from groundwater, particularly in SWSA-gw. The percent support for industrial abstraction is similarly elevated in SWSA-gw compared to the rest of the country with SWSA-gw accounting for 47% of industrial use (133/283 in Table 43).

6.5 Protection status

The protection status of the SWSAs was determined by intersecting them with both the Protected Areas and the Conservation Areas. The information on protected areas was obtained from the spatial datasets compiled by SANBI (Von Staden & Skowno 2017) for the 2018 National Biodiversity Assessment (NBA). This included information on the status of protected areas from the DEA, the South African Protected Areas Database (SAPAD) 2017 second quarter dataset[9] supplemented with SANParks data for 2016, CapeNature for 2017 (Western Cape) and Ezemvelo KZN Wildlife for 2016. Protected areas in Lesotho and Swaziland were excluded from this analysis.

The protected areas dataset includes all areas managed for conservation purposes by a government body, whether national, provincial, district or local government (e.g. National Park, Provincial Conservation Agent,

[9] https://egis.environment.gov.za/protected_areas_database

Local Authority). The dataset includes the protected area name and type (e.g. National Park, Mountain Catchment Area and Local Nature Reserve) as well as the cluster name (e.g. Riviersonderend Mountains and Kruger). The categories used in this analysis were based on those used in the protected areas databases and follow those used in the Protected Areas Act (Act No 57 of 2003). The dataset includes the reserve name, specific type, protected area category and management agent.

A total of 20 437 km^2 of 67 of the SWSAs is formally protected to some extent, with the proportion of an SWSA that is formally protected varying from about 75% for the Kouga to less than 2% in several cases (Table 44). The total area of the SWSAs with at least a portion under formal protection is 152 580 km^2, so that the formally protected areas comprise about 13% of these SWSAs and 11% of all the SWSAs. Only 10% of the critically important Northern Drakensberg SWSA, which includes the Upper Wilge and Upper Tugela catchments, is under formal protection. Much of this area is montane grasslands with extensive areas that have been severely degraded by overgrazing that poses a threat to water security and require restoration (Blignaut et al., 2008). A number of the SWSAs form larger interconnected blocks, particularly in the Western Cape, so that the total areas under formal protection are very extensive. Examples are from the West Coast (Sandveld) through to the Langeberg with only a narrow gap at the western end of the Langeberg (Figure 28). Just over 90% of the protected area is in formal protected areas. The Boland and Groot Winterhoek SWSA-sw and the overlapping SWSA-gw (Table 44) have a total area of 20 196 km^2 with 6 770 km^2 (34%) in formally protected areas, but very little of the protected area is in the lowlands. The Mpumalanga Drakensberg SWSA-sw and overlapping Northern Lowveld Escarpment SWSA-gw have an area of 10 957 km^2 but only 10% is in formally protected areas and the corresponding figures for the Southern Drakensberg are 17 092 km^2 and 14%.

Conservation Areas include all areas of which are not formally protected under the Act but are managed at least partly for conservation. A total of 40 of the SWSAs include conservation areas (Table 45). They only make a relatively small contribution to the protection of the SWSAs because the total protected area only amounts to about 2 265 km^2. However, they can be important for protecting specific water source areas or water sources. In the Central Pan Belt, Crocodile River Valley and Vivo-Dendron SWSAs the Conservation Areas comprise almost all of the protected area.

There are 10 SWSAs, or portions of SWSAs, which do not include protected areas of any kind (Table 46). They add up to about 20 437 km^2, or 12% of the total area of the SWSAs. The majority of these are groundwater source areas and are spread widely across South Africa with the Upper Vaal being the only SWSA-sw with no protection (Table 46).

The formally protected areas analysed here do not include formally protected areas in Lesotho or Swaziland which would add to the total under some protection in the transboundary SWSAs.

Table 44: Formally protected areas in each of the SWSA sections excluding the areas of SWSA-sw that fall into Lesotho and Swaziland. Based on data compiled for the NBA 2018 (Von Staden & Skowno 2017).

Name	Type	Protected Area (km^2)	Total Area (km^2)	Protected Area (%)
Amatole	sw	39	2 078	1.89
Bo-Molopo Karst Belt	gw	98	5 181	1.90
Boland	sw	848	2 624	32.31
Boland & Northwestern Cape Ranges	swgw	60	173	34.47
Boland & Overberg Region	swgw	28	214	13.16
Overberg Region	gw	236	2 002	11.81
Boland & Southwestern Cape Ranges	swgw	1 750	2 672	65.48
Tulbagh-Ashton Valley	gw	403	2 237	18.00
Boland & Tulbagh-Ashton Valley	swgw	152	547	27.73
Southwestern Cape Ranges	gw	4	57	7.81
Central Pan Belt	gw	19	3 265	0.58
Crocodile River Valley	gw	7	1 744	0.39
De Aar Region	gw	3	2 475	0.13
Eastern Cape Drakensberg	sw	165	9 157	1.81
Eastern Karst Belt	gw	69	1 984	3.48
Ekangala Grassland	sw	665	7 709	8.63
Far West Karst Region	gw	80	1 382	5.82
Giyani	gw	12	438	2.78
Groot Winterhoek	sw	959	1 531	62.67
Northwestern Cape Ranges	gw	103	957	10.75
Groot Winterhoek & Northwestern Cape Ranges	swgw	1 578	2 488	63.43
Sandveld	gw	23	3 568	0.66
Groot Winterhoek & Sandveld	swgw	112	424	26.33
Groot Winterhoek & Tulbagh-Ashton Valley	swgw	514	702	73.15
Kouga	sw	442	588	75.14
Kroondal/Marikana	gw	92	795	11.58
Langeberg	sw	785	1 688	46.48
Langeberg & Tulbagh-Ashton Valley	swgw	26	34	78.40
Maloti Drakensberg	sw	39	109	35.63
Mbabane Hills	sw	458	2 280	20.09
Mfolozi Headwaters	sw	136	1 925	7.05
Mpumalanga Drakensberg	sw	410	6 925	5.91
Mpumalanga Drakensberg & Northern Lowveld Escarpment	swgw	294	1 138	25.85
Northern Lowveld Escarpment	gw	338	2 893	11.68
Nyl and Dorps River Valley	gw	324	1 875	17.28
Northern Ghaap Plateau	gw	20	6 274	0.32
Northern Drakensberg	sw	793	8 316	9.54
Outeniqua	sw	771	2 681	28.75
George and Outeniqua	gw	22	156	13.90

Name	Type	Protected Area (km²)	Total Area (km²)	Protected Area (%)
Outeniqua & George and Outeniqua	swgw	209	571	36.66
Phalaborwa	gw	130	404	32.14
Richards Bay GW Fed Estuary	gw	10	606	1.71
Southern Ghaap Plateau	gw	8	6 542	0.12
Southern Drakensberg	sw	1 750	10 339	16.93
Southern Drakensberg & Ixopo/Kokstad	swgw	622	6 753	9.21
Soutpansberg	gw	22	1 249	1.79
Soutpansberg	sw	27	1 019	2.69
Soutpansberg & Soutpansberg	swgw	15	1 301	1.16
Swartberg	sw	500	775	64.50
Table Mountain	sw	105	301	34.96
Table Mountain & Cape Peninsula and Cape Flats	swgw	63	271	23.12
Cape Peninsula and Cape Flats	gw	9	328	2.82
Tsitsikamma	sw	1 002	3 474	28.84
Tsitsikamma & Coega TMG Aquifer	swgw	6	35	16.14
Coega TMG Aquifer	gw	294	1 637	17.97
Upper Usutu	sw	2	5 357	0.03
Upper Sand (Polokwane) Aquifer System	gw	18	938	1.92
Ventersdorp/Schoonspruit Karst Belt	gw	43	2 777	1.56
Vivo-Dendron	gw	30	2 115	1.40
Waterberg	sw	149	1 003	14.81
West Coast Aquifer	gw	244	4 497	5.43
Westrand Karst Belt	gw	287	1 090	26.37
Wolkberg	sw	67	561	11.88
Wolkberg & Letaba Escarpment	swgw	66	948	6.99
Wolkberg & Northern Lowveld Escarpment	swgw	316	1 101	28.71
Zululand Coastal Plain	gw	1 326	3 305	40.13
Total		20 198	152 580	13.24

Table 45: SWSAs with Conservation Areas, excluding areas which fall into Lesotho or Swaziland. Based on protected areas data compiled for the NBA 2018 (Von Staden & Skowno 2017).

SWSA name	Type	Protected Area (km^2)	Total Area (km^2)	Protected Area (%)
Bo-Molopo Karst Belt	gw	87	5 268	1.64
Boland	sw	28	2 652	1.06
Boland & Overberg Region	swgw	5	220	2.48
Overberg Region	gw	39	2 041	1.91
Boland & Southwestern Cape Ranges	swgw	8	2 680	0.31
Tulbagh-Ashton Valley	gw	10	2 247	0.46
Boland & Tulbagh-Ashton Valley	swgw	2	549	0.40
Southwestern Cape Ranges	gw	12	69	17.47
Central Pan Belt	gw	103	3 368	3.06
Crocodile River Valley	gw	419	2 163	19.36
Ekangala Grassland	sw	56	7 765	0.72
Northwestern Cape Ranges	gw	1	958	0.13
Groot Winterhoek & Northwestern Cape Ranges	swgw	19	2 507	0.74
Sandveld	gw	18	3 586	0.51
Groot Winterhoek & Tulbagh-Ashton Valley	swgw	27	730	3.77
Kouga	sw	25	613	4.10
Kroonstad	gw	54	799	6.74
Langeberg	sw	1	1 689	0.03
Mbabane Hills	sw	11	2 291	0.47
Mpumalanga Drakensberg	sw	280	7 205	3.88
Mpumalanga Drakensberg & Northern Lowveld Escarpment	swgw	31	1 169	2.63
Northern Lowveld Escarpment	gw	4	2 898	0.14
Nyl and Dorps River Valley	gw	161	2 036	7.91
Northern Drakensberg	sw	23	8 339	0.28
Outeniqua	sw	12	2 693	0.45
Phalaborwa	gw	29	433	6.73
Southern Drakensberg & Ixopo/Kokstad	swgw	16	6 768	0.23
Soutpansberg	gw	22	1 271	1.72
Soutpansberg	sw	25	1 043	2.37
Soutpansberg & Soutpansberg	swgw	1	1 301	0.06
Tsitsikamma	sw	5	3 479	0.15
Coega TMG Aquifer	gw	10	1 646	0.59
Upper Usutu	sw	31	5 388	0.57
Upper Sand (Polokwane) Aquifer System	gw	28	966	2.86
Ventersdorp/Schoonspruit Karst Belt	gw	98	2 875	3.41
Vivo-Dendron	gw	441	2 555	17.25
Waterberg	sw	30	1 033	2.94
West Coast Aquifer	gw	89	4 586	1.94
Wolkberg	sw	3	565	0.61

SWSA name	Type	Protected Area (km²)	Total Area (km²)	Protected Area (%)
Wolkberg & Letaba Escarpment	swgw	1	948	0.07
Total		2 265	101 394	2.23

Table 46: SWSAs which have no protected areas, excluding areas which fall into Lesotho or Swaziland. Based on protected area data compiled for the NBA 2018 (Von Staden & Skowno 2017).

SWSA name	Type	Area (km²)
Eastern Cape Drakensberg & Transkei Middleveld	swgw	5 191
Eastern Kalahari A	gw	2 010
Eastern Kalahari B	gw	2 656
KwaDukuza	gw	2 290
Letaba Escarpment	gw	1 203
Sishen/Kathu	gw	4 827
Southern Drakensberg & KwaDukuza	swgw	63
Transkei Middleveld	gw	416
Upper Vaal	sw	1 401
Total		20 437

7. IMPACTS ON STRATEGIC WATER SOURCE AREAS

This section focuses on an assessment on the impacts on water resources in the SWSA-sw and SWSA-gw based on an analysis of the land cover in these areas, mining activities or potential for mining or shale gas, and the impacts of alien plant invasions.

7.1 Water impacts – land cover

This section first describes the current state of the land cover in the SWSA-sw and then the SWSA-gw. Detailed data for a greater number of classes for each of the SWSA polygons (surface, ground and overlap) are given in Appendix 13.1.

Although surface and ground water are treated separately, they are tightly interlinked because groundwater recharge originates as surface water and aquifers generally discharge into surface water systems (Wiens, 2002; Winter et al., 1999). These discharges occur both at points (e.g. springs, seeps) and as diffuse discharge through river banks and sustain flows between rainfall events and during the dry season. These flows are a key part of the water cycle (Postel, 2008) as described in the Introduction.

7.1.1 Surface water SWSAs

The dominant land cover in most of the SWSA-sw is still natural vegetation with the lowest proportions being found in Upper Usutu, Mpumalanga Drakensberg and Table Mountain with less than 50% (Table 47). The other mountain SWSA-sw of the Western Cape all have high proportions of natural vegetation, with the relatively remote Swartberg being 95% natural. The highest percentage natural is in the relatively remote and rugged Kouga followed by the Maloti Drakensberg (excluding the portion inside Lesotho where recent land cover data are lacking). The Upper Usutu is characterised by the most extensive wetlands (6%), which highlights the importance of their protection. Relatively high proportions of wetlands also occur in the South African portion of the Mbabane Hills, Boland, Enkangala Grassland, Southern Drakensberg, Langeberg and Upper Vaal SWSA-sw.

There is extensive dryland cultivation in the Upper Vaal, Langeberg, Southern Drakensberg, Eastern Cape Drakensberg and Tsitsikamma (Table 47). Irrigated agriculture is the most extensive in the Boland, followed by the Soutpansberg, Groot Winterhoek and Wolkberg. Dryland agriculture has the potential to reduce water quality by increasing soil loss while irrigated agriculture requires relatively large volumes of water and can also affect water quality through pollution of return flows, especially in areas used for intensive production of vegetables and fruit.

Plantation forestry is the major land-use in the Mpumalanga Drakensberg, Upper Usutu, Mbabane Hills, Wolkberg and Mfolozi Headwaters and also occupies a substantial proportion of the Enkangala Grassland, Southern Drakensberg, Outeniqua and Amatole SWSAs (Table 47). Plantations are known to use more water than native vegetation so they could be seen as a threat to water quantity. However, the areas under plantation forestry have been regulated to keep the surface water flow reductions within set limits (Dye and Versfeld, 2007) so, provided these limits are respected and the plantation layouts conform to the industry environmental guidelines (Forestry Industry Environmental Committee, 2002), the impacts should be acceptable.

The Table Mountain SWSA-sw also has by far the greatest urban area (43%), with most of these being the formal urban and industrial suburbs of the City of Cape Town (Table 47). The Soutpansberg also has extensive residential urban areas which are part of Thohoyandou and nearby dense rural settlements. Although urban areas are the main land cover class in the Table Mountain SWSA-sw, they are mainly located on the mid-to lower-slopes and lowlands and have not affected the high runoff areas.

In summary, about half (or more) of the Table Mountain, Upper Usutu and Mpumalanga Drakensberg have been transformed from their natural state. Although these are the most transformed of the SWSA-sw, it is clear that these areas need to be managed as multifunctional landscapes and the main objective should be minimising the impacts of human activities in these landscapes on water quantity and quality.

Based on this analysis the areal extent of mining in SWSA-sw is relatively small but it does have disproportionate impacts on water quality. However, an assessment of prospecting and mining licenses that have been granted showed that there is immense potential for this area to increase, with roughly 70% of the SWSAs in Mpumalanga (as defined by Nel et al., 2013) under some sort of mining or prospecting license (La Grange, 2011) (see also Section 7.1.2).

Table 47: Summary of the land cover (percentage, total area in km²) in the SWSA-sw based on the National Land Cover data set for South Africa (GTI, 2015). Data includes overlaps with groundwater SWSA-sw. Only 1% of the Maloti Drakensberg and about 23% of the Mbabane Hills SWSA-sw are located in South Africa.

SWSA-sw name	Waterbodies	Wetlands	Natural	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban	Total area (km²)
Amatole	0.6	0.6	74.5	6.7	0.6	10.4	0.0	6.7	2000
Boland	1.9	2.0	71.7	6.7	12.5	2.3	0.0	2.7	6 157
Eastern Cape Drakensberg	0.3	1.4	76.1	12.1	0.0	3.7	0.0	6.5	14 358
Enkangala Drakensberg	0.3	2.4	73.8	9.1	0.5	12.3	0.0	1.6	7 785
Groot Winterhoek	0.7	1.3	85.9	5.7	5.9	0.3	0.0	0.2	5 254
Kouga	0.0	1.4	98.5	0.1	0.0	0.0	0.0	0.0	614
Langeberg	0.3	2.6	76.8	15.6	1.6	2.7	0.0	0.4	1 735
Maloti Drakensberg	0.0	0.5	97.2	2.2	0.0	0.1	0.0	0.0	114
Mbabane Hills	0.1	1.5	59.9	2.7	1.6	32.1	0.1	2.1	2 318
Mfolozi Headwaters	0.0	0.4	67.3	8.1	0.5	17.6	0.0	6.1	1 932
Mpumalanga Drakensberg	0.3	1.5	52.8	1.9	2.0	39.4	0.1	2.0	8 396
Northern Drakensberg	0.8	1.5	81.0	9.3	1.3	2.3	0.0	3.7	8 358
Outeniqua	1.2	1.2	71.2	7.4	1.8	14.2	0.0	3.0	3 015
Southern Drakensberg	0.5	2.5	61.0	12.0	2.1	15.7	0.0	6.2	17 213
Soutpansberg	0.4	0.2	64.8	3.8	6.3	8.7	0.0	15.7	2 350
Swartberg	0.1	0.4	95.4	3.9	0.1	0.0	0.0	0.0	778
Table Mountain	2.0	2.0	47.9	1.3	1.0	2.1	0.6	43.2	472
Tsitsikamma	0.3	1.0	75.9	10.2	3.0	8.0	0.0	1.6	3 216
Upper Usutu	1.2	5.6	44.8	7.3	0.3	38.4	0.1	2.3	5 410
Upper Vaal	0.2	3.8	62.9	30.9	0.1	0.4	0.0	1.8	1 402
Waterberg	0.2	0.3	92.4	5.9	1.1	0.1	0.0	0.1	1 033
Wolkberg	0.7	0.7	69.0	1.9	6.3	17.6	0.0	3.8	2 619

7.1.2 Groundwater SWSAs

Many of the SWSAs for groundwater have high percentages of natural land (Table 48). However many are also located in areas where the rainfall is too low for cultivation and so are still largely natural, although the natural vegetation is typically used as rangeland for livestock and so may be degraded. Where the vegetation loss is sufficiently severe it can result in changes in water flows with reduced infiltration and recharge and increased soil erosion (Huber-Sannwald et al., 2006; Le Maitre et al., 2007; Meadows and Hoffman, 2002). In other areas overgrazing may reduce grass cover, resulting in less intense fires and an increase in the density of the woody shrubs and trees, commonly known as bush encroachment (Adams and Redford, 2010; Masubelele et al., 2015a, 2015b; Wigley et al., 2009). This probably results in an increase in evaporation and a corresponding reduction in surface water runoff as well as groundwater recharge (Le Maitre et al., 1999).

The Richards Bay GW Fed Lakes SWSA has the lowest proportion of natural vegetation (23%), and a high percentage under plantations (41%) and formal residential areas (17%), as well as a substantial proportion under irrigation (11%) (Table 48). The extensive plantations are a concern as it is likely that the trees are able to access groundwater and are potentially lowering the water table in the planted area. The Eastern Karst Belt SWSA-gw also has as low percentage of natural vegetation (40%), a high percentage of dryland cultivation and urban areas.

About 45% of Arlington and the West Coast Aquifer are under dryland cultivation and high percentages are found in the Hertzogville, Eastern Kalahari A & B, Central Pan Belt, Kroonstad and Westrand Karst Belt SWSAs. KwaDukuza, Vivo-Dendron, Sandveld, and Tulbagh-Ashton valley all have relatively high percentages under irrigated crops.

The most extensively urbanised of the SWSA-gw is the Cape Peninsula and Cape Flats where about 60% is under urban areas, including about 13% under informal settlements and townships and 11% under industrial and commercial areas (Table 48). This places this resource under high risk of contamination, especially given the SWSA-gw predominantly has predominantly high groundwater vulnerability (related to the unconfined sandy Cape Flats aquifer, Section 7.5).

The extent of mining, particularly open-cast, combined with its disproportionate impacts on water quality, is a significant concern because of its impacts on water security (Colvin et al., 2011). Groundwater source areas with the largest coverage of mining include Phalaborwa (11%), Port Nolloth (10%), and Kroondal/ Marikana (6%).

Table 48: Summary of the land cover (percentage, total area in km²) in the SWSA-gw based on the National Land Cover data set for South Africa (GTI, 2015). Data includes full area for SWSA-gw (i.e. including the overlaps with SWSA-sw).

Name	Waterbodies	Wetlands	Natural	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban	Total area (km^2)
Blouberg	0.0	0.0	74.9	12.5	0.0	0.0	0.0	12.5	666
Bo-Molopo Karst Belt	0.1	0.2	75.6	16.7	1.6	0.2	1.3	4.5	5 265
Cape Peninsula and Cape Flats	1.0	1.7	32.0	1.5	1.9	1.5	0.4	60.0	608
Central Pan Belt	0.1	0.9	51.4	35.2	2.9	0.5	0.3	8.7	3 366
Coega TMG Aquifer	0.3	1.1	87.0	2.2	0.2	0.1	0.6	8.5	1 681
Crocodile River Valley	0.1	1.7	80.5	6.6	9.2	0.0	1.3	0.7	2 161
De Aar Region	0.0	0.4	98.2	0.3	0.0	0.0	0.2	0.8	2 477
Eastern Kalahari A	0.0	0.0	60.3	31.7	5.5	0.0	0.0	2.5	2 013
Eastern Kalahari B	0.1	0.0	51.1	41.7	1.0	0.0	0.3	5.7	2 656
Eastern Karst Belt	0.6	4.3	39.7	28.7	3.6	2.0	2.0	19.3	1 983
Far West Karst Region	0.3	3.1	69.8	16.2	1.6	1.1	1.5	6.4	1 381
George and Outeniqua	0.1	1.0	80.8	7.4	0.5	9.3	0.0	0.9	730
Giyani	0.0	0.0	75.1	12.8	1.8	0.1	0.2	10.1	439
Hertzogville	0.2	1.1	58.1	39.2	0.5	0.2	0.0	0.6	447
Ixopo/Kokstad	0.3	2.4	57.6	13.1	1.3	18.4	0.0	6.9	7 157
Komaggas Cluster	0.0	0.0	99.3	0.3	0.0	0.0	0.3	0.1	371
Kroondal/Marikana	0.3	1.0	65.4	13.4	2.1	1.2	5.6	11.0	795
Kroonstad	0.4	2.9	59.6	30.6	0.8	1.0	0.0	4.8	799
KwaDukuza	0.1	0.1	55.6	3.2	19.0	2.4	0.0	19.6	2 359
Letaba Escarpment	0.7	0.6	60.1	7.9	8.4	15.8	0.1	6.5	2 155
Nelspoort	0.0	0.3	99.3	0.3	0.0	0.0	0.0	0.1	510
Northern Ghaap Plateau	0.0	0.0	97.6	0.2	0.0	0.0	0.1	2.1	6 277
Northern Lowveld Escarpment	0.1	0.8	84.8	2.2	1.2	7.1	0.1	3.7	5 178
Northwestern Cape Ranges	1.4	1.8	80.7	8.7	6.9	0.2	0.0	0.2	3 681
Nyl and Dorps River Valley	0.1	1.8	75.4	17.1	1.3	0.1	0.2	4.0	2 036

Name	Waterbodies	Wetlands	Natural	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban	Total area (km²)
Overberg Region	1.4	3.2	67.1	26.4	0.9	0.4	0.0	0.6	2 279
Phalaborwa	0.4	0.0	84.8	0.9	0.0	0.1	10.5	3.3	435
Port Nolloth	0.0	0.0	89.8	0.0	0.0	0.0	9.8	0.4	515
Richards Bay GW Fed Estuary	4.6	1.3	23.1	1.4	11.4	40.7	0.3	17.3	609
Sandveld	0.4	1.1	59.6	25.7	13.0	0.1	0.0	0.1	4 066
Sishen/Kathu	0.0	0.0	97.3	0.0	0.0	0.0	2.4	0.3	4 841
Southern Ghaap Plateau	0.0	0.0	98.8	0.1	0.0	0.0	0.8	0.3	6 556
Southwestern Cape Ranges	2.7	2.0	79.7	3.2	9.2	2.7	0.0	0.5	2 783
Soutpansberg	0.4	0.2	68.1	4.2	5.2	9.0	0.0	12.9	2 577
Strandfontein	0.0	0.1	79.9	18.8	1.2	0.0	0.1	0.1	296
Transkei Middleveld	0.1	1.5	70.7	14.7	0.0	4.9	0.0	8.1	5 605
Tulbagh-Ashton Valley	1.7	1.4	79.6	5.8	10.1	0.5	0.0	0.9	3 597
Upper Sand (Polokwane) Aquifer System	0.2	0.4	74.2	4.5	1.5	0.1	0.7	18.6	966
Ventersdorp/Schoonspruit Karst Belt	0.1	0.5	69.6	25.2	3.5	0.2	0.4	0.7	2 873
Vivo-Dendron	0.1	0.0	80.9	3.7	14.5	0.0	0.1	0.8	2 557
West Coast Aquifer	0.5	1.7	49.1	44.8	2.7	0.2	0.1	0.8	4 657
Westrand Karst Belt	0.1	1.7	58.5	29.1	4.9	0.8	0.5	4.5	1 089
Zululand Coastal Plain	10.1	5.3	58.3	1.6	1.7	13.9	0.0	9.1	3 323

7.2 Mining

Mining activities are known to have adverse effects on both water quantity, mainly through water consumption in the mining processes, and on water quality in the forms of acid mine drainage (AMD), discharges, slimes dam overflows, or runoff (Ashton and Dabrowski, 2011; Colvin et al., 2011; CSIR, 2011; Matthews, 2017). Although there has been a lot of emphasis on AMD from gold mines (Ambani and Annegarn, 2015; DWAF, 2013), open cast and extensive shallow coal mining can have significant impacts over a much wider area through AMD (Colvin et al., 2011; McCarthy, 2011).

7.2.1 Coal Mining

South Africa has extensive coalfields in the eastern and northern parts of the country which overlap with the SWSAs (Figure 56), and many fields have not been mined or have only been partially mined. So we have focused on the spatial overlap between the SWSAs and coal fields as areas where there is a potential for mining to increase acid mine drainage and affect all downstream water-users and ecosystems.

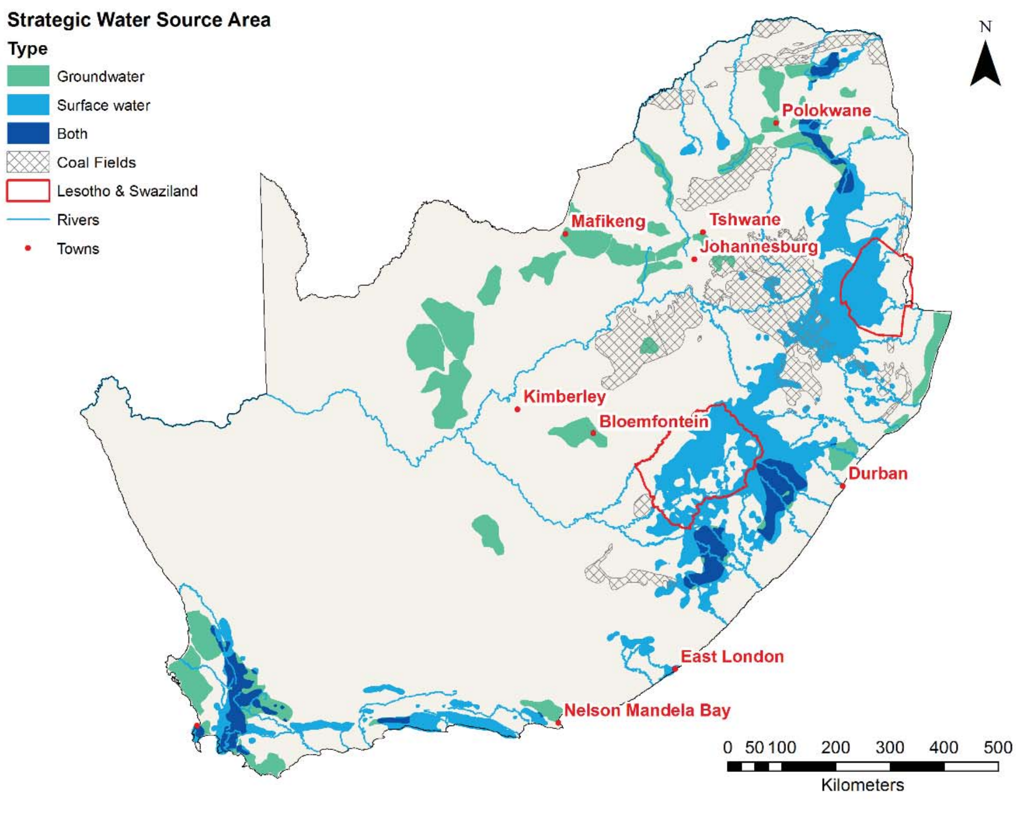

Figure 56: The location of South African coal fields in relation to the SWSAs. Coal field data were taken from the South African Mine Water Atlas datasets (WRC, 2016).

There are significant coal reserves which mainly support power production and current plans envisage that the majority of the electricity will be generated from coal-fired power for the foreseeable future, especially base-load power. In 2000 coal accounted for 79% of South Africa's national primary power supply (i.e. including electricity and petroleum) (DoE, 2005), but that has declined as renewable electricity sources have become more significant. South Africa has 19 coal fields within the Karoo super group strata with the total recoverable reserves estimated at 55 333 Mt or about 50 years of coal supply. Most of the coal reserves that overlap with SWSAs are located in the Highveld, Witbank and Ermelo fields (Table 49), so there are substantial coal reserves in areas that do not overlap with SWSAs (Colvin et al., 2011).

The degree of overlap between the coals fields and the SWSAs varies, the greatest being in the Upper Vaal and Kroonstad where the SWSA polygons completely overlap with coalfields (Table 49). The next most extensive is the Enkangala Grasslands at nearly 42% followed by the Eastern Karst Belt at 40%[10] and the Nyl & Dorps River Valley. The Enkangala Grasslands has already been identified as a critical water-energy conflict area (Colvin et al., 2011). However, the overlap is not the best indicator of the potential impact because the important factors are the remaining and recoverable coal within each coal field and the nature of the mining required to extract that coal. There are very large reserves in the Highveld and Ermelo coal fields which overlap with SWSAs, particularly the Upper Vaal and Enkangala. This information must be taken into account when considering coal mining in any of the SWSAs.

Nationally, the total area of the overlap between the coalfields and the SWSAs is about 10 007 km^2 which is equivalent to just 8% of the total area of the coalfields. The Vryheid coal field shows the greatest overlap at 68% of the entire coal field, virtually the same as the Utrecht coalfield at 61% followed by the Ermelo coal field at 33%. Many of the coal fields do not overlap at all so there is potentially a large amount of coal that could be mined instead of extending the existing mines, or opening new mines, in those SWSAs which have been significantly affected already or could be adversely affected by further mining.

[10] This overlap is not geologically possible and probably is due to mismatches in the scales of mapping and needs to be properly assess with more accurate data.

Table 49: The area of each Strategic Water Source Area which overlaps with coal fields in South Africa (excluding those SWSAs and coal fields with no overlap), the type of SWSA (sw = surface water, gw = groundwater), the coal field's economically recoverable potential, the run-of-mine (ROM) production, and (thus) the remaining coal reserves (after (Colvin et al., 2011)). Coal field data were taken from the South African Mine Water Atlas datasets (WRC, 2016). (nd = no data)

SWSA Name	Type	Coal Field	Extent of coal field (km^2)	Recoverable Mt	ROM production (1982-2000) Mt	Remaining Mt	Overlap area (km^2)	Total SWSA area (km^2)	Overlap (% of SWSA)	Total overlap (%)
Eastern Cape Drakensberg	sw	Molteno-Indwe	4 699	nd	nd	nd	139	10 814	1.29	1.29
Eastern Karst Belt (see text)	gw	Witbank	8 473	12 460	2 320	10 140	8	1 984	40.50	40.50
Enkangala Drakensberg	sw	Ermelo	9 919	4 698	101	4 597	1 590	8 582	18.53	
Enkangala Drakensberg	sw	Highveld	9 794	10 979	972	10 007	643	8 582	7.49	
Enkangala Drakensberg	sw	Utrecht	2 169	649	64	585	1 330	8 582	15.50	
Enkangala Drakensberg	sw	Vryheid	499	204	82	122	53	8 582	0.62	42.13
Kroonstad	gw	Welkom	10 603	4 919	0	4 919	799	799	100.00	100.00
Mfolozi Headwaters	sw	Nongoma & Somkele	1 601	98	15	83	72	1 925	3.76	
Mfolozi Headwaters	sw	Vryheid	499	204	82	122	288	1 925	14.96	18.71
Northern Drakensberg	sw	Highveld	9 794	10 979	972	10 007	0.04	10 302	0.00	
Northern Drakensberg	sw	Klip River	4 928	655	85	570	886	10 302	8.60	8.60
Northern Highveld	gw	Witbank	8 473	12 460	2 320	10 140	63	1 345	4.70	4.70
Nyl and Dorps River Valley	gw	Springbok Flats	8 256	1 700	0	1 700	767	2 036	37.68	37.68
Upper Usutu	sw	Ermelo	9 919	4 698	101	4 597	1262	6 191	20.38	20.38
Upper Vaal	sw	Ermelo	9 919	4 698	101	4 597	390	1 401	27.86	
Upper Vaal	sw	Highveld	9 794	10 979	972	10 007	732	1 401	52.29	
Upper Vaal	sw	Witbank	8 473	12 460	2 320	10 140	75	1 401	5.34	85.49
Vivo-Dendron	gw	Tshipise Pafuri	6 473	267	6	261	112	2 555	4.40	4.40

7.2.2 Other mining (mineral provinces)

The recently released Mine Water Atlas (WRC, 2016) provides a spatial delineation of all mineral provinces in South Africa. In addition to an assessment of coal reserves, assessing these areas provides an indication of the potential risk to water resources posed by future mining in areas (Figure 57). The risk to water resources from potential mining in these provinces varies however, and is related to the ground condition, geology, mining method employed, and management practices onsite. This section focuses on the overlaps with SWSA-gw but many impacts on surface water occur through direct discharge to surface water or from discharges of polluted groundwater into surface water bodies (Ashton and Dabrowski, 2011; CSIR, 2011). The direct discharges to surface water should be managed through enforcement of the mine's water permit conditions and Environmental Management Plans but this does not always happen (Dabrowski et al., 2013). The geographical distribution of South Africa's geological formations and its orogeny has resulted relatively little overlap between the SWSA-sw and mineral provinces, except for those in the Drakensberg, Enkangala, Upper Vaal, Upper Usutu, Wolkberg and Soutpansberg. The greatest potential impacts are in the Enkangala, Upper Vaal and Upper Usutu and are due to coal mining which is dealt with in Section 4.2.1.

Rather than define a risk here for each SWSA-gw, we have highlighted the overlaps as areas where there is a potential interaction between SWSA and current/future mining, such that greater focus can be placed on these areas, by for example prioritising them for the completion of SEAs for mining (Table 50).

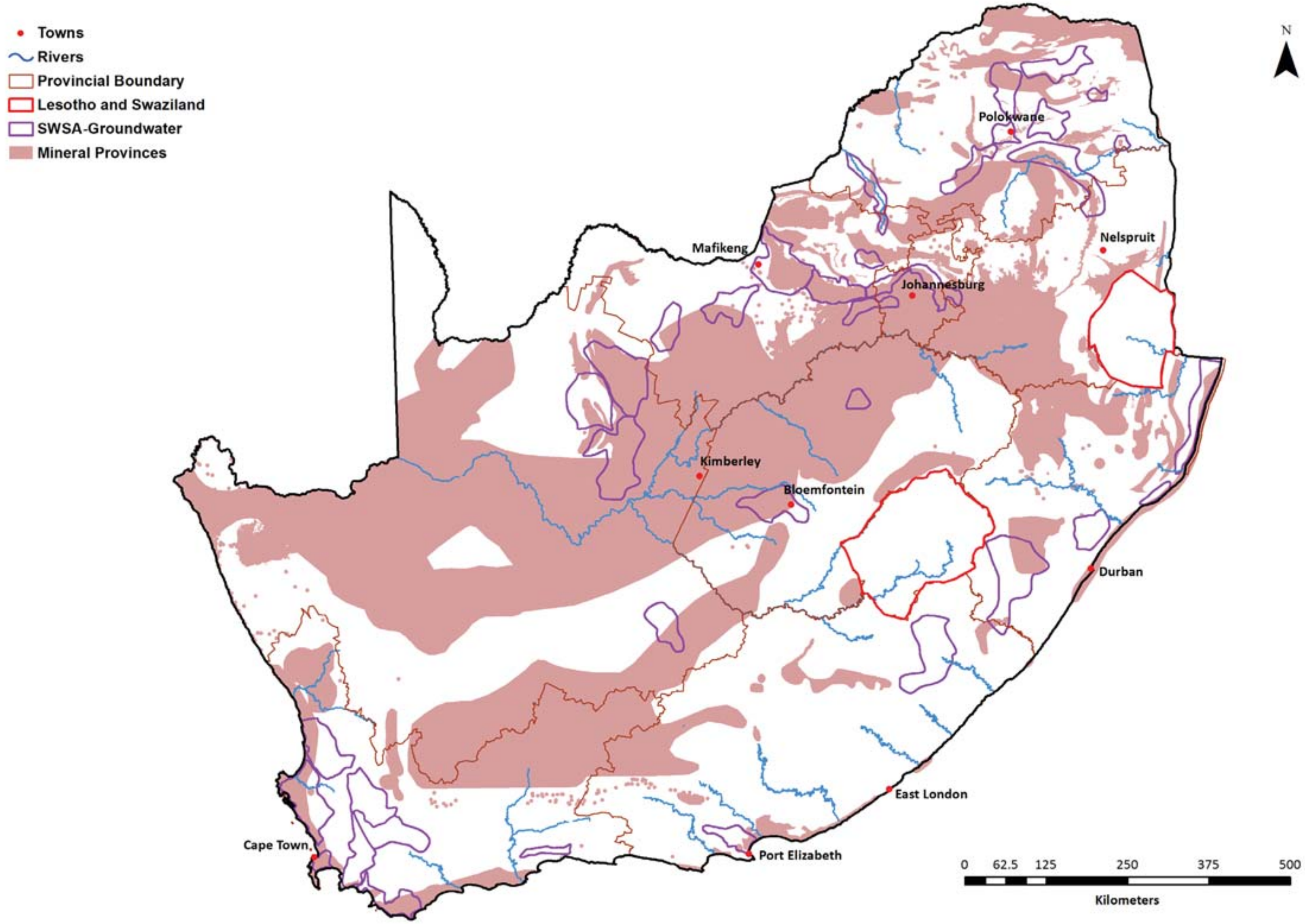

Figure 57: The location of South African mineral provinces (WRC, 2016), in relation to the SWSA-gw.

Table 50: Spatial overlap of mineral provinces and primary commodities in South Africa, and SWSA-gw.

SWSA-gw	SWSA-gw area (km²)	Mineral province	Commodity	Area (km²)[11]
Bo-Molopo Karst Belt	5268	Alluvial Diamond Field	Diamond	123
		Kimberlite Diamond Field	Diamond	781
		Metamorphic Province Andalusite	Andalusite	206
		Pretoria Group Residual Manganese	Manganese	357
		Transvaal Supergroup Dolomite	Lead, Limestone	3286
		Vhembe District Vermiculite	Zinc	881
Cape Peninsula and Cape Flats	599	Other Limestone	Limestone	310
		Recent Sediment Phosphates	Phosphate	17
		Surficial Salt and Gypsum Deposits	Salt	536
Central Pan Belt	3368	Surficial Salt and Gypsum Deposits	Salt	2655
Coega TMG Aquifer	1682	Other Limestone	Limestone	287
		Surficial Salt and Gypsum Deposits	Salt	346
Crocodile River Valley	2163	BIC Phosphate Deposits	Phosphate	39
		BIC Western Limb	Chromium, Iron, Lead, Nickel, Platinum, Vanadium	197
		Metamorphic Province Andalusite	Andalusite	216
		Transvaal Supergroup BIF	Iron	130
		Transvaal Supergroup Dolomite	Limestone	407
De Aar Region	2475	Karoo Uranium Province	Uranium	1029
Eastern Kalahari A	2010	Kimberlite Diamond Field	Diamond	28
		Surficial Salt and Gypsum Deposits	Salt	858
Eastern Kalahari B	2656	Kimberlite Diamond Field	Diamond	28
		Surficial Salt and Gypsum Deposits	Salt	1235
		Transvaal Supergroup Dolomite	Limestone	7
Eastern Karst Belt	1984	Pretoria Group Residual Manganese	Manganese	1
		Transvaal Supergroup Dolomite	Lead, Limestone	822
		Witbank Coalfield mainly seams 1 & 2	Coal	803
		Witwatersrand Basin	Gold, Uranium	1190
Far West Karst Region	1382	Alluvial Diamond Field	Diamond	232
		Kimberlite Diamond Field	Diamond	127
		Transvaal Supergroup BIF	Iron	24
		Transvaal Supergroup Dolomite	Limestone	1142
		Witwatersrand Basin	Gold, Uranium	1249
Giyani	438	Giyani Goldfields	Gold, Nickel	219
		Giyani/Polokwane Greenstone BIF	Iron	127
Ixopo/Kokstad	7150	Bauxite Fields	Aluminium	2260
		Kokstad Karoo	Nickel	186

[11] Area reflects the area covered by this commodity within this mineral province, within the SWSA-gw. There is overlap in mineral provinces so these values cannot be summed directly to compare to the total area of the SWSA-gw.

SWSA-gw	SWSA-gw area (km^2)	Mineral province	Commodity	Area (km^2)[11]
Kroondal/Marikana	795	BIC Western Limb	Chromium, Gold, Nickel, Platinum, Vanadium	518
Kroonstad	799	Welkom Coalfield	Coal	799
		Witwatersrand Basin	Gold, Uranium	799
KwaDukuza	2352	Natal Metamorphic Province	Lead	6
Letaba Escarpment	2151	Gravelotte Greenstone Belt	Copper, Vanadium	4
		Polokwane Goldfields	Gold	90
		Vhembe District Vermiculite	Vermiculite	0
Northern Ghaap Plateau	6274	Transvaal Supergroup Asbestos	Asbestos	853
		Transvaal Supergroup Dolomite	Limestone	5457
Northern Lowveld Escarpment	5168	BIC Eastern Limb	Chromium, Iron, Nickel, Platinum, Titanium, Vanadium	223
		Gravelotte Greenstone Belt	Gold	3
		Metamorphic Province Andalusite	Andalusite	606
		Other Limestone	Limestone	178
		Polokwane Goldfields	Gold	7
		Transvaal Supergroup Asbestos	Asbestos	865
		Transvaal Supergroup Dolomite	Limestone	1233
		Transvaal Supergroup Gold	Gold	227
Nyl and Dorps River Valley	2036	BIC Northern Limb	Iron, Lead, Nickel, Platinum, Vanadium	335
		Other Limestone	Limestone	73
		Polokwane Goldfields	Gold	50
		Springbok Flats Coalfield	Coal, Uranium	846
		Transvaal Supergroup Dolomite	Lead	56
Overberg Region	2261	Other Limestone	Limestone	878
		Surficial Salt and Gypsum Deposits	Salt	1428
Phalaborwa	433	Alkaline Complex	Phosphate	61
		Metamorphic Province Fluorite	Fluorspar	27
		Palabora Copperfields	Copper	24
Richards Bay Groundwater Fed Lakes	606	Heavy Mineral Sands	Titanium, Zirconium	167
Sandveld	4010	Recent Sediment Phosphates	Phosphate	242
		Surficial Salt and Gypsum Deposits	Gypsum, Salt	1188
Sishen/Kathu	4827	Kalahari Manganese Field	Manganese	339
		Transvaal Supergroup Asbestos	Asbestos	521
		Transvaal Supergroup BIF	Iron	758
		Transvaal Supergroup Dolomite	Iron, Limestone	398
Southern Ghaap Plateau	6542	Kalahari Manganese Field	Manganese	105
		Northern Cape Base Metals	Lead, Zinc	2161
		Surficial Salt and Gypsum Deposits	Gypsum, Salt	1630
		Transvaal Supergroup Asbestos	Asbestos	1387
		Transvaal Supergroup BIF	Iron	327

SWSA-gw	SWSA-gw area (km^2)	Mineral province	Commodity	Area (km^2)[11]
		Transvaal Supergroup Dolomite	Limestone	4321
Southwestern Cape Ranges	2749	Other Limestone	Limestone	121
Soutpansberg	2573	Alkaline Complex	Iron	1
		Archaean Granite-Gneiss Terrane	Lead	24
		Laterite Louis Trichardt	Nickel	238
		Recent Sediment Phosphates	Phosphate	15
Upper Sand (Polokwane) Aquifer System	966	Polokwane Goldfields	Gold	96
Ventersdorp/Schoonspruit Karst Belt	2875	Alluvial Diamond Field	Diamond	126
		Kimberlite Diamond Field	Diamond	1003
		Metamorphic Province Andalusite	Andalusite	38
		Pretoria Group Residual Manganese	Manganese	454
		Transvaal Supergroup Dolomite	Limestone	2323
		Witwatersrand Basin	Gold	165
Vivo-Dendron	2555	Archaean Granite-Gneiss Terrane	Lead	28
		Giyani/Polokwane Greenstone BIF	Iron	12
		Laterite Louis Trichardt	Nickel	1350
		Polokwane Goldfields	Gold	47
		Recent Sediment Phosphates	Phosphate	68
		Tshipise & Pafuri Coalfields	Coal	112
		Vhembe District Vermiculite	Vermiculite	219
West Coast Aquifer	4586	Other Limestone	Limestone	1244
		Recent Sediment Phosphates	Phosphate	692
		Surficial Salt and Gypsum Deposits	Gypsum, Salt	2877
Westrand Karst Belt	1090	Kimberlite Diamond Field	Diamond	87
		Pretoria Group Residual Manganese	Manganese	530
		Transvaal Supergroup Dolomite	Lead, Limestone	696
		Witwatersrand Basin	Gold, Uranium	204
Zululand Coastal Plain	3305	Heavy Mineral Sands	Titanium, Zirconium	995
		Kimberlite Diamond Field	Diamond	12
		Other Limestone	Limestone	69

7.3 Petroleum production

The potential for shale gas exploration and production in the Karoo has received significant attention in recent years due to the potential for negative impacts on water resources. What is widely referred to as "fracking" with reference to the Karoo, is "Shale Gas extraction via high-volume slickwater long-lateral (HVSWLL) stimulation", and its definition is provided in Box 1. For ease, the term "fracking" is used below, to refer to HVSWLL stimulation.

Box 1 Definition of Shale Gas extraction via high-volume slickwater long-lateral stimulation

Shale gas extraction via "high-volume slickwater long-lateral" (HVSWLL) stimulation:

"..the technique of "stimulation" – inducing the flow of hydrocarbon gases and fluids from rock materials in which they would normally be firmly locked – … consists of four separate technologies that have been combined only within the last few years. These four elements are: i) directional drilling; ii) high frac-fluid volumes; iii) "slickwater" additives; and iv) multi-well drilling pads. It is, therefore, a grave error to conflate this novel technology with the older, established applications of hydraulic fracturing. It should rather be given its exact technical designation as "high-volume slickwater long-lateral" (HVSWLL) stimulation. As such, it is a newly evolving technology…" (Hartnady, 2011)

Fracking and associated activities (i.e. not only the stimulation or extraction from a well) can impact on surface and groundwater quality and quantity via several mechanisms. Substantial volumes of water resources are required for the drilling and injection process, and the Karoo does not have abundant surface water resources and limited potable groundwater resources. Groundwater is the sole supply source to several towns in the Karoo and as such, there has been concern raised over potential competition for resources in the Karoo.

Significant concern has surrounded the actual injection activity, and whether this could enhance a natural pathway and allow injected chemicals to reach a receptor (e.g. a borehole in use). As at 2012 there were no recorded contamination impacts that can be directly linked to an injection event via the enhancement of a natural pathway (Steyl et al., 2012). A critical review of the potential risks that shale gas operations pose to water resources found evidence for a host of fracking impacts, yet concludes "the direct contamination of shallow groundwater from hydraulic fracturing fluids and deep formation waters by hydraulic fracturing itself, however, remains controversial". The mechanism for contamination is feasible; hence this lack of recording may be because those impacts have not yet reached a receptor.

One impact that has been widely recorded is groundwater contamination via leaking boreholes. In these cases, improper sealing, or poor construction, enables the targeted gas and /or injected chemicals to migrate to overlying formations (which may be used for drinking water supply (Cooley and Donnelly, 2012; US EPA, 2011; Vengosh et al., 2014)).

Significant volumes of wastewater are generated by the fracking process, and there are cases of this wastewater contaminating shallow groundwater through leaking storage ponds (Cooley and Donnelly, 2012), or through disposal at mal-functioning wastewater treatment works (Vengosh et al., 2014). Contamination has also been generated by surface activities, i.e. spills in transport activities, onsite leaks, illegal activities and vandalism (Cooley and Donnelly, 2012; Vengosh et al., 2014).

In addition to fracking, other activities (gas extraction, coal bed methane) also pose risks to water resources. As such, all onshore areas under application or under existing exploration rights with the Petroleum Agency of South Africa, are shown in Figure 58 along with SWSA-gw. In addition, areas of overlap, i.e. where a licence area (under application or under existing right) overlaps with a SWSA-gw are listed in Table 51 (only water source areas with some overlap are listed). These results show:

- Current applications for Shale Gas (hydrocarbon) exploration licences do not overlap with SWSA-gw. However, six sub-national WSA-gw have some overlap with exploration licence areas; two of these are totally incorporated within license areas.
- A natural gas exploration licence has been granted in the Springbok Flats area, which overlaps with part of the Nyl and Drops River Valley groundwater source area, and includes a groundwater control area.
- In summary, five SWSA-gw have >50% of their area falling into a licence area.

Table 51: Petroleum Licence Areas within SWSA-gw

SWSA-gw name	Total area (km^2)	Minerals	Licence status	Licence type*	Area under licence (km^2)	% of SWSA area covered
Eastern Karst Belt	1984	Petroleum & Gas	Issued	Technical Cooperation Permit	17	0.9
Far West Karst Region	1382	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	266	19.3
Ixopo/Kokstad	7150	Petroleum & Gas	Granted	Technical Cooperation Permit	668	9.3
Kroonstad	799	Petroleum & Gas	Accepted – in progress, Granted	Technical Cooperation Permit	799	100.0
KwaDukuza	2352	Petroleum & Gas	Granted	Technical Cooperation Permit	32	1.3
Northern Lowveld Escarpment	5168	Petroleum & Oil	Accepted – in progress	Exploration Right	207	4.0
Northwestern Cape Ranges	3638	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	1667	45.8
Nyl and Dorps River Valley	2036	Natural Gas	Granted – to be issued	Exploration Right	123	6.0
Richards Bay Groundwater Fed Lakes	606	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	201	33.1
Sandveld	4010	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	3400	84.8
Sishen/Kathu	4827	Petroleum & Gas	Granted	Technical Cooperation Permit	423	8.8
Vanrhynsdorp	1423	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	1095	77.0
West Coast Aquifer	4586	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	448	9.8
Zululand Coastal Plain	3305	Petroleum & Gas	Accepted – in progress	Technical Cooperation Permit	3301	99.9

*Where >1 licence type is listed, there is >1 licence application areas in the SWSA. In these cases, multiple licence status are given

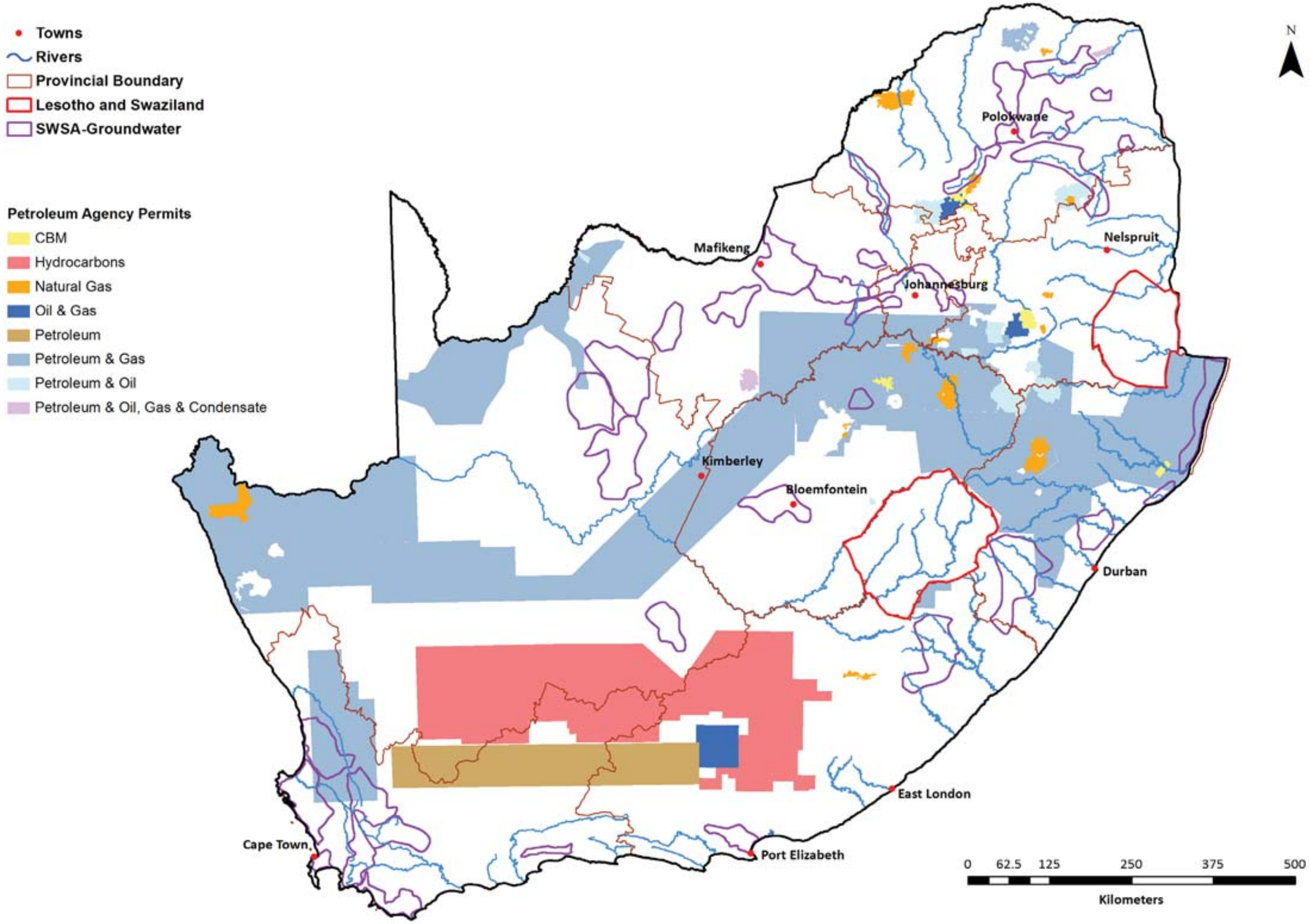

Figure 58: The location of Petroleum Licence areas in relation to the Strategic Water Source Areas.

7.4 Invasive alien plants

Invasive alien plants typically use more water than indigenous plants because they grow taller, have deep roots, are evergreen and can have a higher transpiration rates or interception losses (Everson et al., 2011; Gush et al., 2015; Le Maitre et al., 2015; Meijninger and Jarmain, 2014). Invasions of these species substantially reduce the mean annual runoff (MAR) in a catchment in proportion the density of the invasions and the kind of species that is invading. The reductions are comparable to those from commercial forestry plantations and, given that invasions often are found in riparian areas, they may even exceed them (Le Maitre et al., 2015). Recognition of these impacts led to the establishment of the Working for Water programme which was aimed specifically at increasing water security by clearing invasions (van Wilgen et al., 1998). Although the programme has made some progress, it is clear that a much greater effort will be needed to halt the spread and reverse the impacts of these invasions (Van Wilgen et al., 2012; van Wilgen and Wannenburgh, 2016). This section reports on an assessment of the impacts of the most important taxa of invasive alien trees in the SWSA-sw on the MAR from these areas. Overall, the current impacts of invasion on water resources amount to about 1 444 million m^3/a or 3.0% of the pre-development (naturalised) mean annual runoff (Le Maitre et al., 2016). At a quaternary catchment level, the impacts of invasions exceed 25% in some areas (Figure 59), including the Boland, Outeniqua, Tsitsikamma, Amatole and parts of the Drakensberg SWSA-sw.

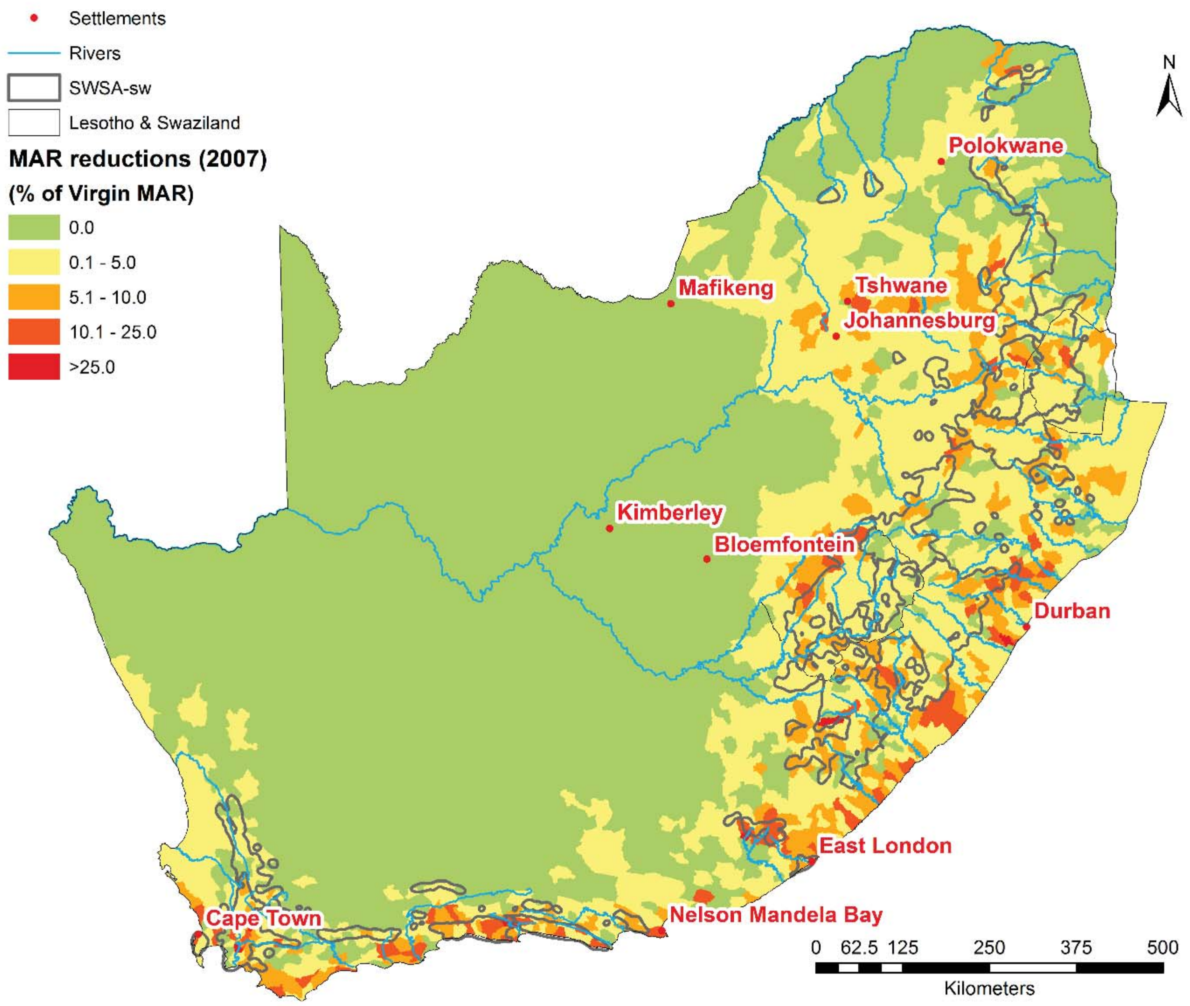

Figure 59: Percentage reductions in the pre-development mean annual runoff at the quaternary catchment level due to invasive alien plants (Le Maitre et al., 2016) overlaid with the SWSA-sw outlines.

We used data from the National Invasive Alien Plant Survey (Kotzé et al., 2010) to quantify the invasions by eucalypts, pines and wattles (*Acacia mearnsii, A. dealbata, A. decurrens*) in SWSA-sw in South Africa. These taxa were chosen because they are the most widespread and common invasive alien trees and have the greatest impacts on water resource nationally (Le Maitre et al., 2013). The IAP mapping units used by (Kotzé et al., 2010) which overlap with SWSA-sw were extracted and used calculate the areas invaded (Table 52). The values presented here are conservative because they are based on dryland reduction factors and exclude adjustments for the greater reductions recorded for riparian invasions (Le Maitre et al., 2013).

We used dryland MAR reduction factors for eucalyptus, pine and black wattle from Le Maitre et al. (2013) which are based on a review of the available information on the impacts on invasions on water flows. These reduction factors vary across South Africa depending on growing conditions and the species involved. For example the high veld grasslands are invaded by these species but the cold conditions in winter do not provide ideal growing conditions but on the slopes of the Drakensberg escarpment (e.g. in Mpumalanga) the conditions are ideal.

The 2013 study of the SWSAs found that invasions by eucalypts, pines and wattles (*Acacia mearnsii, A. dealbata, A. decurrens*) resulted in a cumulative reduction of 461 million m^3/a for all the SWSAs (Nel et al., 2013b), based on modelling by (Le Maitre et al., 2013) and mapping of the invasions for the National Invasive Alien Plant Survey (Kotzé et al., 2010). The findings of this analysis are similar, with a total MAR reduction of 485.8 million m^3/a, or 2.6% of the pre-development (virgin) MAR for these SWSAs (Table 52). This is greater than the estimated water requirement for 2015 for the EThekwini City Region (DWS, 2015c) which supports a population of over 4 million people. The total reductions due to IAPs nationally were estimated to be at least 1 444 million m^3 per year (2.9%) and possibly as high as 2 444 million m^3 per year (Le Maitre et al., 2016). Thus the impacts of invasions by just these three taxa (pines, eucalypts, wattles) on MAR from SWSA-sw amount to 33.65% of the total reduction from only 21.00% of the total condensed invaded area. This highlights the importance of giving priority to clearing these invasions.

By far the greatest reductions, by volume, are found in the South Africa portions of the Eastern Cape Drakensberg, Southern Drakensberg and Boland, while the greatest percentage reductions are found in the South African portions of the Maloti Drakensberg, Amatole, Enkangala Drakensberg, Outeniqua and Boland (Table 52). These reductions are critical because they affect all downstream users and the extent of the invasions is still increasing at about 5-10% per year. The mapping by Kotzé et al. (2010) underestimated the extent and density invasions in the Boland where an analysis of the impacts shows that the current reductions in yields are about 38 million m^3/a or the volume of the Wemmershoek Dam (Görgens et al., 2016). The Outeniqua invasions are of particular concern because there have been severe water shortages in many of the towns in the small coastal catchments. Some of those towns had to resort to expensive emergency measures such as desalination, and emergency measures are being implemented in Cape Town at present. The 2014-2015 drought in the summer rainfall areas has also resulted in critical water shortages in many catchments, including the rivers in the Inkomati-Usutu Water Management Area which are supplied by the Upper Usutu, Mbabane Hills and Mpumalanga Drakensberg SWSA-sw. These shortages were increased by the reductions in river flows caused by alien plant invasions.

Table 52: Reductions in Mean Annual Runoff (MAR) caused by invasive alien eucalypts, pines and acacia species per surface water Strategic Water Source Area in South Africa only. The condensed area is the equivalent area when the density (%) is converted to 100% (i.e. 100 ha with 50% density = 50 condensed ha).

SWSA Name	Condensed Area (ha)			MAR reduction (million m^3)			Totals (million m^3)		
	Eucalypts	Pines	Acacias	Eucalypts	Pines	Acacias	MAR	MAR reduction	MAR reduction (%)
Amatole	1 930	6 274	12 436	2.03	4.47	11.35	296.67	17.85	6.02
Boland	3 839	21 024	2 294	6.18	74.03	7.56	2 134.64	87.76	4.11
Eastern Cape Drakensberg	8 841	7 789	46 073	14.42	8.52	65.39	2 446.56	88.33	3.61
Enkangala Drakensberg	6 633	788	33 376	5.68	1.00	49.10	1 295.20	55.78	4.31
Groot Winterhoek	30	2 251	319	0.02	2.85	0.26	1 023.07	3.13	0.31
Kouga	126	402	1 812	0.19	0.25	2.09	63.88	2.53	3.95
Langeberg	1 102	1 009	980	1.33	1.06	1.40	349.99	3.80	1.08
Maloti Drakensberg	497	157	990	0.40	0.26	1.14	18.65	1.80	9.64
Mbabane Hills	346	389	2 611	0.54	0.57	3.04	453.41	4.16	0.92
Mfolozi Headwaters	1 677	18	2 118	1.97	0.02	2.44	172.70	4.43	2.57
Mpumalanga Drakensberg	2 255	5 142	10 719	2.59	7.92	15.85	1 951.76	26.36	1.35
Northern Drakensberg	5 462	837	11 123	6.67	2.02	18.15	1 710.11	26.84	1.57
Outeniqua	3 109	18 379	4 192	3.25	21.06	6.27	546.94	30.58	5.59
Southern Drakensberg	11 985	9 416	28 313	21.84	18.69	47.25	3 779.92	87.78	2.32
Soutpansberg	291	160	5	0.33	0.26	0.00	512.23	0.59	0.12
Swartberg	380	12	3	0.20	0.01	0.00	90.31	0.21	0.23
Table Mountain	271	271	0	1.10	0.70	0.00	128.28	1.80	1.40
Tsitsikamma	1 876	6 468	1 923	3.83	12.46	3.12	695.38	19.41	2.79
Upper Usutu	3 407	3 928	11 613	2.17	4.11	11.89	597.52	18.18	3.04
Upper Vaal	2 130	31	103	1.59	0.01	0.06	74.94	1.66	2.21
Waterberg	976	0	9	0.81	0.00	0.00	82.09	0.82	0.99
Wolkberg	320	333	411	0.62	0.93	0.46	511.13	2.01	0.39
Totals	57 483	85 078	171 423	77.77	161.18	246.84	18 935.36	485.80	2.57

7.5 Groundwater vulnerability focusing on contamination

Aquifers have varying susceptibility to contamination from surface sources because of hydrogeological properties such as porosity. This susceptibility has been mapped nationally as groundwater vulnerability, separated into categories ranging from very low to very high.

Sections 7.1, 7.2, and 7.3 raise the potential for contamination of SWSA-gw from various sources such as particular land uses, mining and petroleum exploration. Understanding the vulnerability of the areas at particular risk (in addition to in all groundwater source areas) can assist in prioritising protection in these areas.

As such, the groundwater vulnerability is shown in Figure 60 with SWSA-gw, and the vulnerability for each SWSA-gw is listed in Table 53. The total area under each groundwater vulnerability category allows source areas to be compared (i.e. defining which SWSA-gw has the largest area of high groundwater vulnerability for example) and the % of the source area falling within each category highlights source areas where 100% of the area falls in a higher category.

The analysis clearly highlights the SWSA-gw comprising the higher porosity Cenozoic Sand aquifers and the dolomite aquifers as the most vulnerable:

- SWSA-gw including >1500 km^2 of “high” groundwater vulnerability include many of the dolomitic areas (Ghaap Plateau, Bo-Molopo Karst Belt, Sishen/Kathu, Ventersdorp/Schoonspruit Karst Belt), plus the West Coast Aquifer area (Cenozoic Sand). These same SWSA-gw each have >50% of their area covered by “high” vulnerability.

- SWSA-gw with the highest coverage of “very high” vulnerability again include some large Cenozoic Sand systems (Zululand Coastal Plain, Richards Bay, and Cape Peninsula and Cape Flats, of which Zululand Coastal Plain is the largest, with >1000 km^2 of very high vulnerability). These three areas have the highest percent of very high vulnerability. Comparing between source areas, the Northern Lowveld Escarpment and also has relatively high areas of “very high” vulnerability.

Comparing these most vulnerable areas with the previously described impacts:

- Overlaps between SWSA-gw and coalfields are minimal, excluding Kroonstad which has 100% of its area covered by coalfield; however the area is mostly low with some medium vulnerability

- The SWSA-gw that include highest areas of groundwater with high vulnerability, are not at risk of petroleum activities, apart from Sishen/Kathu, in which a technical cooperation permit has been granted for petroleum & gas. This does not mean that petroleum exploration is not applied for/granted in areas of high vulnerability (note the Kalahari area), but that it is not coinciding with a SWSA-gw which has high vulnerability.

- The SWSA-gw that include highest areas of groundwater with high vulnerability are at risk from the following sources:
  - Urban areas cover 60% of the dominantly very high vulnerability (49%) Cape Peninsula and Cape Flats SWSA-gw, highest overlap for urban areas in any SWSA-gw.

- Urban areas cover 17% of the dominantly very high vulnerability (69%) Richards Bay SWSA-gw, which also has a high portion of plantation (41%).
- Cultivated areas cover 48% of the dominantly high vulnerability (59%) West Coast Aquifers SWSA-gw.
- Cultivated areas cover 29% of the dominantly high vulnerability (66%) Ventersdorp/Schoonspruit Karst Belt groundwater source area

This analysis simply highlights the major risks within the SWSA-gw that include the highest areas of high and very high vulnerability.

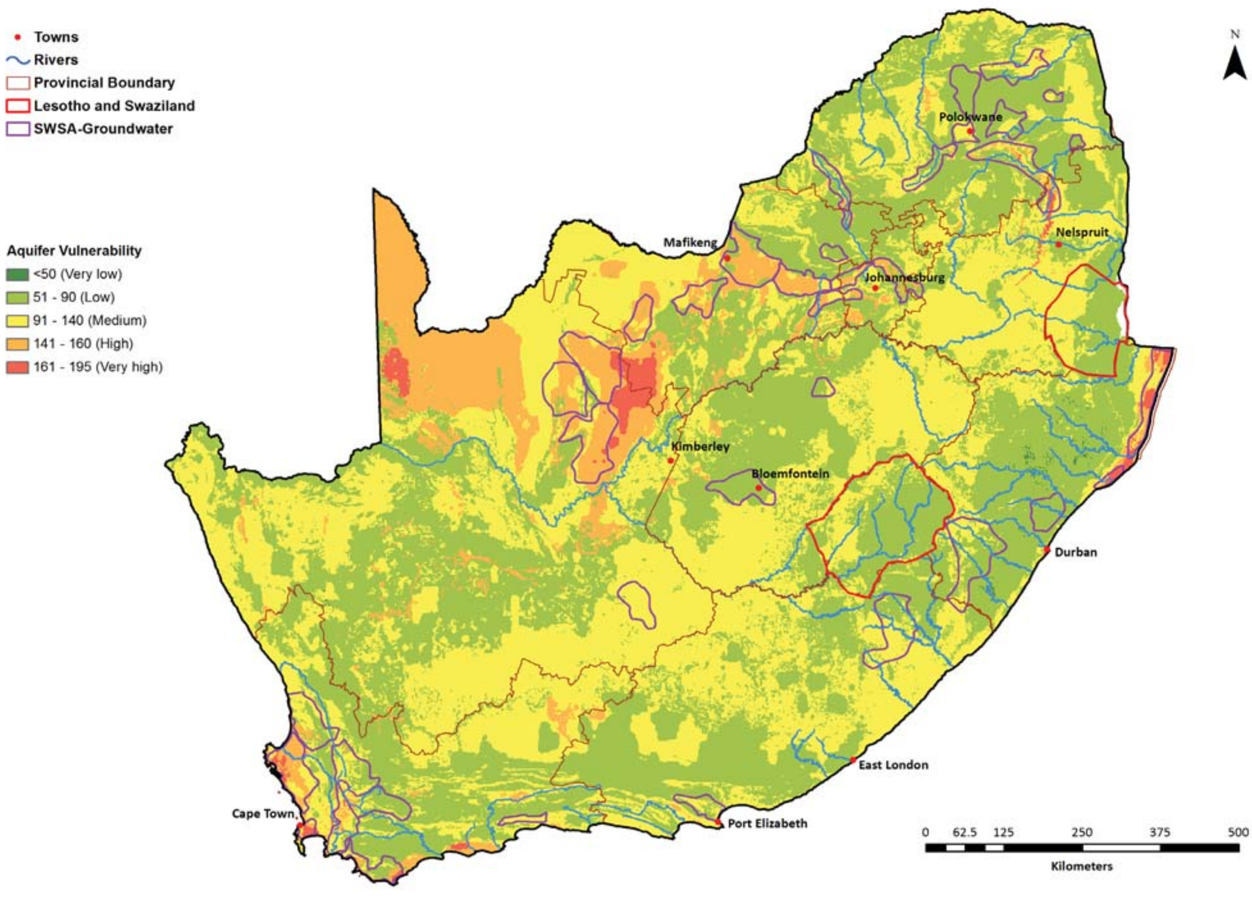

Figure 60: Groundwater vulnerability for South Africa, shown with SWSA-gw.

Table 53: Disaggregation of Groundwater Vulnerability for South Africa for each SWSA-gw

SWSA-gw name	Total area km²	Very Low	Low	Med	High	Very High	Very Low	Low	Med	High	Very High
		Groundwater vulnerability categories per SWSA-gw (area covered km²)					Groundwater vulnerability categories per SWSA-gw (as a % total area)				
National											
Bo-Molopo Karst Belt	5268	0	1170	754	3345	0	0.0	22.2	14.3	63.5	0.0
Cape Peninsula and Cape Flats	599	0	0	178	136	288	0.0	0.0	29.7	22.7	48.0
Central Pan Belt	3368	0	3085	289	0	0	0.0	91.6	8.6	0.0	0.0
Coega TMG Aquifer	1682	0	771	907	0	0	0.0	45.8	53.9	0.0	0.0
Crocodile River Valley	2163	0	1116	845	199	0	0.0	51.6	39.1	9.2	0.0
De Aar Region	2475	0	50	2418	0	0	0.0	2.0	97.7	0.0	0.0
Eastern Kalahari A	2010	0	11	660	1339	0	0.0	0.5	32.8	66.6	0.0
Eastern Kalahari B	2656	0	515	1160	984	0	0.0	19.4	43.7	37.0	0.0
Eastern Karst Belt	1984	0	854	607	526	0	0.0	43.0	30.6	26.5	0.0
Far West Karst Region	1382	0	86	685	606	0	0.0	6.2	49.6	43.9	0.0
George and Outeniqua	727	0	104	625	0	0	0.0	14.3	85.9	0.0	0.0
Giyani	438	0	281	159	0	0	0.0	64.2	36.4	0.0	0.0
Ixopo/Kokstad	7150	0	4367	2780	0	0	0.0	61.1	38.9	0.0	0.0
Kroondal/ Marikana	795	0	667	127	0	0	0.0	83.9	15.9	0.0	0.0
Kroonstad	799	0	615	186	0	0	0.0	77.0	23.2	0.0	0.0
KwaDukuza	2352	0	2352	0	0	0	0.0	100.0	0.0	0.0	0.0
Letaba Escarpment	2151	0	1636	514	0	0	0.0	76.0	23.9	0.0	0.0
Northern Ghaap Plateau	6274	0	215	1155	4378	525	0.0	3.4	18.4	69.8	8.4
Northern Lowveld Escarpment	5168	0	1756	2289	773	353	0.0	34.0	44.3	15.0	6.8
Northwestern Cape Ranges	3638	0	1511	2103	28	0	0.0	41.5	57.8	0.8	0.0
Nyl and Dorps River Valley	2036	0	1094	906	34	0	0.0	53.8	44.5	1.7	0.0
Overberg Region	2261	3	1079	648	430	95	0.1	47.7	28.7	19.0	4.2
Phalaborwa	433	0	411	25	0	0	0.0	95.0	5.7	0.0	0.0
Richards Bay GW Fed Lakes	606	0	0	109	91	404	0.0	0.0	18.0	15.0	66.6
Sandveld	4010	3	1273	2387	343	0	0.1	31.7	59.5	8.5	0.0
Sishen/Kathu	4827	0	412	2290	2125	0	0.0	8.5	47.5	44.0	0.0
Southern Ghaap Plateau	6542	0	195	1541	4636	169	0.0	3.0	23.5	70.9	2.6
Southwestern Cape Ranges	2749	0	380	1783	530	55	0.0	13.8	64.8	19.3	2.0
Soutpansberg	2573	0	1033	1476	52	9	0.0	40.1	57.4	2.0	0.4

SWSA-gw name	Total area km²	Very Low	Low	Med	High	Very High	Very Low	Low	Med	High	Very High
		Groundwater vulnerability categories per SWSA-gw (area covered km²)					Groundwater vulnerability categories per SWSA-gw (as a % total area)				
Transkei Middleveld	5607	0	2260	3350	0	0	0.0	40.3	59.7	0.0	0.0
Tulbagh-Ashton Valley	3560	0	2214	1031	316	0	0.0	62.2	29.0	8.9	0.0
Upper Sand (Polokwane) Aquifer System	966	0	257	710	0	0	0.0	26.6	73.5	0.0	0.0
Ventersdorp/Schoonspruit Karst Belt	2875	0	284	788	1805	0	0.0	9.9	27.4	62.8	0.0
Vivo-Dendron	2555	0	2555	4	0	0	0.0	100.0	0.1	0.0	0.0
West Coast Aquifer	4586	5	35	1354	2743	444	0.1	0.8	29.5	59.8	9.7
Westrand Karst Belt	1090	0	249	471	362	8	0.0	22.9	43.3	33.2	0.7
Zululand Coastal Plain	3305	0	0	968	1201	1133	0.0	0.0	29.3	36.3	34.3

7.6 Groundwater drought

The risk of groundwater drought for the Southern African Development Community (SADC) region has been assessed and presented as mapped risk categories (low to very high) (Villholth et al., 2013). A SWSA-gw with high risk of future drought may benefit from specific management /protection criteria. As such, the groundwater drought risk is shown in Figure 61, and the drought risk indices for each SWSA-gw is listed in Table 54. Both the total area under each drought risk category is provided per source area, along with the % of the source area falling within each category. The former enables a comparison between source areas (i.e. defining which SWSA-gw has the largest area of high risk for example) and the latter enables potentially smaller source areas to still be highlighted if 100% of the area falls in a higher category for example.

The groundwater drought risk increases away from the coastline and towards the interior of South Africa, and is more pronounced in the northwest, followed by north and northeast of the country (Figure 61). As such, the SWSA-gw most affected by high to very high groundwater drought risk (i.e. those with the largest area covered by the high to very high category) are the sub-national WSA-gw which fall in the northwest of the country (Kamieskroon, Carnarvon, Port Nolloth, Komaggas Cluster, and Vanrhynsdorp – see Appendix 2 (Section 10).

Areas with the largest coverage of moderate groundwater drought risk move further east towards the north and northeast of the country, including Southern Ghaap Plateau (the largest area of moderate risk >6000 km²), Ixopo/Kokstad, Northern Lowveld Escarpment, and Northern Ghaap Plateau.

Groundwater source areas in coastal areas in the south and east of the country have very low drought risk, including Zululand Coastal Plain, Coega TMG Aquifer, and Richards Bay GW Fed Lakes.

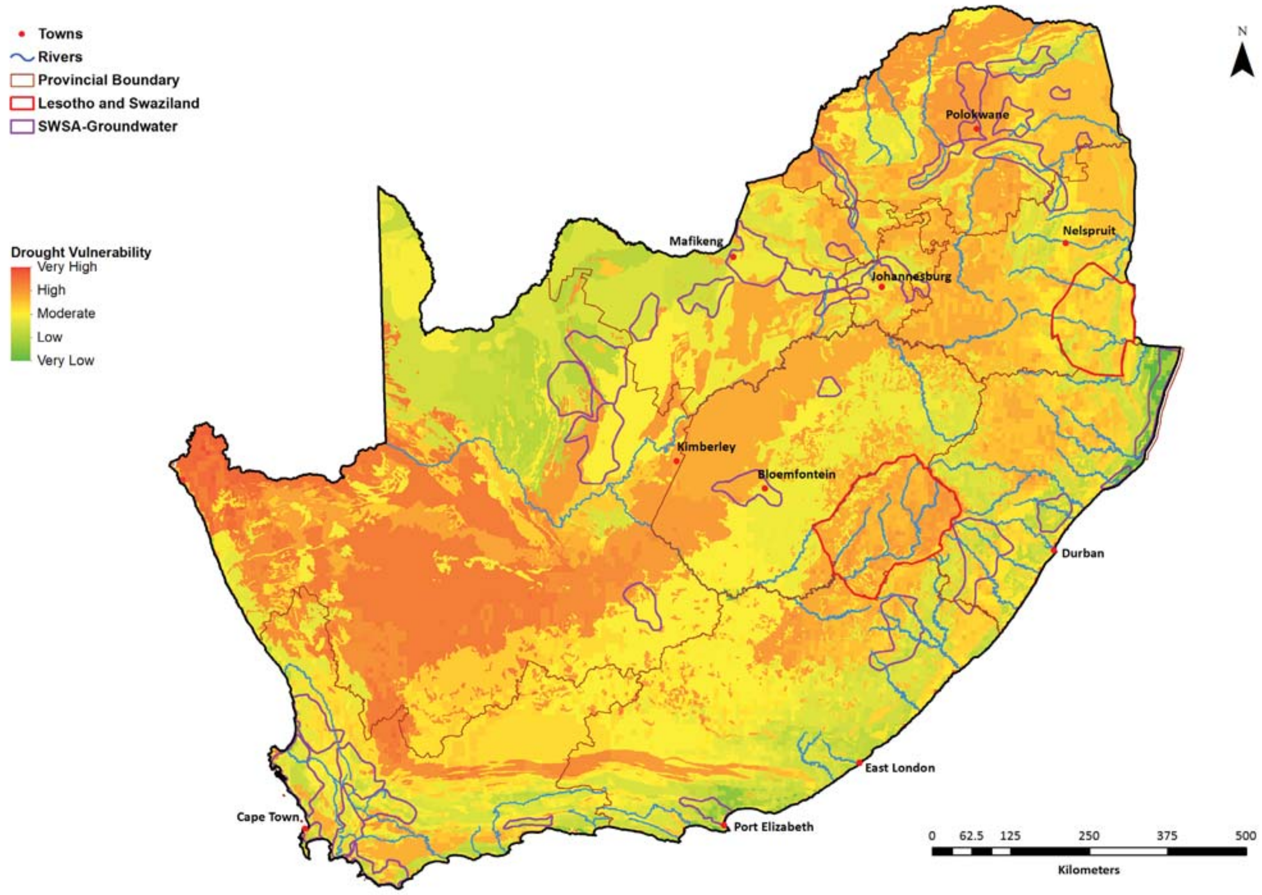

Figure 61: Groundwater drought risk for South Africa, shown with SWSA-gw.

Table 54: Disaggregation of groundwater drought risk for South Africa for each SWSA-gw

SWSA-gw	Total area km^2	Very Low	Low to Moderate	Moderate	High to Very High	Very Low	Low to Moderate	Moderate	High to Very High
		Groundwater Drought Risk categories per SWSA-gw (area km^2)				Groundwater Drought Risk categories per SWSA-gw (as a % total area)			
Bo-Molopo Karst Belt	5268	0	4334	935	0	0.0	82.3	17.7	0.0
Cape Peninsula and Cape Flats	599	0	392	171	39	0.0	65.4	28.5	6.5
Central Pan Belt	3368	0	998	2375	0	0.0	29.6	70.5	0.0
Coega TMG Aquifer	1682	510	1090	77	0	30.3	64.8	4.6	0.0
Crocodile River Valley	2163	0	474	1686	0	0.0	21.9	77.9	0.0
De Aar Region	2475	0	0	2387	81	0.0	0.0	96.5	3.3
Eastern Kalahari A	2010	0	1821	189	0	0.0	90.6	9.4	0.0
Eastern Kalahari B	2656	0	2524	134	0	0.0	95.0	5.1	0.0
Eastern Karst Belt	1984	0	909	1078	0	0.0	45.8	54.3	0.0
Far West Karst Region	1382	0	89	1289	0	0.0	6.4	93.2	0.0
George and Outeniqua	727	0	617	111	0	0.0	84.9	15.3	0.0

SWSA-gw	Total area km²	Very Low	Low to Moderate	Moderate	High to Very High	Very Low	Low to Moderate	Moderate	High to Very High
Giyani	438	0	0	438	0	0.0	0.0	100.0	0.0
Ixopo/Kokstad	7150	0	2967	4180	0	0.0	41.5	58.5	0.0
Kroondal/Marikana	795	0	70	724	0	0.0	8.8	91.0	0.0
Kroonstad	799	0	667	134	0	0.0	83.4	16.8	0.0
KwaDukuza	2352	0	2004	348	0	0.0	85.2	14.8	0.0
Letaba Escarpment	2151	0	0	2150	0	0.0	0.0	99.9	0.0
Northern Ghaap Plateau	6274	0	3424	2849	0	0.0	54.6	45.4	0.0
Northern Lowveld Escarpment	5168	0	2134	3036	2	0.0	41.3	58.7	0.0
Northwestern Cape Ranges	3638	0	1628	1955	59	0.0	44.8	53.7	1.6
Nyl and Dorps River Valley	2036	0	270	1764	0	0.0	13.3	86.6	0.0
Overberg Region	2261	14	1251	978	14	0.6	55.3	43.2	0.6
Phalaborwa	433	0	0	433	0	0.0	0.0	100.0	0.0
Richards Bay GW Fed Lakes	606	306	190	108	0	50.6	31.3	17.8	0.0
Sandveld	4010	0	1534	2445	25	0.0	38.3	61.0	0.6
Sishen/Kathu	4827	0	3630	1197	0	0.0	75.2	24.8	0.0
Southern Ghaap Plateau	6542	0	344	6196	0	0.0	5.3	94.7	0.0
Southwestern Cape Ranges	2749	0	1612	1123	12	0.0	58.6	40.8	0.5
Soutpansberg	2573	0	1825	740	6	0.0	71.0	28.8	0.2
Transkei Middleveld	5607	0	2790	2820	0	0.0	49.8	50.3	0.0
Tulbagh-Ashton Valley	3560	0	2436	1114	10	0.0	68.4	31.3	0.3
Upper Sand (Polokwane) Aquifer System	966	0	0	967	0	0.0	0.0	100.1	0.0
Ventersdorp/Schoonspruit Karst Belt	2875	0	2786	91	0	0.0	96.9	3.2	0.0
Vivo-Dendron	2555	0	44	2508	6	0.0	1.7	98.1	0.3
West Coast Aquifer	4586	15	3494	1002	70	0.3	76.2	21.8	1.5
Westrand Karst Belt	1090	0	984	107	0	0.0	90.3	9.8	0.0
Zululand Coastal Plain	3305	2680	525	74	22	81.1	15.9	2.3	0.7
Arlington	1553	0	1194	358	0	0.0	76.8	23.1	0.0
Beaufort West	786	0	0	695	90	0.0	0.0	88.5	11.4
Blouberg	666	0	9	658	0	0.0	1.4	98.8	0.0
Carnarvon	659	0	0	0	658	0.0	0.0	0.0	99.9
Eastern Upper Karoo	6131	0	304	5753	76	0.0	5.0	93.8	1.2
Great Kei	1416	20	1116	282	0	1.4	78.8	19.9	0.0
Hertzogville	447	0	0	446	0	0.0	0.0	99.9	0.0
Kamieskroon	3314	0	223	981	2105	0.0	6.7	29.6	63.5
Komaggas Cluster	364	0	35	51	279	0.0	9.5	14.1	76.8
Lower Mzimvubu	1199	0	64	1132	0	0.0	5.3	94.4	0.0
Loxton	397	0	0	329	66	0.0	0.0	82.8	16.8
Nelspoort	509	0	0	509	0	0.0	0.0	100.0	0.0
Northern Highveld	1345	0	77	1271	0	0.0	5.8	94.5	0.0

SWSA-gw	Total area km²	Very Low	Low to Moderate	Moderate	High to Very High	Very Low	Low to Moderate	Moderate	High to Very High
Port Nolloth	512	0	25	71	408	0.0	4.9	13.8	79.6
Strandfontein	291	0	241	49	0	0.0	83.0	16.9	0.0
Sutherland	1253	0	0	1099	154	0.0	0.0	87.7	12.3
Upper Keurbooms	1223	0	1200	17	6	0.0	98.1	1.4	0.5
Van Wyksdorp	599	0	408	190	0	0.0	68.1	31.7	0.0
Vanrhynsdorp	1423	0	444	710	268	0.0	31.2	49.9	18.9
Willowmore	289	0	263	26	0	0.0	91.0	9.0	0.0

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9. APPENDIX 1: SUMMARY OF THE AREA AND MAR STATISTICS FOR ALL THE SURFACE WATER SOURCE AREAS IDENTIFIED BY THIS STUDY

SWSA	Area (km^2)	MAR mill m^3	MAR m^3/ha	Percent of total
*Alexandria	59	6.68	1141	0.01
*Lebombo	36	4.21	1177	0.01
*Middle Kei	26	2.90	1122	0.01
*Ndumo	50	6.34	1276	0.01
*Nuweveld	86	10.44	1213	0.02
*Somerset East	66	8.56	1307	0.02
*Ubombo	31	4.12	1329	0.01
Amatole	2 001	332.70	1662	0.67
Boland	6 083	2 182.33	3588	4.41
Eastern Cape Drakensberg	15 997	2 672.79	1671	5.40
Enkangala Grassland	8 582	1 412.37	1646	2.85
Groot Winterhoek	5 191	1 002.47	1931	2.02
Kouga	613	77.37	1262	0.16
Langeberg	1 722	342.65	1989	0.69
Maloti Drakensberg	12 003	2 231.94	1859	4.51
Mbabane Hills	10 015	2 237.12	2234	4.52
Mfolozi Headwaters	1 925	276.76	1438	0.56
Mpumalanga Drakensberg	8 374	1 929.08	2304	3.90
Northern Drakensberg	10 302	2 447.58	2376	4.94
Outeniqua	3 005	579.79	1929	1.17
*Pondoland Coast	12 902	2 353.54	1824	4.75
Southern Drakensberg	20 225	4 317.41	2135	8.72
Soutpansberg	2 345	531.63	2267	1.07
Swartberg	775	96.01	1239	0.19
Table Mountain	465	126.86	2730	0.26
Tsitsikamma	3 213	707.90	2203	1.43
Upper Usutu	6 191	721.85	1166	1.46
Upper Vaal	1 401	122.16	872	0.25
Waterberg	1 033	98.83	957	0.20
Wolkberg	2 614	506.38	1937	1.02
*Zululand Coast	11 501	2 046.54	1779	4.13
Total	148 830	29 397.31		

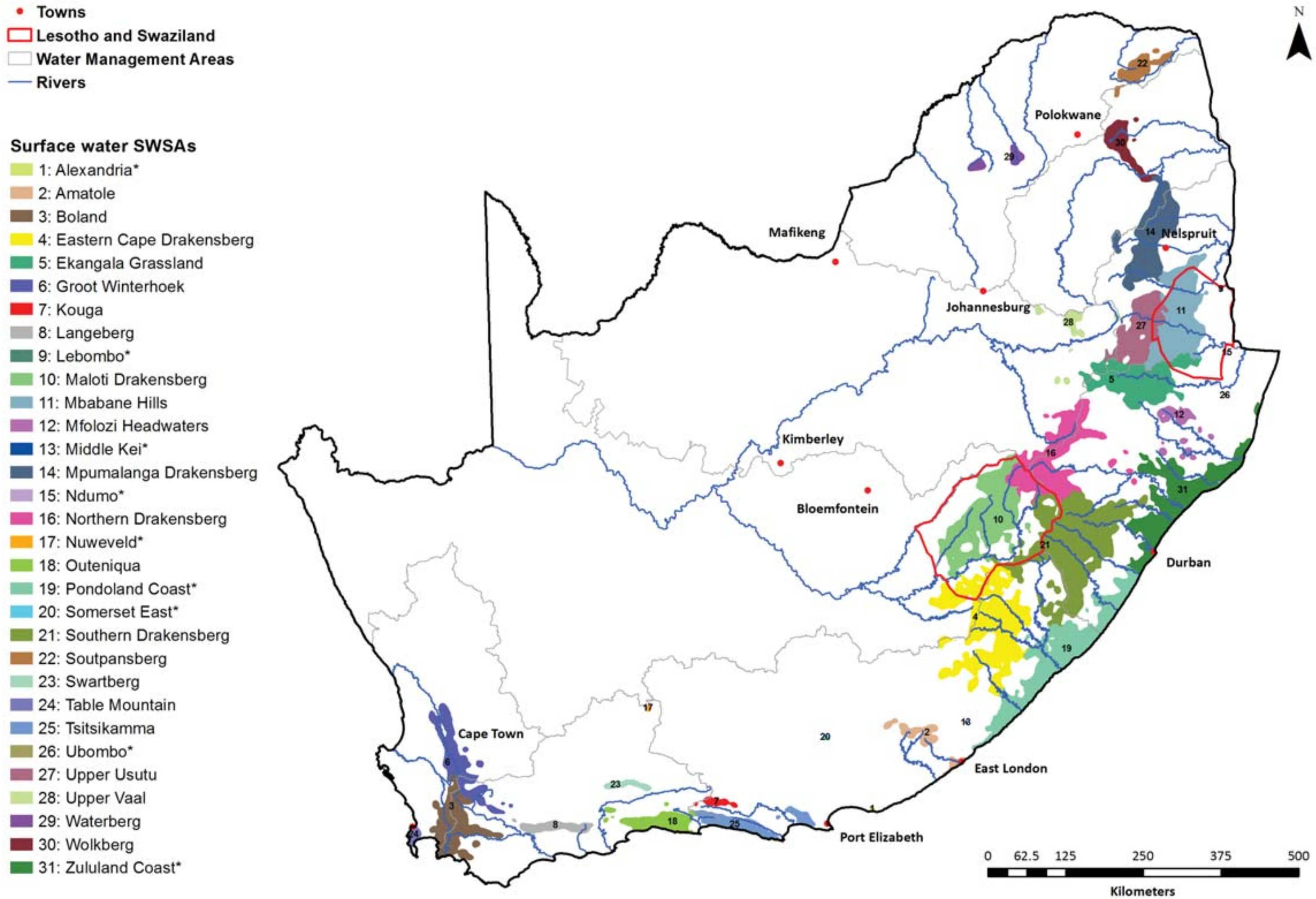


Figure 62: All the SWSA-sw identified in this study. Names with an * are of sub-national importance.

10. APPENDIX 2: STATISTICS FOR SUB-NATIONAL WSA-GW

Table 55: Groundwater contribution to the sub-national WSA-sw (through analysis of baseflow as a % runoff)

SWSA-sw	Baseflow/MAR %
Pondoland Coast	13.8%
Zululand Coast	13.6%
Middle Kei	8.0%
Lebombo	5.4%
Alexandria	3.2%
Somerset East	2.9%
Ndumo	2.9%
Ubombo	2.5%

Table 56: Groundwater contribution from sub-national WSA-gw to surface water (through analysis of baseflow as a % runoff)

SWSA-gw	Baseflow/MAR %
Northern Highveld	17.2%
Upper Keurbooms	16.9%
Lower Mzimvubu	15.3%
Great Kei	12.7%
Arlington	11.5%
Eastern Upper Karoo	5.5%
Van Wyksdorp	3.4%
Nelspoort	1.5%
Sutherland	1.4%
Beaufort West	1.4%
Blouberg	0.8%
Vanrhynsdorp	0.3%
Willowmore	0.1%
Carnarvon	0.0%
Hertzogville	0.0%
Kamieskroon	0.0%
Komaggas Cluster	0.0%
Loxton	0.0%
Port Nolloth	0.0%
Strandfontein	0.0%

Table 57: Municipal sole groundwater supply towns within sub-national WSA-gw (SWSA-gw with no sole supply groundwater settlements are excluded in this list)

SWSA-gw	Study_Name[*1]	Population per town	Population per SWSA-gw
Arlington	Arlington Town Area	5 030	5 030
Beaufort West	Murraysburg	4 416	37 740
	Beaufort West	33 324	
Blouberg	Avon Groundwater Scheme	27 389	83 159
	Blouberg Regional Water Scheme	22 500	
	Thalahane Groundwater Scheme	3 389	
	Ga-Hlako Rural Water Scheme	29 881	
Carnarvon	Carnarvon Town	5 184	
Eastern Upper Karoo	Noupoort Town Area	7 050	26 326
	Nieu-Bethesda	1 156	
	Middelburg and Rosmead	18 120	
Great Kei	Centane	5 167	138 032
	Mnquma Rural Village 1 Cluster	87 499	
	Great Kei Villages	45 366	
Hertzogville	Hertzogville Town Area	9 430	9 430
Kamieskroon	Garies	1 657	6 313
	Kamieskroon	909	
	Leliefontein	867	
	Southern Namaqualand GRWSS	2 880	
Komaggas Cluster	Komaggas Cluster	3 761	3 761
Lower Mzimvubu	WSU 2b Villages	94 685	94 685
Loxton	Loxton Town	6 680	6 680
Nelspoort	Nelspoort	1 485	1 485
Northern Highveld	Doornkop Cluster	1 751	3 676
	Bankfontein Cluster	1 925	
Port Nolloth	Port Nolloth Town Area	7 509	7 509
Sutherland	Sutherland Town	1 821	1 821
Upper Keurbooms	Krakeel	3 000	5 100
	Misgund	2 100	
Van Wyksdorp	Van Wyksdorp	653	653
Vanrhynsdorp	Nieuwoudtville Town	1 464	1 464
Willowmore	Willowmore	9 027	9 027

[*1] Towns name refers to the name of the reconciliation strategy developed for this area under the DWS All Towns Reconciliation Strategy Study, hence in some areas is a name given to a cluster of villages or a rural scheme

Table 58: Summary of sole groundwater source (>50% supply) towns and population within all (sub-national and national) SWSA-gw and nationally

Item	Count	Population
Sole GW source settlements within SWSA-gw	126 (32% of all sole GW source settlements, or 13% of all settlements)	1 933 329 (29% of the population within sole GW source settlements, or 4% of all South Africans)
All sole GW source settlements (Figure 15)	394 (41% of all settlements)	6 726 172 (12% of South Africans)
All South Africa[12]	966	54 000 000

Table 59: Agriculture and industry supported by sub-national groundwater per SWSA-gw, as water volume, and for agriculture as GVA[13]

SWSA-gw Name	Agricultural GW Use (WARMS, m^3/a)	Industrial GW Use (WARMS, m^3/a)	Agricultural GW use as a % total	Industrial GW use as a % total	Agricultural GW contribution to GVA (R millions)
Vivo-Dendron	42 961 207	18 576	6.0	100.0	49.56
West Coast Aquifer	12 260 265	848 676	83.7	0.0	351.90
Westrand Karst Belt	41 255 096	82 415	100.0	n/a	36.76
Zululand Coastal Plain	107 826	0	91.8	100.0	2.88
Arlington	165 176	11 500	67.4	100.0	3.01
Beaufort West	1 100 178	0	2.9	57.5	3.01
Blouberg	106 530	0	100.0	n/a	1.24
Carnarvon	83 640	326 705	0.0	n/a	0.22
Eastern Upper Karoo	6 471 914	338 000	100.0	n/a	18.13
Great Kei	57 496	99 308	0.0	n/a	0.90
Hertzogville	409 100	0	32.5	n/a	6.05
Kamieskroon	0	0	n/a	n/a	0.00
Komaggas Cluster	180 000	0	12.1	0.6	1.10
Lower Mzimvubu	0	0	n/a	n/a	0.00
Loxton	115 800	0	100.0	n/a	0.28
Nelspoort	0	0	34.3	100.0	n/a
Northern Highveld	838 668	44 341	4.7	2.4	5.61
Port Nolloth	0	0	31.5	100.0	n/a
Strandfontein	628 800	0	88.0	100.0	2.80
Sutherland	210 400	130 000	24.6	n/a	1.09
Upper Keurbooms	3 283 717	1 576	6.0	100.0	1.79
Van Wyksdorp	1 068 651	42 000	83.7	0.0	4.48
Vanrhynsdorp	7 274 104	655 200	100.0	n/a	22.07
Willowmore	300 335	0	91.8	100.0	1.03

[12] South African population listed for 2014, in line with the data available for population per town (All Towns data, a mix of 2013, 2014 and 2015).

[13] n/av in % column reflect no registered (surface or groundwater) use for agriculture within SWSA-gw. Conversely a 0% indicates there is some surface water use registered, yet zero registered groundwater use, hence groundwater forms 0%.

Table 60: Spatial overlap of mineral provinces and primary commodities in South Africa, and sub-national WSA-gw.

WSA-gw	WSA-gw area (km^2)	Mineral province	Commodity	Area (km^2)[14]
Arlington	1553	Witwatersrand Basin	Uranium	45
Beaufort West	786	Karoo Uranium Province	Uranium	786
Blouberg	666	Laterite Louis Trichardt	Nickel	76
Eastern Upper Karoo	6131	Karoo Uranium Province	Uranium	883
Great Kei	1416	Heavy Mineral Sands	Titanium, Zirconium	59
Hertzogville	447	Surficial Salt and Gypsum Deposits	Gypsum, Salt	447
Kamieskroon	3314	Surficial Salt and Gypsum Deposits	Gypsum	209
		West Coast Diamonds Inland	Diamond	42
Komaggas Cluster	364	Northern Cape Base Metals	Copper	364
		West Coast Diamonds Inland	Diamond	43
Loxton	397	Karoo Uranium Province	Uranium	397
Nelspoort	509	Karoo Uranium Province	Uranium	509
Northern Highveld	1345	BIC Eastern Limb	Chromium, Iron, Lead, Nickel, Titanium, Vanadium, Vermiculite	85
		BIC Phosphate Deposits	Phosphate	33
		Witbank Coalfield mainly seams 1 & 2	Coal	63
Port Nolloth	512	Northern Cape Surficial Deposits	Uranium	500
		West Coast Diamonds Coastal	Diamond	206
Strandfontein	291	Recent Sediment Phosphates	Phosphate	53
		Surficial Salt and Gypsum Deposits	Gypsum, Salt	248
		West Coast Diamonds Coastal	Diamond	33
Sutherland	1253	Karoo Uranium Province	Uranium	1253
Vanrhynsdorp	1423	Surficial Salt and Gypsum Deposits	Gypsum	591
		Vredendal Goassanous Iron	Iron, Lead	340
		West Coast Diamonds Inland	Diamond	28

[14] Area reflects the area covered by this commodity within this mineral province, within the SWSA-gw. There is overlap in mineral provinces so these values cannot be summed directly to compare to the total area of the SWSA-gw.

Table 61: Petroleum Licence Areas within sub-national Water Source Areas

SWSA-gw name	Total area (km²)	Minerals	Licence status	Licence type*	Area under licence (km²)	% of SWSA area covered
Arlington	1553	Petroleum & Gas	Granted – to be issued	Technical Cooperation Permit	910	58.6
Beaufort West	786	Hydrocarbons, Petroleum	Accepted – in progress	Exploration Right	94	12.0
Carnarvon	659	Hydrocarbons	Accepted – in progress	Exploration Right	52	7.9
Eastern Upper Karoo	6131	Hydrocarbons	Accepted – in progress	Exploration Right	4978	81.2
Hertzogville	447	Petroleum & Gas	Granted – to be issued	Technical Cooperation Permit	447	100.0
Kamieskroon	3314	Petroleum & Gas	Issued	Technical Cooperation Permit	1475	44.5
Komaggas Cluster	364	Petroleum & Gas	Issued	Technical Cooperation Permit	364	100.0
Loxton	397	Hydrocarbons	Accepted – in progress	Exploration Right	397	100.0
Nelspoort	509	Hydrocarbons	Accepted – in progress	Exploration Right	509	100.0
Port Nolloth	512	Petroleum & Gas	Issued	Technical Cooperation Permit	505	98.6
Sutherland	1253	Hydrocarbons, Petroleum	Accepted – in progress	Technical Cooperation Permit	919	73.3

Table 62: Disaggregation of Groundwater Vulnerability for South Africa for each sub-national WSA-gw

WSA-gw name	Total area km²	Very Low	Low	Med	High	Very High	Very Low	Low	Med	High	Very High
		Groundwater vulnerability categories per WSA-gw (area covered km²)					Groundwater vulnerability categories per WSA-gw (as a % total area)				
Arlington	1553	0	789	763	0	0	0.0	50.8	49.1	0.0	0.0
Beaufort West	786	0	177	607	0	0	0.0	22.6	77.3	0.0	0.0
Blouberg	666	0	326	341	0	0	0.0	49.0	51.2	0.0	0.0
Carnarvon	659	0	231	427	0	0	0.0	35.1	64.8	0.0	0.0
Eastern Upper Karoo	6131	0	1374	4760	0	0	0.0	22.4	77.6	0.0	0.0
Great Kei	1416	0	115	1303	0	0	0.0	8.1	92.0	0.0	0.0
Hertzogville	447	0	170	175	101	0	0.0	38.1	39.2	22.7	0.0
Kamieskroon	3314	0	787	2481	42	0	0.0	23.7	74.9	1.3	0.0
Komaggas Cluster	364	0	39	281	45	0	0.0	10.7	77.3	12.4	0.0
Lower Mzimvubu	1199	0	185	1011	0	0	0.0	15.4	84.3	0.0	0.0
Loxton	397	0	0	395	0	0	0.0	0.0	99.6	0.0	0.0
Nelspoort	509	0	0	510	0	0	0.0	0.0	100.1	0.0	0.0
Northern Highveld	1345	0	346	1003	0	0	0.0	25.7	74.6	0.0	0.0
Port Nolloth	512	11	0	492	0	0	2.2	0.0	96.1	0.0	0.0
Strandfontein	291	3	0	287	0	0	1.2	0.0	98.7	0.0	0.0
Sutherland	1253	0	57	1196	0	0	0.0	4.6	95.4	0.0	0.0
Upper Keurbooms	1223	0	659	563	0	0	0.0	53.9	46.0	0.0	0.0
Van Wyksdorp	599	0	491	106	0	0	0.0	82.0	17.8	0.0	0.0
Vanrhynsdorp	1423	0	907	516	0	0	0.0	63.7	36.2	0.0	0.0
Willowmore	289	0	289	0	0	0	0.0	100.0	0.0	0.0	0.0

Table 63: Disaggregation of groundwater drought risk for South Africa for each sub-national WSA-gw

SWSA-gw	Total area km²	Very Low	Low to Moderate	Moderate	High to Very High	Very Low	Low to Moderate	Moderate	High to Very High
		Groundwater Drought Risk categories per WSA-gw (area km²)				Groundwater Drought Risk categories per WSA-gw (as a % total area)			
Arlington	1553	0	1194	358	0	0.0	76.8	23.1	0.0
Beaufort West	786	0	0	695	90	0.0	0.0	88.5	11.4
Blouberg	666	0	9	658	0	0.0	1.4	98.8	0.0
Carnarvon	659	0	0	0	658	0.0	0.0	0.0	99.9
Eastern Upper Karoo	6131	0	304	5753	76	0.0	5.0	93.8	1.2
Great Kei	1416	20	1116	282	0	1.4	78.8	19.9	0.0
Hertzogville	447	0	0	446	0	0.0	0.0	99.9	0.0
Kamieskroon	3314	0	223	981	2105	0.0	6.7	29.6	63.5
Komaggas Cluster	364	0	35	51	279	0.0	9.5	14.1	76.8
Lower Mzimvubu	1199	0	64	1132	0	0.0	5.3	94.4	0.0

SWSA-gw	Total area km^2	Very Low	Low to Moderate	Moderate	High to Very High	Very Low	Low to Moderate	Moderate	High to Very High
Loxton	397	0	0	329	66	0.0	0.0	82.8	16.8
Nelspoort	509	0	0	509	0	0.0	0.0	100.0	0.0
Northern Highveld	1345	0	77	1271	0	0.0	5.8	94.5	0.0
Port Nolloth	512	0	25	71	408	0.0	4.9	13.8	79.6
Strandfontein	291	0	241	49	0	0.0	83.0	16.9	0.0
Sutherland	1253	0	0	1099	154	0.0	0.0	87.7	12.3
Upper Keurbooms	1223	0	1200	17	6	0.0	98.1	1.4	0.5
Van Wyksdorp	599	0	408	190	0	0.0	68.1	31.7	0.0
Vanrhynsdorp	1423	0	444	710	268	0.0	31.2	49.9	18.9
Willowmore	289	0	263	26	0	0.0	91.0	9.0	0.0

Table 64: Summary of the SWSA-gw for South Africa with the estimated recharge, and relative contribution to national recharge.

Name	Recharge (million m^3/a)	Area (km^2)	National recharge (%)
Arlington	1553	48.31	<0.1
Beaufort West	786	6.95	<0.1
Blouberg	666	14.28	<0.1
Carnarvon	659	3.17	<0.1
Eastern Upper Karoo	6131	92.09	<0.1
Great Kei	1416	124.48	<0.1
Hertzogville	447	7.61	<0.1
Kamieskroon	3314	9.98	<0.1
Komaggas Cluster	364	0.15	<0.1
Lower Mzimvubu	1199	186.54	<0.1
Loxton	397	1.52	<0.1
Nelspoort	509	4.47	<0.1
Northern Highveld	1345	70.98	<0.1
Port Nolloth	512	0.57	<0.1
Strandfontein	291	0.61	<0.1
Sutherland	1253	8.96	<0.1
Upper Keurbooms	1223	115.44	<0.1
Van Wyksdorp	599	8.37	<0.1
Vanrhynsdorp	1423	9.28	<0.1
Willowmore	289	1.29	<0.1

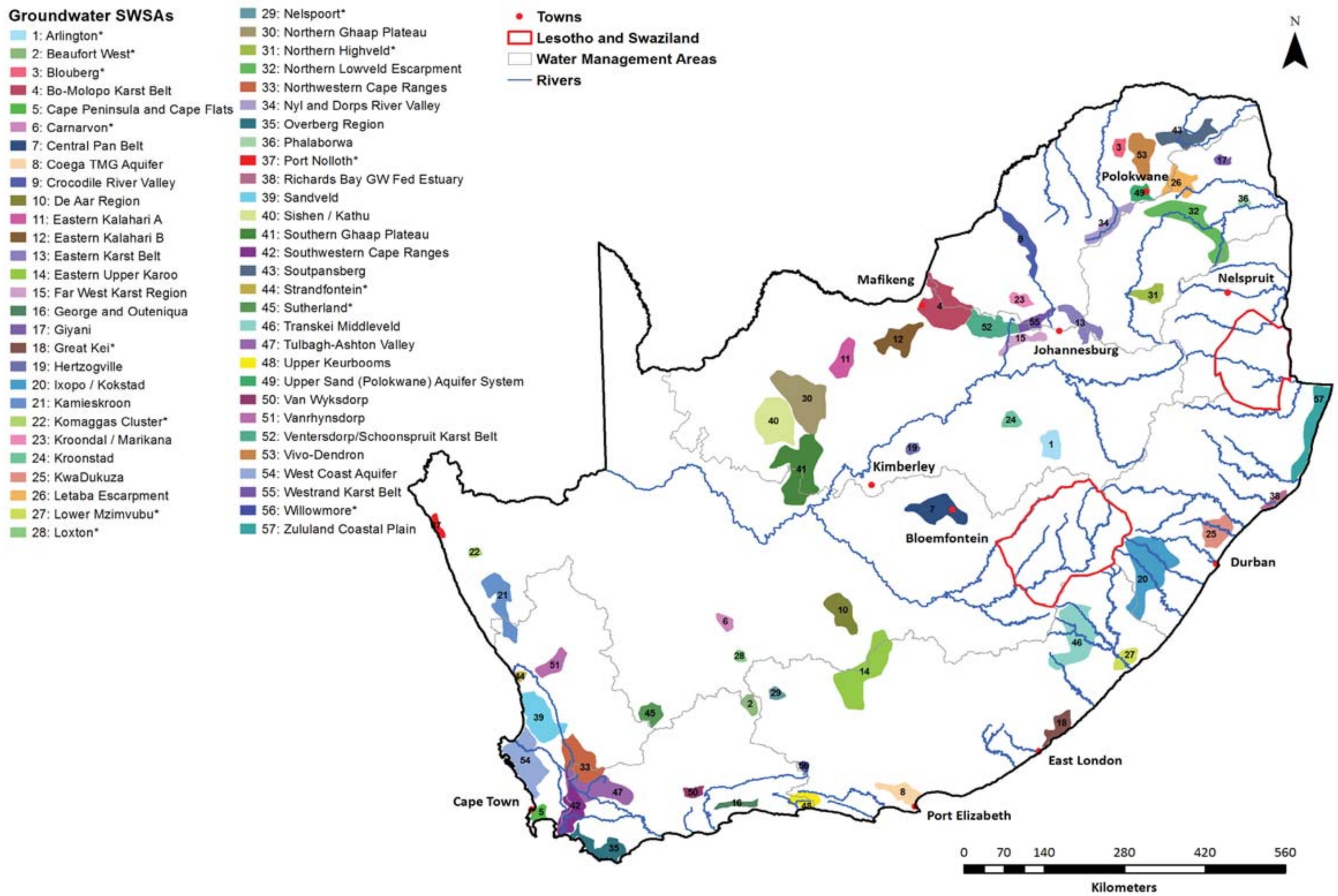
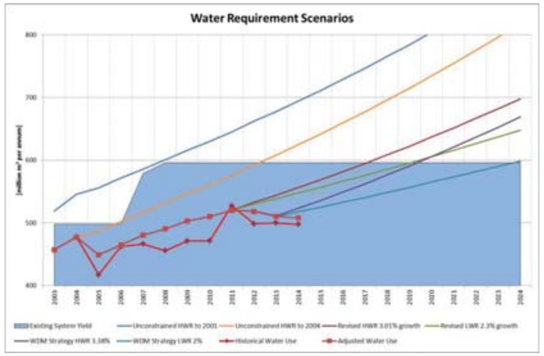


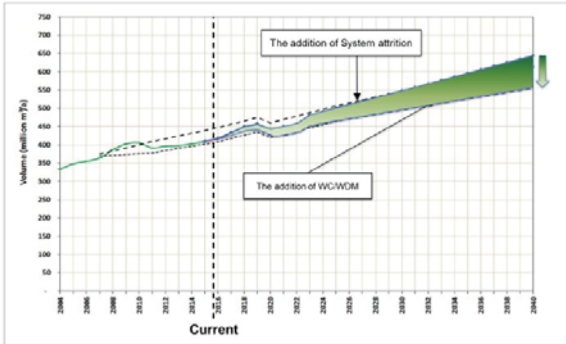
Figure 63: All the SWSA-gw identified in this study. Names with an * are of sub-national importance.

11. APPENDIX 3: GRAPHICAL SUMMARIES OF THE RECONCILIATION STRATEGIES FOR WATER SUPPLY SCHEMES SHOWN IN THE NATIONAL WATER RESOURCE STRATEGY (DWA 2013)

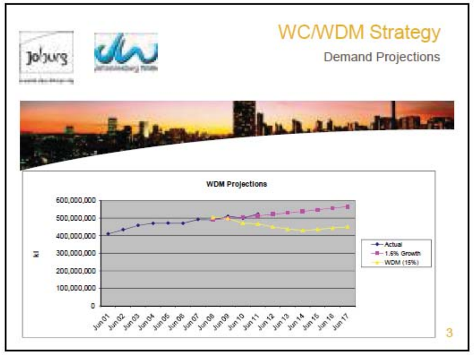
a) City of Cape Town (Riemann, 2014)



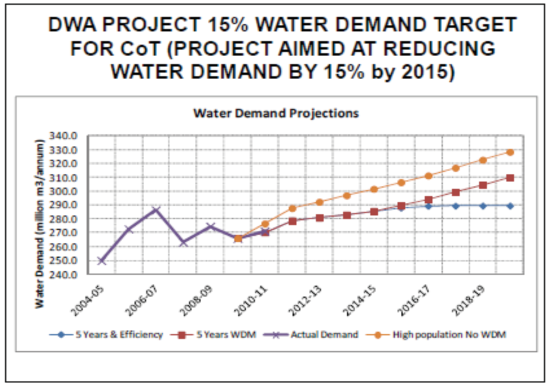
b) KZN CMA, Mgeni WSS (AECOM SA , 2015)



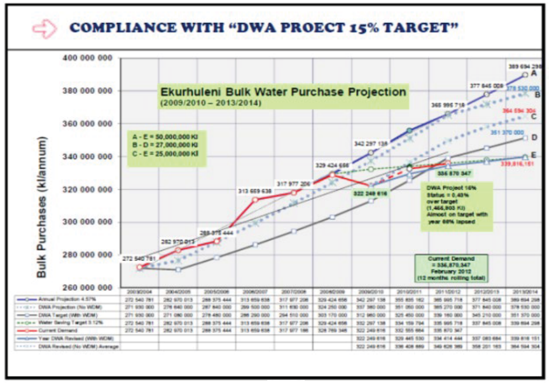
c) City of Johannesburg projected water usage with WC/WDM



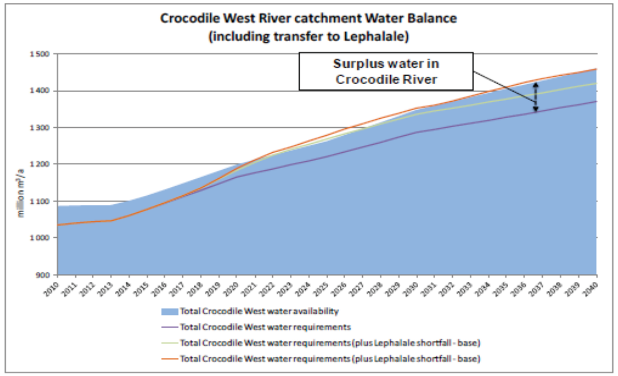
d) City of Tshwane projected water usage with WC/WDM



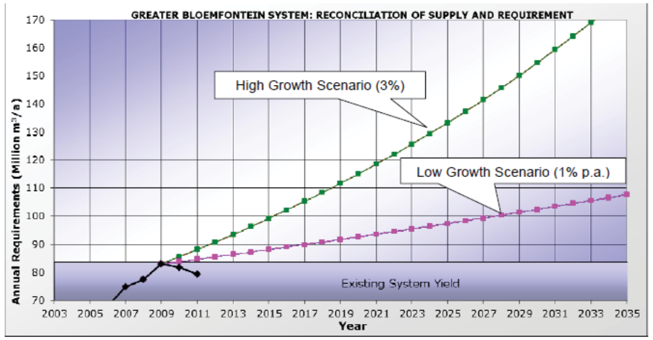
e) Ekurhuleni projected water usage



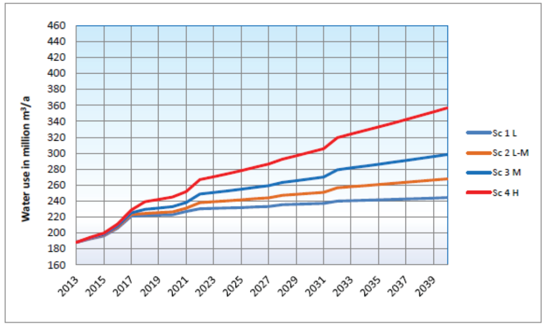
f) Crocodile West (Schroder et al., 2012)



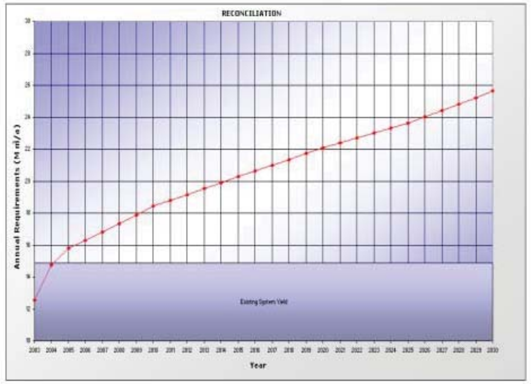
g) Greater Bloemfontein (DWAF, 2012a)



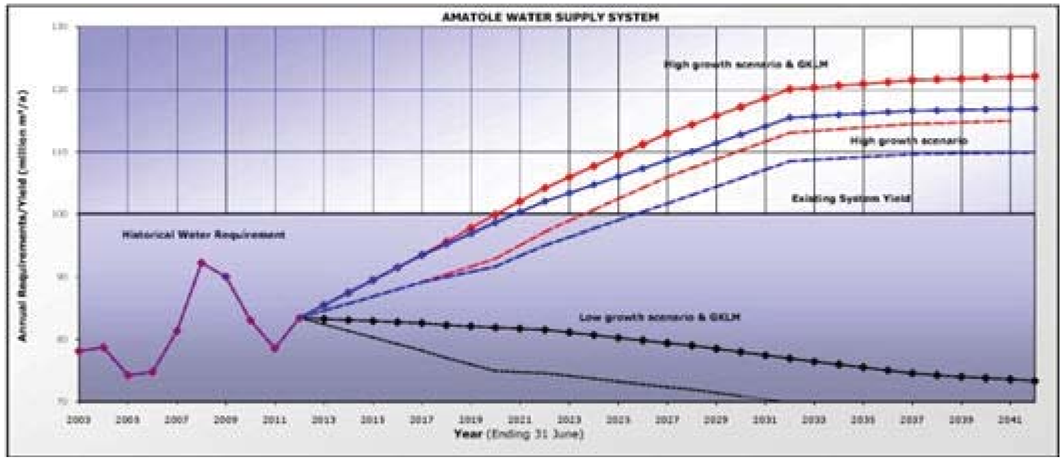
h) Richards Bay (DWS, 2015)



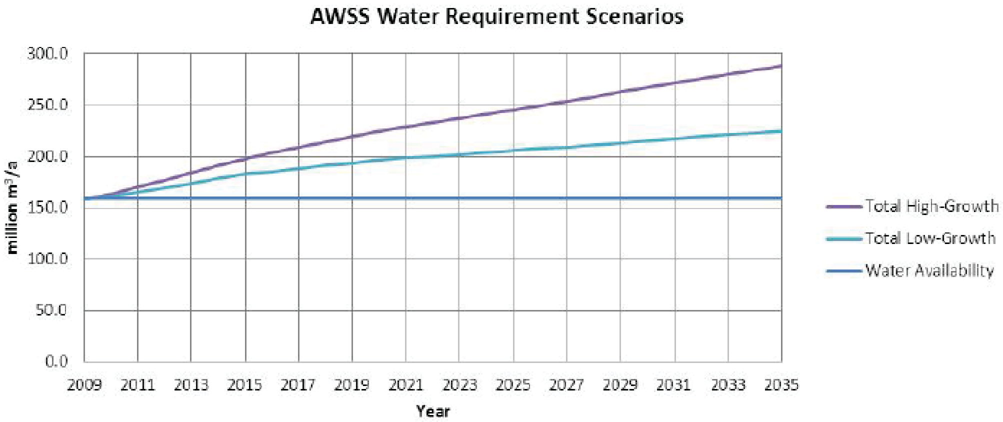
i) Mosselbay (DWAF, 2007)



(j) Amatole (Kleynhans et al., 2008)



k) Algoa WSS (DWAF, 2011a)



l) Olifants (DWAF, 2013)

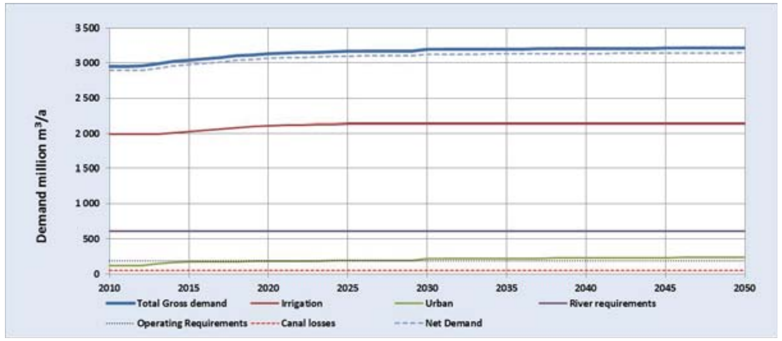


Figure 64: Summary of the reconciliation graphs used to construct the tables of water use for the urban centres

12. APPENDIX 4: REVIEW OF RECHARGE PROCESSES, ESTIMATION TECHNIQUES, AND DATASETS

12.1 Recharge Processes

12.1.1 Overview

The processes leading to the generation of recharge and specifically in semi-arid environments, and the associated measurement techniques, are well described and researched by several previous workers (i.e. Lerner et al., 1990; Seiler and Gat, 2007; Kinzelbach et al., 2002). Furthermore, several other researchers have provided summaries and reviews of these original works, including case studies of South Africa (Xu and Beekman, 2003), and discussion of applicability to national recharge estimates, (DWAF, 2006). Key information is briefly summarized here, focusing on elements relevant for use of a national scale recharge for South Africa.

12.1.2 Natural and man-influenced; direct and indirect recharge

Groundwater recharge has been defined as the downward flow of water reaching the water table, forming an addition to the groundwater table (Lerner et al., 1990). Recharge occurs naturally from precipitation, rivers, lakes, and as a result of man-made processes such as from irrigation, leakage from urban reticulation networks, and leakage from dams. A local scale investigation is generally required to identify man-made influence on recharge, and the focus here is on national recharge, and therefore natural recharge. Two principle types of natural recharge are recognised and described as:

I. Direct recharge, which is defined as "water added to groundwater in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone" and;

II. Indirect recharge, which "results from percolation to the water table following runoff and localisation in joints, as ponding in low-lying areas and lakes, or through the beds of surface watercourses" (Lerner et al., 1990).

Indirect recharge can be summarised as either being associated with surface water, or resulting from horizontal surface concentration of water (in joints, ponds, preferential pathways), in the absence of well-defined channels. These processes are shown in Figure 65. Furthermore, lateral subsurface flow may be an important recharge mechanism for an aquifer (and a discharge mechanism from another), and is not incorporated in Figure 65.

Lerner et al. (1990) motivate that a distinction should be made, conceptually and in any modelling or quantification exercise, between actual recharge (water that reaches the saturated zone), and the potential amount of water available for recharge from the unsaturated zone. The most understandable example of where these two are different is the case of a high water table, when potential recharge cannot infiltrate and becomes runoff, and where if the water table fell, more actual recharge would occur from the same potential recharge (Lerner et al., 1990).

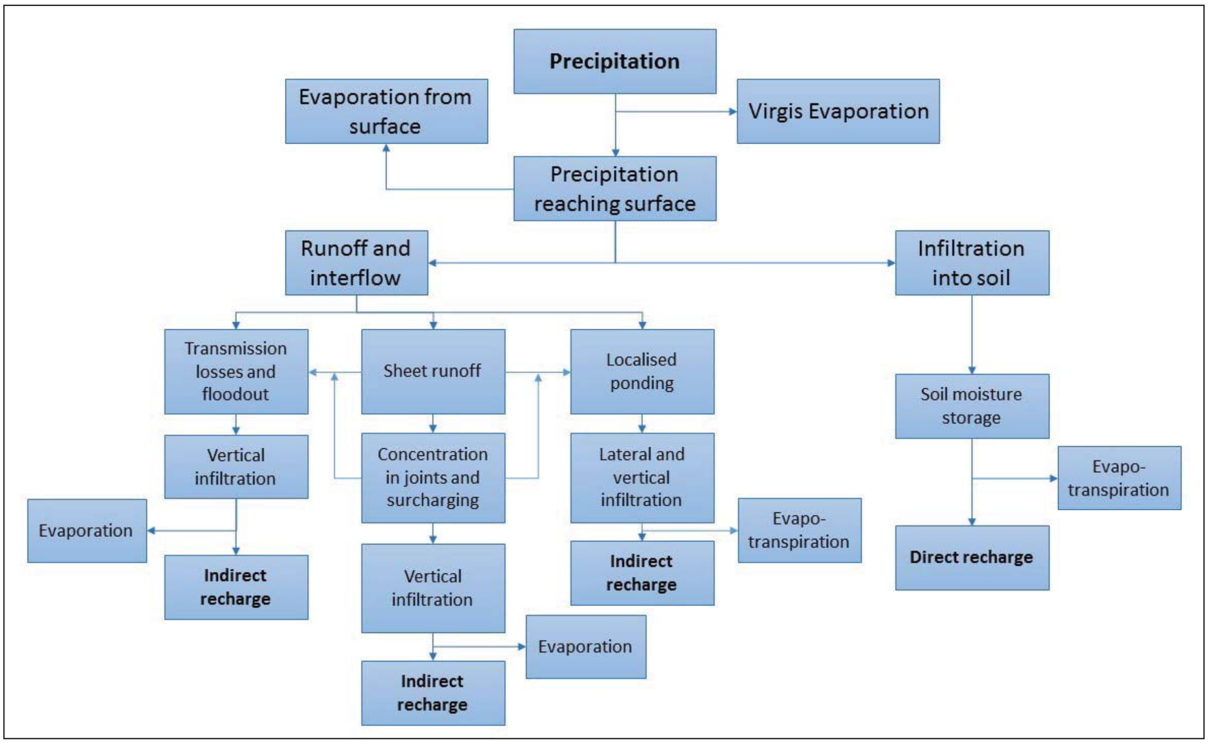


Figure 65: Elements leading to the generation of indirect and direct recharge (from Lloyd, 1986 cited in Lerner et al., 1990)

The processes involved in direct recharge are conceptually easier to define and hence form the basis of numerous recharge estimation techniques currently in common use. Regardless of the easier conceptualisation, quantification of direct recharge is still complicated by factors such as heterogeneity in the unsaturated zone, and the sensitive interrelation of unsaturated zone hydraulic properties; moisture content, matric potential (pore water pressure relative to air), and relative hydraulic conductivity (Lerner et al., 1990). Further challenges are introduced in that the factors influencing the processes that generate recharge (Figure 65) are wide ranging, and include (Rushton, 1998, cited in Lerner et al., 1990):

- At the land surface:
    - Topography
    - Precipitation: magnitude, intensity, duration, spatial distribution,
    - Runoff, ponding of water,
    - Land use (including surface sealing), cropping pattern, actual evapotranspiration
- Irrigation:
    - Nature of irrigation scheduling
    - Losses from canals and water courses
    - Application to fields, land preparation, losses from fields
- Rivers:
    - Nature of surface-groundwater interaction
- Soil zone:
    - Nature of soil zone, depth, hydraulic properties

  - Spatial and depth variability of the soil
  - Rooting depths
  - Cracking of soil on drying out or swelling due to wetting
- Unsaturated zone
  - Flow mechanisms through unsaturated zone
  - Varying hydraulic properties
- Aquifer
  - Ability of the aquifer to accept water
  - Variation of aquifer properties with time

Lerner et al. (1990) highlight that hydrological processes are the same in various climatic regions (wet, arid), hence the processes shown in Figure 65 apply regardless of climate, however the interrelationship between processes may be different under different conditions, and the amounts involved in a process are frequently more extreme for arid environments. In humid environments, recharge mostly occurs as direct recharge (Seiler and Gat, 2007). As aridity increases, because of diminished precipitation, increased evaporation, and precipitation variability, direct recharge becomes less important, and indirect recharge becomes more important (Lerner et al., 1990). The eastern regions of South Africa are considered sub-humid, with high summer rainfall and hence dominantly direct recharge. The majority of the country is considered semi-arid, and the west and north-west considered arid hence with dominantly indirect recharge (Figure 66). Semi-arid regions can be considered those characterized by a precipitation of around 250-500 mm/year, but with a ratio of precipitation to evapotranspiration of <0.5, and arid regions are considered those with precipitation of less than 250 mm/year, and a ratio of precipitation to evapotranspiration of <0.5 (Seiler and Gat, 2007).

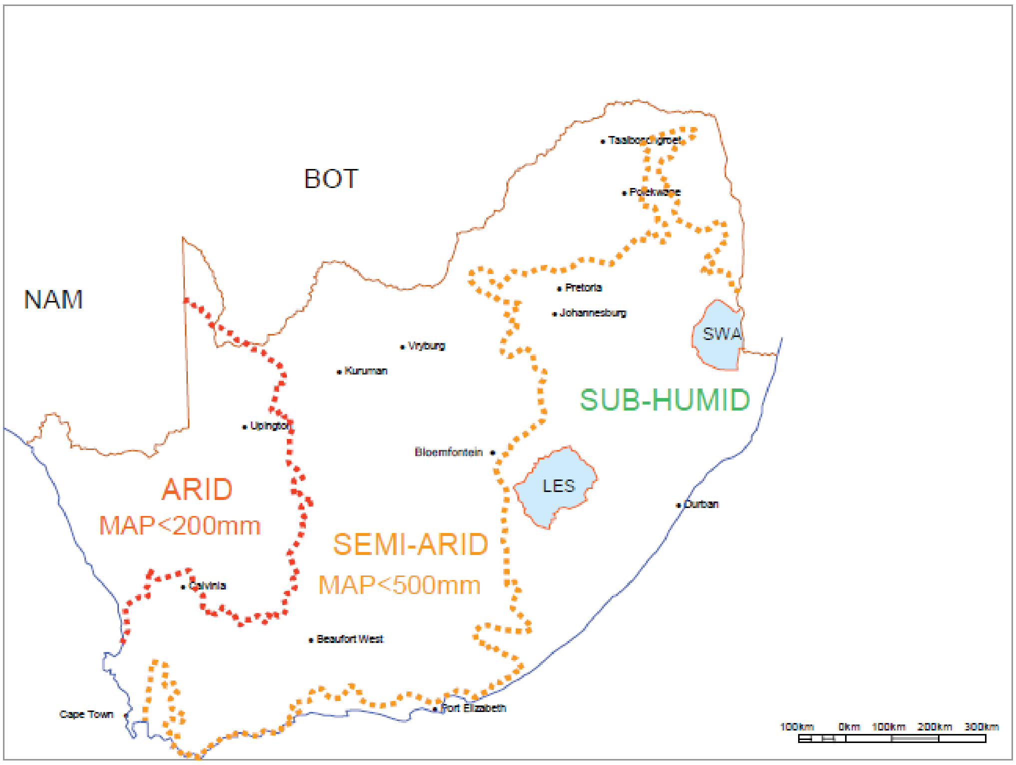


Figure 66: Climate zone boundaries in South Africa (from van Wyk, 2010)

12.1.3 Time and space variability

Considering the range of processes dictating recharge generation and factors influencing these, large variations in recharge with time and space are to be expected. The frequency of recharge events, and the transit time between event and recharge occurring, influence the choice of recharge quantification method, and eventual resource management. Although recharge quantification methods are briefly discussed in Section 2.1.2 these methods derive recharge over different time steps (the period over which recharge is averaged), and the time step of interest is based on a number of factors. The acceptable or required time step will differ for various aspects of a resource study (Table 65); for example a large scale reconnaissance study will be interested in a long term historical recharge average, whereas a small scale design stage study will require knowledge of event recharge (Lerner et al., 1990). Furthermore, in an arid environment, event-based recharge becomes more important because arid and semi-arid zone precipitation has such a high inter-annual variability.

Spatial heterogeneity can be large: across some large areas recharge appears to vary minimally, whilst in other small and apparently similar areas it can range by an order of magnitude (Lerner et al., 1990). The accuracy of measurement techniques is variable (Section 12.2), and introduces a further unknown when recharge results are variable. It is generally accepted that multiple site scale recharge estimations in the area of interest are required to gain insight on spatial variability in recharge.

Table 65: Factors influencing the choice of time step for recharge estimation (adapted from Lerner et al., 1990).

Aspects of a groundwater resources study	Time period over which recharge is averaged[15]:			
	Event	Season	Year	Historical Average
Size of study area	Small ←→ Large			
Level of study	Design ←→ Reconnaissance			
Degree of aridity	Arid ←→ Humid			
Resource exploitation	Heavy ←→ Light			
Quantity of data	Large ←→ Small			

12.1.4 Hard rock, arid and semi-arid terrains

The majority of South Africa is arid or semi-arid, in which the soil/regolith horizon is relatively thin. Vegter (1995) classifies that over 90% of the southern African aquifer systems are hard rock type aquifers, with significant secondary porosity occurring as joints and fractures (cited in van Wyk, 2010). As such, indirect recharge is dominant in the majority of the country, where the joints/fractures in fractured hard rock terrains act as flow paths for excess rainwater after interception, surface runoff, and depression storage capturing at ground surface (van Wyk, 2010). Given the precipitation/evapotranspiration ratio in arid and

[15] Two time periods over which recharge can be considered are not included in the table (instantaneous, and geological time), as although recharge may be considered on these time scales for research purposes, they are not generally relevant time periods for groundwater resource management.

semi-arid environments, the lack of even distribution of precipitation the year around, excess water for either run-off or groundwater recharge can be rare, and episodic recharge in response to unusually high rainfall events becomes important (Seiler and Gat, 2007). The capacity of the ground surface to accept episodic high recharge also becomes more important in these cases, which points to why the South Africa dolomites are so important in semi-arid areas such as Kuruman; as the dolomites have such high hydraulic conductivity and are generally able to accept high episodic recharge events and respond rapidly (van Wyk, 2010). Although these basic mechanisms that apply to recharge in arid and semi environments may be understood, quantification of indirect recharge elements is more challenging because in its nature it is a localised phenomenon, for which data and information is more scarce (Lerner et al., 1990).

Van Wyk (2010) provides several examples that illustrate the importance of episodic recharge in South Africa's hard rock semi-arid terrains. For example, the most significant wet period in the southern African semi-arid region was in the 1970s, and the longest flash flood in the Kuruman River system occurred in 1976 (6 months duration compared to most that last a few days). In response, groundwater levels in the Kalahari Group Aquifer System increased by (at least) 35 m. By 2010, the groundwater level was still elevated above the pre-flood (viz indirect recharge event) level. Data from areas with thin (<0.25) to absent soil horizon overlying a fractured and weathered hard rock aquifer show water table responses to what is termed therein as "extraordinary rainfall events", is within hours or days. A test site near Beaufort West (Figure 66) shows two consecutive hydrological years with similar mean annual precipitation (257 mm and 253 mm), and recharge only occurring in one of the two years, in response to an extraordinary rainfall event (110 mm in <21 hours). In these cases the rainfall is sufficient to generate direct recharge. Areas with some soil / regolith capping illustrate "bimodal" recharge mechanisms of direct and indirect (lateral flow dominant) recharge.

Through the several case studies presented, Van Wyk (2010) shows that significant recharge may result only from infrequent large events. There cannot therefore be a direct relationship between mean annual rainfall and recharge (even per geological terrain), as recharge depends on rainfall intensity (overcoming evaporation in arid areas, rewetting soil where significant soil profiles are established), and even the notion of annual rainfall is challenging when inter-seasonal variability is high. Mean annual recharge is therefore an even more improbable notion. This (lack of) relationship is well illustrated by Figure 67, in which Xu & Beekman (2003) collated the results of recharge studies in southern Africa, up to 1997, and plotted these against the annual rainfall of the region. Most of the recharge results collated applied the Equal Volume (spring flow) technique (modified water balance), and are grouped as such in the graph (although the authors note other methods are included in this shading). Two methods fell outside of this band: River Baseflow results fell below the band, and Chloride above, presumably controlled by the measurement method (rather than hydrogeological terrain, climate or other factors for these sites). The Botswana results fall within one area, presumably due to similar site characteristics. Below 500 mm/year (i.e. arid and semi-arid regions), the differences in the recharge values derived is large and the authors state that a satisfactory explanation cannot (yet) be given, citing the requirement for further studies to be carried out (Xu & Beekman, 2003). The later work of Van Wyk (2010) supports that a high variability in recharge compared to rainfall in arid and semi-arid areas is to be expected.

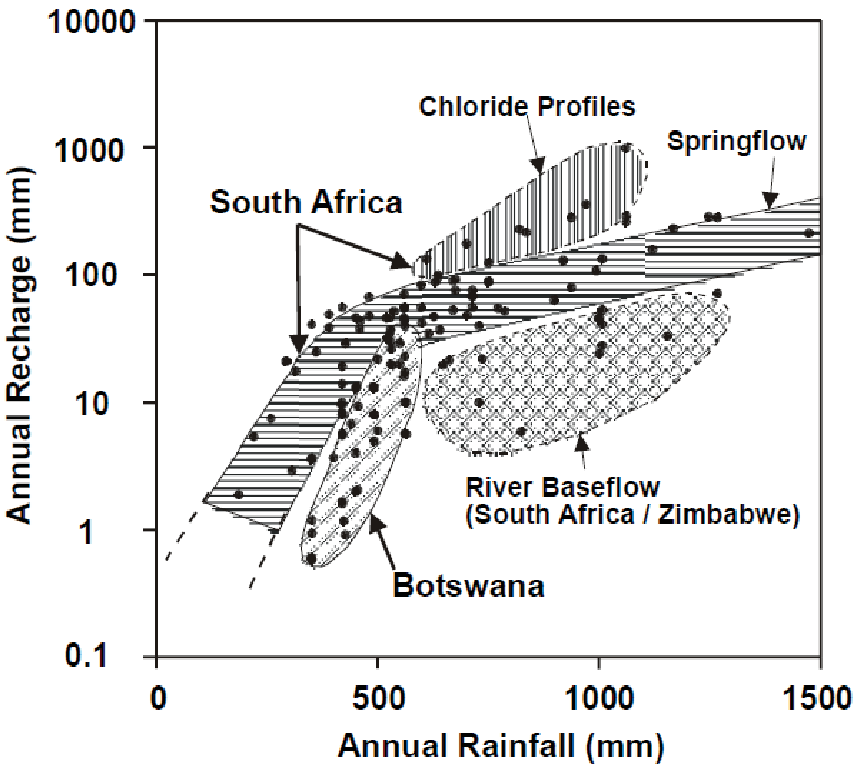


Figure 67: Collation of results recharge studies (up to 1997), compared to annual rainfall (Xu and Beekman, 2003)

A note on terminology: Direct recharge (as defined by Lerner et al., 1990) strictly only refers to that rainfall which falls on the ground and infiltrates in the same position. With this definition there is an immediate conceptual grey-area particularly in fractured hard rock terrains, summarised by Lerner et al. (1990) as "how far can water move sideways and then infiltrate before counting as indirect recharge?" (op. cit. p111). Any lateral movement of rainfall/potentially infiltrating surface water suggests there is a variability in the spatial properties which can invalidate many of the estimation methods for direct recharge, and from Figure 65, this would be termed indirect recharge. However if the movement is so small that it would not be assessed or quantified individually, when considering a regional study area, this recharge would likely be considered direct. Thus an intermediate category is suggested by Lerner et al. (1990), termed localised recharge, in which recharge where some horizontal, surface flow occurs but not involving a mapped water course. As the terrains included in Van Wyk (2010) are all fractured the "direct" recharge discussed therein falls into this category of localised recharge.

12.1.5 Sub-Humid environments

In contrast to hard rock semi-arid terrains, certain areas of SA fall into sub-humid environment. Many of the sub-humid environments coincide with coarse grained unconsolidated sediments (i.e. alluvial aquifers of the coastal Cenozoic in the Southern Cape, and northern KwaZulu-Natal). Direct recharge here will take place with deep and rapid penetration into the subsurface, also protecting the infiltrated water from re-evaporation (Seiler and Gat 2007).

Rainfall is high in the western limb of the Cape Fold Belt Mountains, (hence not included in the semi-arid demarcation in Figure 66) where the dominant aquifer is fractured rock (Table Mountain Group), with little to no soil cover. Again therefore, the dominant recharge mechanism is likely to be via preferential flow in joints/fractures of excess rainwater after interception, surface runoff, and depression storage capturing at ground surface.

12.2 Recharge survey methods

"It is certainly risky to try and relate recharge by a constant factor to precipitation in an arid zone" (Kinzelbach et al., 2002)

A full review of recharge methods is not necessary here, however to inform the applicability of any national map of recharge for the purposes of Water Source Area delineation, a preliminary discussion of recharge methods and their accuracy is worthwhile.

The successful estimation of recharge to an area depends first on successful identification of the key recharge mechanisms, as it cannot be assumed that a procedure developed for one area will be applicable in another (Lerner et al., 1990). Even if the appropriate mechanisms can be correctly determined, as recharge cannot be measured directly on any reasonable spatial scale, the complexity of recharge and the large variety of mechanisms has meant that there is no single, reliable method for measuring groundwater recharge (Kinzelbach et al., 2002). This is particularly true in arid and semi-arid areas, where recharge is sporadic (event related), hence extremely difficult to directly observe and analyse (Kinzelbach et al., 2002, Van Wyk, 2010).

Recharge methods commonly fall into the following categories (Kinzelbach et al., 2002), and are summarised in Table 66:

1. Direct measurement (for example by lysimeter)
2. Water balance methods (which include hydrograph methods)
3. Darcyan methods (including application of Darcy equation to derive flux)
4. Tracer methods

Accuracy ratings are assigned in Table 66, and are based on Kinzelbach et al. (2002), and correspond to the list below. Xu and Beekman (2003) adjusted the ratings of Kinzelbach et al. (2002) based on the authors experience and project workshops, and the resulting ratings are generally lower than Kinzelbach et al. (2002). Those from Kinzelbach are used here, as they reflect the *potential* accuracy if the limitations are acknowledged, and the method applied to the aquifer setting and scale to which it is appropriate.

1. Class 1: within a factor of 2
2. Class 2: within a factor of 5 (of the same order of magnitude)
3. Class 3: within a factor of 10 or more (with large errors likely)

Xu and Beekman (2003) also provide (based on Lerner et al., 1990) indicative applicability ranges for each recharge estimation method, including the recharge flux range that the method is able to determine, the area it is applicable to, and the time scale of recharge that the method averages over. The area that unsaturated zone methods are applicable to is small, presumably based on the high heterogeneity of the unsaturated zone, and the point scale investigation techniques. Those methods applicable over the largest areas, thus potentially relevant on national scale if aggregated, include (and are highlighted in Table 66):

1. Hydrograph separation (10-1,000 km^2), yet only applicable in wet climates
2. Watershed modelling (0.1 to 500,000 km^2)
3. Cumulative rainfall departure (1-1,000 km^2)

4. Saturated Volume Fluctuation (1-1,000 km^2)
5. Groundwater modelling (point scale to 1,000,000 km^2)

Of these methods – the accuracy is greatest (it includes class 1) for hydrograph separation, and for saturated volume fluctuation. Both have limitations when considered as a method for generation of a high confidence national scale recharge dataset: hydrograph separation is only applicable in humid environments, and saturated volume fluctuation requires long time series of sufficient and well spread water level data.

The chloride mass balance is one of the most commonly used methods in South Africa, potentially because of its relative ease (if chloride concentrations in the unsaturated zone are neglected), cost effectiveness, and lack of long-term monitoring data required for alternative methods (van Tonder and Bean, 2003), and has a reported applicability area of point scale to 0.01 km^2 (Xu and Beekman, 2003). The results are essentially point scale and a user must determine the relevant aquifer area over which the results may be meaningful. Of all methods, CMB has the longest potential recharge timeline of up to 10,000 years.

In addition to the methods listed in Table 66, totally empirical methods are also often applied especially at largest scale. These generally calculate recharge as a function of precipitation, where the function may be linear or non-linear, and would involve easily measured variables such as altitude, or catchment area (Lerner et al., 1990). This has been the approach applied in South African national recharge mapping (Section 2.1.2).

Actual recharge is required to understand the observed behaviour of groundwater systems, and as a baseline for resource quantification and planning future resource development, however where development lowers water tables, potential recharge will also need to be considered (Lerner et al., 1990). Most methods of estimating recharge provide potential rather than actual recharge. Although an important distinction, Lerner et al. (1990), Kinzelbach (2002), and Xu and Beekman (2003) do not clearly state whether the methods described therein quantify actual or potential recharge.

Table 66: Summary of Recharge Methods, accuracy and applicability (based on Kinzelbach et al., 2002, and Xu and Beekman, 2003)

Zone	Approach	Method	Principle	Limitations	Accuracy class
Surface water	Water balance techniques	Hydrograph Separation – Baseflow	Stream hydrograph separation based on the assumption that low flow conditions represent pure groundwater outflow: i.e. recharge. Estimates for entire catchment are possible, likely to be best available method in humid zone.	Not applicable in ephemeral rivers, nor arid zones	Class 1 in humid zone
		River channel water budget	Recharge derived from difference in flow upstream and downstream, accounting for evapotranspiration, in and outflow and channel storage change	Flow measurements may be inaccurate, only derives recharge from seepage from river channel	1-2
		Watershed modelling	Numerical rainfall-runoff modelling; recharge estimated as a residual term	Not applicable in ephemeral rivers	2
Unsaturated	Direct	Lysimeter	Drainage proportional to moisture flux/ recharge	Local estimate only. Surface runoff cannot be taken into account. Maybe irrelevant in arid regions.	For point values, class 1
	Darcyan	Unsaturated flow modelling	Unsaturated flow simulation to estimate recharge flux, e.g. by using numerical solutions to Richards equation, requiring estimation of head gradient and unsaturated zone properties representative of the scale on which recharge is to be determined	Poorly understood relationship between hydraulic conductivity and moisture content. Point values only	3
	Direct	Zero flux plane	Soil moisture storage changes directly measured (i.e. neutron probe), in the unsaturated zone to derive moisture flux /recharge	Local estimate only. Subsurface heterogeneity, periods of high infiltration	For point values, class 1 to 2
	Tracer	Historical	Vertical distribution of tracer as a result of activities in the past (^3H)	Poorly known porosity; present ^3H levels almost undetectable	2-3
Saturated – unsaturated	Water balance technique	Cumulative rainfall departure	Water level response from recharge proportional to cumulative rainfall departure curve. Conversion to recharge volume possible if storage coefficient is known.	Requires long time series data, and only applicable in closed spring catchment. Accuracy depends on accuracy of storage coefficient and abstraction rates	2-3

Zone	Approach	Method	Principle	Limitations	Accuracy class
		EARTH model[16]	Lumped distributed model simulating water level fluctuations by coupling climatic, soil moisture and groundwater level data	Accuracy depends on accuracy of storage coefficient and abstraction rates	1-2
		Water table fluctuation	Water level response proportional to recharge/discharge	In/outflow usually unknown, and accuracy depends on accuracy of storage coefficient and abstraction rates	2
	Tracer	Chloride Mass Balance	Amount of Cl into the system (rainfall and recharge) balanced by amount of Cl out of the system (evaporation), hence with rainfall and groundwater chloride concentration, recharge can be calculated, assuming negligible surface runoff	Long-term atmospheric deposition unknown, inapplicable where other chloride sources (i.e. halites in soil), area associated with recharge rate has to be determined.	2-3
Saturated	Darcyan	Groundwater modelling	Recharge inversely derived from numerical modelling groundwater flow and calibrating on hydraulic heads / groundwater ages	Calibration with head data is usually not unique: Many combinations of recharge rate and transmissivities (and storage coefficients) can yield the observed heads.	Class 3. Class 2 with time-varying data and tracer information.
	Water balance technique	Saturated Volume Fluctuation	Water balance over time based on averaged groundwater levels from monitoring boreholes	Requires long time series data. Flow-through region; multi-layered aquifers	1-2
		Equal volume – Spring flow	Water balance at catchment scale	Confined aquifer	1-2
	Tracer	Groundwater Dating	Age gradient derived from tracers, inversely proportional to recharge; Recharge in unconfined aquifer based on vertical age gradient (^{3}H, CFCs, $^{3}H/^{3}He$); Recharge in confined aquifer based on horizontal age gradient (^{14}C)	^{14}C, $^{3}H/^{3}He$, CFC: poorly known porosity / correction for dead carbon contribution	3

[16] Extended model for Aquifer Recharge and Moisture Transport through Unsaturated Hardrock

12.3 Recharge Case Studies and Results from South Africa

Considering the complexity of processes leading to recharge generation, and the uncertainties in its measurement, it is clear that generation of a national scale recharge map is a challenging undertaking. It is also questionable as to how relevant national scale data, for a primarily local or regional process, can ever be.

Nevertheless, a national recharge map was developed by Vegter (1995), as mm/a. The resulting recharge contours are based on the following (Vegter, 1995, and DWAF, 2006a):

- Recharge estimates from 28 case study locations across South Africa, based on a variety of techniques
- Where there is baseflow, recharge was based on a proportion of baseflow, through empirical assignment of recharge values to various baseflow values (i.e. if baseflow is 25 mm/a, recharge is considered 50 mm/a, up to 200 mm/a recharge where baseflow is 200 mm/a, i.e. a non-linear relationship)
- Where there is no baseflow, recharge was based on a proportion of effective rainfall.

The resulting recharge values were contoured into broad and smoothed categories (map included in Section 2.4).

A national recharge map was also an explicit requirement as part of the second phase of the Groundwater Resources Assessment Study (GRAII, DWAF 2006). The driving motivation for the selection of methodology was that it had to be applied across the country, and that the approach needed to be verified against point estimations of recharge. The resulting recharge map is largely based on the Chloride mass balance method, with empirical adjustments to accommodate various factors and calibrate to point data. The assumptions associated with the method applied include i) that it only considered vertical flow (direct recharge), ii) that the nature of precipitation was not taken into account in detail, and iii) preferential recharge flow paths (via root channels, dissolution cavities, etc.) were not accounted for (Conrad and Münch 2006). In order to provide spatially disaggregated data, the GIS modelling was carried out on a 1 km by 1 km grid square. The final result was a recharge map, a map expressing this as a percentage of precipitation, and an aggregated recharge volume per quaternary catchment. The methodology applied is summarised in the sequential steps below (summarised from Conrad and Münch 2006):

1. A national chloride in rainfall map was generated, based on 79 measurement points. An initial dataset of 92 was available to the project team, however extreme values were discarded (these points were assumed elevated due to site-specific enrichment and not representative of background or long term recharge). The 79 points used were largely clustered in the Berg catchment, and in the north of South Africa, very few in the Eastern Cape, KwaZulu-Natal or central Karoo areas. To generate a chloride map, an empirical relationship between topography and Chloride concentration was developed, with a correlation coefficient (R^2) of 0.787.

2. A national chloride in groundwater map was generated (at a 1 km^2 grid scale), through contouring chloride data from 28,465 locations, taken from the (then) National Groundwater Database. Again, outliers were eliminated from the dataset where data was more than three standard deviations away from the mean. The remaining points were interpolated using Kriging, to generate a national distribution. Due to the interpolation technique, the range of values in the resulting map

significantly reduced from the raw data, i.e. the measured range was lost (1.5-18,943 mg/l in raw data to 2.6-5.9 mg/l in initial map). As such, all original data (per 1 km^2 grid cell) was superimposed on the resulting map.

3. The recharge percentage (of MAP) was calculated based on the national rainfall and groundwater chloride concentration maps (R%= 100 x (Chloride in rainfall/chloride in groundwater))

4. Resulting groundwater recharge percent values ranged between 0.01-79.59%. Following smoothing the range reduced to 0.02-21.8%. The correlation between the resulting map and (a set of unknown) literature values was low (R^2=0.205), leading to the enhancement of the map with empirical factors, applied through GIS "filters":

5. The following factors were taking into account, to remove anomalies and account for local variation in likely recharge. Each of these filters was assigned a range or multiplication factor to adjust the underlying Chloride-derived recharge map:

    a. Unsaturated thickness

    b. Soil drainage rate

    c. Rainfall seasonality

    d. Geology

    e. Land cover

    f. Topography

    g. Coefficient of variation of annual precipitation

6. The resulting output was calibrated using multiple regression, against 42 recharge point data (unknown which ones were used) based on Chloride mass balance method, and smoothed. The resulting recharge ranged from -4.1% to 31.8% (it is not known how the negative recharge value can be derived), and the calibration is reported as low.

7. In parallel to the GRAII recharge study (DWAF, 2006a), a SW/GW interaction study was conducted (DWAF, 2006b), which also derived recharge values as a percentage of MAP. The values derived from the two studies were compared, and correlated by an R^2 value of 0.69. The empirical equation derived in the SW/GW interaction study, was then applied as a further GIS filter on the recharge map.

8. The resulting recharge map was further adjusted, based on the fact that the computed recharge was less than baseflow derived during the SW/GW interaction project (DWAF, 2006b). Hence, values were increased in the adjusted recharge map, and negative values set to 0.0001%. The final "adjusted recharge" range was 0.0001% to 35.6947%. Following this adjustment, the recharge values from the two assessments (DWAF 2006a and DWAF 2006b) was improved from an R^2 of 0.69 to 0.7039.

9. A final comparison is made between the adjusted mapped recharge, and the 42 recharge literature values from Chloride approach, which were used as calibration of the Chloride and GIS-derived recharge map (step 6). The correlation between these datasets is $R^2 = 0.5676$.

The resulting GRAII recharge map has become a reference document for preliminary recharge values for desktop or reconnaissance stage groundwater resources assessments in South Africa. In the third phase of the Groundwater Resources Assessment Study (GRAIII), the following concerns were made on the GRAII recharge map (DWA, 2009):

- With reference to the first step in the sequence above, the generation of a national rainfall chloride map: "the initial poor to almost absent correlations between chloride content in precipitation and MAP or elevation (R^2 only around 27%) for the inland station question the applied approach. The apparently better correlation between the final smoothed calculated dataset and observed values (R^2= 79%) is a direct result of the predominance of coastal chloride values with high concentration ranges. The inland values show a completely different (linear) relation in comparison to coastal values, and calculated correlation coefficients are therefore not representative."

- With reference to the derivation of a national groundwater chloride map, step 2 above: "In view of cyclic variations of chloride content or even linear trends for impacted stations the calculation of harmonic averages for stations with time series data is generally questionable".

- With reference to the application of the chloride mass balance approach itself, DWA (2009) point out that the method is applicable to chloride in soil water and/or the groundwater surface, whilst the NGDB data represent mostly pumped samples representative of the aquifer not necessarily the unsaturated zone.

- Further concerns raised in DWA (2009) relate to the interpolation and calibration methods, and points out that these do not significantly improve the correlation to observed, stating that the final correlation is still poor at 56%.

13. APPENDIX 5: LAND COVER AND COAL FIELDS IN SWSAS

13.1 Land cover

Land cover was calculated for all the polygons and is presented separately for SWSA sections which are surface water and groundwater or both. Only 11% of the Maloti Drakensberg and about 33% of the Mbabane Hills SWSA-sw extend into South Africa. Land cover data extracted from the National Land Cover data set for South Africa (GTI, 2015).

Table 67: Summary of the land cover (area in km^2) in the Strategic Water Source Areas

SWSA Name	Type	Water bodies	Wet-lands	Natural	Degraded (donga)	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban (commercial-industrial)	Urban (informal)	Urban (residential)	Urban (sports)	Urban (township)
Amatole	sw	3.4	7.0	1 202.1	0.0	108.2	11.8	197.7	0.0	0.1	0.0	55.2	0.4	0.0
Arlington	gw	0.9	67.6	763.5	2.5	699.8	1.3	12.3	0.1	0.2	0.0	1.6	0.3	2.3
Beaufort West	gw	1.2	2.0	649.1	0.0	1.8	0.1	0.0	1.0	0.4	0.0	3.5	0.9	3.6
Blouberg	gw	0.1	0.0	498.0	0.5	83.6	0.0	0.1	0.1	0.0	0.0	83.5	0.0	0.0
Boland	sw	38.0	60.4	1 609.2	0.0	298.2	354.5	53.0	1.2	24.3	2.1	83.8	20.7	16.9
Boland & Northwestern Cape Ranges	swgw	2.2	3.1	110.7	0.0	27.5	50.2	1.9	0.1	0.1	0.0	1.2	0.2	0.0
Northwestern Cape Ranges	gw	8.6	11.0	591.3	0.0	66.7	16.8	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Boland & Overberg Region	swgw	9.8	4.0	164.3	0.0	31.8	11.0	1.4	0.0	0.0	0.0	1.0	0.0	0.0
Overberg Region	gw	27.6	67.1	1 283.6	0.0	563.8	9.5	6.7	0.6	0.5	0.2	9.7	1.0	0.8
Boland & Southwestern Cape Ranges	swgw	74.6	54.5	2 160.9	0.0	89.6	263.7	74.1	0.8	1.9	0.6	6.9	1.4	3.4
Southwestern Cape Ranges	gw	0.0	0.0	8.6	0.0	0.1	1.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Boland & Tulbagh-Ashton Valley	swgw	4.8	6.6	231.2	0.0	65.7	116.6	10.6	0.2	0.2	0.2	1.7	0.4	0.8
Tulbagh-Ashton Valley	gw	50.2	28.9	1 810.3	0.0	115.2	142.8	1.1	0.9	3.9	0.8	12.8	2.8	2.4
Bo-Molopo Karst Belt	gw	2.6	9.4	3 969.0	8.3	877.6	82.2	8.4	69.3	12.5	72.6	122.5	5.9	23.2
Carnarvon	gw	0.5	0.1	269.4	0.0	0.7	0.0	0.0	0.2	0.3	0.0	1.8	1.0	0.4

SWSA Name	Type	Water bodies	Wet-lands	Natural	Degraded (donga)	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban (commercial-industrial)	Urban (informal)	Urban (residential)	Urban (sports)	Urban (township)
Central Pan Belt	gw	4.9	30.9	1 721.9	0.3	1 186.0	98.0	16.1	9.4	20.3	11.6	217.3	10.2	33.5
Crocodile River Valley	gw	2.5	37.0	1 735.5	1.1	142.1	198.3	0.6	27.4	0.7	2.3	9.1	0.9	1.5
De Aar Region	gw	1.1	10.7	2 180.1	43.6	6.8	0.3	0.2	4.5	1.3	0.0	13.5	2.0	3.2
Eastern Cape Drakensberg	sw	24.9	139.4	7 108.1	33.3	1 144.0	1.4	262.0	1.1	0.7	0.0	553.3	0.1	0.0
Eastern Cape Drakensberg & Transkei Middleveld	swgw	6.7	77.7	3 759.2	7.5	759.3	1.4	273.3	0.6	0.8	0.0	405.6	0.4	0.4
Eastern Kalahari A	gw	0.0	0.0	1 210.5	0.1	637.8	110.4	0.4	0.3	0.0	0.0	48.6	0.1	0.8
Eastern Kalahari B	gw	2.3	0.0	1 356.6	0.3	1 108.7	26.5	1.2	7.4	0.5	0.3	148.7	0.8	1.7
Eastern Karst Belt	gw	6.1	41.1	596.9	0.0	407.0	63.1	31.2	19.9	18.8	10.5	202.6	21.8	19.2
Eastern Upper Karoo	gw	13.4	88.8	5 743.7	0.0	79.1	4.7	2.2	2.1	2.0	0.0	14.2	3.3	5.5
Enkangala Drakensberg	sw	26.6	203.7	5 724.2	6.0	752.3	41.9	958.8	1.8	1.4	0.5	113.6	2.1	2.6
Far West Karst Region	gw	4.7	42.4	961.2	0.3	223.1	22.0	15.6	21.1	3.7	7.7	56.3	4.8	16.9
George	gw	0.1	0.1	7.9	0.0	4.3	0.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Giyani	gw	0.1	0.0	328.0	0.4	56.0	7.8	0.2	0.7	1.2	0.8	29.0	0.6	12.9
Great Kei	gw	3.5	3.5	1 099.7	0.0	161.2	1.8	13.0	0.1	1.6	0.0	130.0	0.1	0.2
Groot Winterhoek	sw	5.2	13.2	1 332.1	0.0	147.2	58.2	2.7	0.0	0.2	0.0	1.8	0.3	0.1
Groot Winterhoek & Northwestern Cape Ranges	swgw	39.8	51.8	2 134.3	0.0	224.1	185.3	6.2	0.3	0.8	0.2	3.8	1.2	1.6
Groot Winterhoek & Sandveld	swgw	1.3	3.0	251.3	0.0	28.7	32.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Sandveld	gw	16.5	40.3	2 129.3	0.0	1 000.7	487.8	4.5	0.6	0.3	0.1	1.5	0.5	0.7
Groot Winterhoek & Tulbagh-Ashton Valley	swgw	3.3	12.2	633.2	0.0	23.2	81.7	5.5	0.4	0.1	0.1	2.4	1.9	0.3
Hertzogville	gw	1.1	5.1	258.8	0.0	175.4	2.1	1.1	0.1	0.1	0.1	1.0	0.2	1.4
Kamieskroon	gw	0.5	0.0	3 115.0	0.0	175.4	0.0	0.0	0.8	0.2	0.0	1.8	0.3	1.5
Komaggas Cluster	gw	0.0	0.0	352.7	0.0	1.1	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.5
Kouga	sw	0.0	6.2	457.2	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kroondal/Markina	gw	2.1	8.2	505.5	4.5	106.4	16.4	9.8	44.9	8.1	5.4	54.5	4.6	15.0

SWSA Name	Type	Water bodies	Wet-lands	Natural	Degraded (donga)	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban (commercial-industrial)	Urban (informal)	Urban (residential)	Urban (sports)	Urban (township)
Kroonstad	gw	2.8	23.0	475.8	0.0	244.9	6.0	7.7	0.4	3.7	0.0	23.2	2.9	8.4
Langeberg	sw	2.1	8.7	228.3	0.0	151.8	19.7	0.6	0.1	0.0	0.0	0.4	0.0	0.0
Langeberg	gw	1.2	9.3	296.4	0.0	172.0	5.6	0.9	0.1	0.0	0.0	0.0	0.0	0.0
Langeberg & Langeberg	swgw	3.9	43.5	1 295.4	0.0	255.7	19.6	48.2	0.1	0.4	0.0	3.3	0.5	2.8
Lower Mzimvubu	gw	1.8	3.8	798.5	0.0	157.5	4.0	5.0	0.0	0.5	0.0	224.6	0.1	0.0
Loxton	gw	0.6	0.4	181.7	0.0	1.7	0.7	0.0	0.2	0.0	0.0	0.5	0.0	0.1
Maloti Drakensberg	sw	0.0	0.6	119.0	0.0	2.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mbabane Hills	sw	5.4	43.9	1 547.1	0.3	70.3	59.4	742.4	1.8	2.4	0.5	34.9	1.4	30.7
Mfolozi Headwaters	sw	0.4	4.1	721.4	1.1	89.5	8.0	264.2	0.2	0.0	0.0	53.7	0.3	0.2
Mpumalanga Drakensberg	sw	24.7	94.2	2 948.5	0.7	129.8	151.8	1 987.4	1.8	1.9	0.0	163.6	1.7	10.0
Mpumalanga Drakensberg & Eastern Lowveld Escarpment	swgw	1.1	19.7	852.0	0.2	31.0	22.5	966.9	6.1	1.9	0.0	9.7	0.7	1.1
Eastern Lowveld Escarpment	gw	0.0	0.3	3.6	0.0	0.2	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0
Mpumalanga Drakensberg & Northern Lowveld Escarpment	swgw	2.6	22.9	820.2	0.1	16.6	0.8	348.5	0.3	0.6	0.1	20.9	0.3	0.3
Northern Lowveld Escarpment	gw	1.5	13.5	2 443.2	18.8	82.7	54.8	0.3	4.2	0.2	0.0	135.6	0.1	2.0
Nelspoort	gw	0.1	1.4	467.5	0.0	1.6	0.2	0.0	0.1	0.0	0.0	0.2	0.0	0.2
Northern Drakensberg	sw	57.3	111.0	5 520.7	18.3	608.1	124.0	181.6	2.4	1.1	0.0	211.0	2.9	36.5
Northern Ghaap Plateau	gw	0.1	0.0	6 078.9	1.8	14.6	1.4	0.4	3.7	1.7	3.1	121.5	1.5	4.4
Northern Highveld	gw	2.1	19.9	888.8	0.0	370.5	10.1	37.0	4.1	0.3	0.0	7.9	0.0	0.0
Nyl and Dorps River Valley	gw	2.9	36.6	1 534.6	0.3	347.5	26.4	1.3	3.9	4.1	0.2	54.0	6.2	16.8
Outeniqua	sw	35.5	35.0	1 626.8	0.0	228.8	54.1	379.0	0.3	9.1	2.9	37.3	17.7	13.6
Outeniqua & George	swgw	0.5	2.2	349.9	0.0	18.8	2.3	34.8	0.0	0.4	0.0	4.0	0.6	0.6
Outeniqua & Upper Keurbooms	swgw	0.0	0.2	77.9	0.0	0.4	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Phalaborwa	gw	1.8	0.0	364.1	0.1	3.7	0.2	0.3	45.6	0.9	0.0	11.7	1.9	0.0

SWSA Name	Type	Water bodies	Wet-lands	Natural	Degraded (donga)	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban (commercial-industrial)	Urban (informal)	Urban (residential)	Urban (sports)	Urban (township)
Port Nolloth	gw	6.5	0.0	443.6	0.0	0.0	0.0	0.0	49.5	0.3	0.0	0.8	0.1	0.9
Richards Bay GW Fed Lakes	gw	27.9	7.9	136.8	0.0	8.7	69.0	246.1	1.8	10.4	0.2	80.6	1.9	11.5
Sishen/Kathu	gw	0.3	0.0	4 652.1	0.0	2.0	0.2	0.0	113.8	2.2	0.5	9.5	1.7	1.8
Southern Drakensberg	sw	93.5	425.1	10 340.5	14.1	2 163.2	319.3	2 605.5	0.8	11.3	11.5	1 038.9	9.0	25.5
Southern Ghaap Plateau	gw	0.1	0.0	6 434.2	0.0	3.7	1.2	0.3	52.7	1.8	2.1	10.5	1.4	5.4
Soutpansberg	sw	6.2	1.5	717.0	0.0	57.6	55.8	7.9	0.4	1.3	0.0	170.0	0.1	0.0
Soutpansberg	gw	2.3	2.6	1 010.9	0.1	58.6	25.3	43.6	0.3	3.1	0.0	112.2	1.1	1.0
Soutpansberg & Soutpansberg	swgw	6.7	3.1	739.4	0.0	49.0	109.5	188.6	0.3	1.6	0.0	212.0	0.0	0.0
Strandfontein	gw	0.0	0.1	232.4	0.0	54.6	3.5	0.0	0.2	0.0	0.0	0.1	0.0	0.0
Sutherland	gw	4.6	0.9	984.4	0.0	7.2	0.1	0.0	0.2	0.2	0.0	0.7	0.4	0.3
Swartberg	sw	0.9	3.3	698.0	0.0	30.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Table Mountain	sw	3.5	5.2	121.7	0.0	0.0	0.2	2.8	2.0	12.9	0.8	32.4	4.0	2.2
Table Mountain & Cape Peninsula and Cape Flats	swgw	5.2	4.3	96.4	0.0	6.1	4.6	7.0	1.4	33.2	1.7	92.0	22.9	18.2
Cape Peninsula and Cape Flats	gw	0.8	5.9	94.2	0.0	3.0	6.5	2.1	1.0	34.5	11.9	83.6	14.5	47.2
Transkei Middleveld	gw	1.0	4.6	174.0	2.8	62.8	0.0	1.9	0.1	0.0	0.0	44.9	0.0	0.0
Tsitsikamma	sw	9.5	28.8	1 739.2	0.0	321.7	71.5	235.0	0.1	0.6	0.0	39.1	1.4	1.2
Tsitsikamma & Coega TMG Aquifer	swgw	0.0	0.0	43.1	0.0	3.2	0.0	0.0	0.0	0.2	0.1	1.2	0.0	0.0
Coega TMG Aquifer	gw	5.2	18.0	1 411.6	0.0	34.6	3.2	0.9	10.3	15.5	0.4	74.7	14.3	36.7
Tsitsikamma & Upper Keurbooms	swgw	1.7	10.8	778.1	0.0	15.2	37.3	20.0	0.1	1.0	0.0	4.3	0.0	0.5
Upper Keurbooms	gw	1.5	4.0	226.7	0.0	7.9	18.4	7.0	0.0	0.0	0.0	2.0	0.0	0.0
Upper Sand (Polokwane) Aquifer System	gw	1.5	3.4	692.3	22.7	44.1	14.7	0.6	6.3	9.7	0.3	147.9	5.9	15.4
Upper Usutu	sw	72.7	299.2	2 216.2	0.5	367.1	21.8	2 107.1	6.7	1.3	0.4	122.1	0.6	1.9
Upper Vaal	sw	1.8	34.0	498.4	0.1	277.3	0.2	1.2	0.7	1.7	1.8	9.0	1.1	6.3

SWSA Name	Type	Water bodies	Wet-lands	Natural	Degraded (donga)	Cultivated (dryland)	Cultivated (irrigated)	Plantation/ woodlot	Mining	Urban (commercial-industrial)	Urban (informal)	Urban (residential)	Urban (sports)	Urban (township)
Van Wyksdorp	gw	0.8	5.2	564.1	0.0	5.6	1.8	0.1	0.0	0.0	0.0	0.2	0.0	0.0
Vanrhynsdorp	gw	1.7	4.5	1 175.7	0.0	182.7	16.2	0.2	3.4	0.2	0.0	2.1	0.2	0.7
Ventersdorp/Schoonspruit Karst Belt	gw	2.3	14.2	2 001.0	0.1	723.3	100.1	4.9	10.1	0.8	0.9	13.9	0.6	2.5
Vivo-Dendron	gw	1.5	0.0	2 066.9	0.0	94.1	369.3	0.5	1.4	0.1	0.7	18.7	0.1	1.5
Waterberg	sw	1.4	2.8	766.9	0.1	53.3	11.5	0.6	0.1	0.0	0.0	0.5	0.0	0.0
West Coast Aquifer	gw	23.6	79.5	2 246.0	0.0	2 053.6	123.3	10.1	6.2	6.5	0.3	23.0	2.5	4.1
Westrand Karst Belt	gw	0.5	18.1	636.1	0.0	317.9	52.7	9.2	4.9	0.7	1.3	45.5	1.2	0.6
Willowmore	gw	0.4	0.3	267.8	0.0	3.1	0.0	0.1	0.1	0.2	0.0	1.2	0.6	1.2
Wolkberg	sw	4.1	5.3	326.6	0.1	25.3	17.0	111.7	0.2	0.3	0.0	46.5	0.0	5.7
Wolkberg & Letaba Escarpment	swgw	13.6	8.8	500.4	0.0	21.2	155.8	327.9	0.6	3.3	0.0	16.2	1.2	4.0
Letaba Escarpment	gw	1.4	4.2	787.5	2.3	148.6	25.2	11.6	0.3	0.2	0.6	110.3	0.7	4.0
Wolkberg & Northern Lowveld Escarpment	swgw	0.6	6.2	1 067.7	0.3	15.8	3.5	18.5	0.0	0.0	0.0	31.3	0.0	0.0
Zululand Coastal Plain	gw	338.3	173.5	1 922.1	0.0	51.3	56.8	458.8	0.5	0.5	0.0	299.5	0.6	0.0

13.2 Coal fields

The area of each Strategic Water Source Area which overlaps with coal fields in South Africa (excluding those SWSAs and coal fields with no overlap), the type of SWSA (sw = surface water, gw = groundwater), the coal fields' economically recoverable potential, the run-of-mine (ROM) production, and (thus) the remaining coal reserves (after (Colvin et al., 2011)). Coal field data were taken from the South African Mine Water Atlas datasets (WRC, 2016).

Table 68: Summary of information on the overlaps with coal fields for all the SWSAs (nd = no data)

SWSA Name	Type	Coal Field	Extent of coal field (km^2)	Recoverable Mt	ROM production (1982-2000) Mt	Remaining Mt	Overlap area (km^2)	Total SWSA area (km^2)	Overlap (% of SWSA)	Total overlap (%)
Eastern Cape Drakensberg	sw	Molteno-Indwe	4 699	nd	nd	nd	140	10 814	1.29	1.29
Eastern Karst Belt	gw	Witbank	8 473	12 460	2 320	10 140	803	1 984	40.50	40.50
Enkangala Drakensberg	sw	Ermelo	9 919	4 698	101	4 597	1 590	8 582	18.53	
Enkangala Drakensberg	sw	Highveld	9 794	10 979	972	10 007	643	8 582	7.49	
Enkangala Drakensberg	sw	Utrecht	2 169	649	64	585	1 330	8 582	15.50	
Enkangala Drakensberg	sw	Vryheid	499	204	82	122	53	8 582	0.62	42.13
Kroonstad	gw	Welkom	10 603	4 919	0	4 919	799	799	100.00	100.00
Mfolozi Headwaters	sw	Nongoma & Somkele	1 601	98	15	83	72	1 925	3.76	
Mfolozi Headwaters	sw	Vryheid	499	204	82	122	288	1 925	14.96	18.71
Northern Drakensberg	sw	Highveld	9 794	10 979	972	10 007	0	10 302	0.00	
Northern Drakensberg	sw	Klip River	4 928	655	85	570	886	10 302	8.60	8.60
Northern Highveld	gw	Witbank	8 473	12 460	2 320	10 140	63	1 345	4.70	4.70
Nyl and Dorps River Valley	gw	Springbok Flats	8 256	1 700	0	1 700	767	2 036	37.68	37.68
Upper Usutu	sw	Ermelo	9 919	4 698	101	4 597	1 262	6 191	20.38	20.38
Upper Vaal	sw	Ermelo	9 919	4 698	101	4 597	390	1 401	27.86	
Upper Vaal	sw	Highveld	9 794	10 979	972	10 007	732	1 401	52.29	

SWSA Name	Type	Coal Field	Extent of coal field (km^2)	Recoverable Mt	ROM production (1982-2000) Mt	Remaining Mt	Overlap area (km^2)	Total SWSA area (km^2)	Overlap (% of SWSA)	Total overlap (%)
Upper Vaal	sw	Witbank	8 473	12 460	2 320	10 140	75	1 401	5.34	85.49
Vivo-Dendron	gw	Tshipise Pafuri	6 473	267	6	261	112	2 555	4.40	4.40
Lebombo*	sw	Kangwane	704	nd	nd	nd	1	36	1.78	1.78
Zululand Coast*	sw	Somkele	1 145	nd	nd	nd	126	8 578	1.47	1.47

14. APPENDIX 6: PROTECTION STATUS STATISTICS FOR ALL THE STRATEGIC WATER SOURCE AREAS, TRANSBOUNDARY, NATIONAL AND SUBNATIONAL

Table 69: Formally protected areas in each of the SWSA sections and as a whole excluding the areas of SWSA-sw that fall into Lesotho and Swaziland. Based on data compiled for the NBA 2018 (Von Staden & Skowno 2017).

SWSA name	Type	Area (ha)	Total PA (ha)	Total area in section (ha)	Protected SWSA area (%)	Whole area (ha)	Protected SWSA area (%)
***Alexandria**	sw	4 185	4 185	5 850	71.54		71.54
***Nuweveld & Beaufort West**	swgw	7 828	7 828	8 606	90.96		90.96
***Pondoland Coast**	sw	24 334		1 119 635	2.17		
***Pondoland Coast & Great Kei**	swgw	120	24 453	51 650	0.23	1171285	2.09
***Somerset East**	sw	2 534	2 534	6 552	38.68		38.68
***Ubombo**	sw	168	168	3 104	5.41		5.41
***Zululand Coast**	sw	36 109		857 831	4.21		
***Zululand Coast & Richards Bay GW Fed Estuary**	swgw	1 039		60 574	1.71		
***Zululand Coast & Zululand Coastal Plain**	swgw	35 738	72 885	54 305	65.81	972711	7.49
Amatole	sw	3 913	3 913	200 140	1.96		1.96
Beaufort West	gw	19 969		69 991	28.53		
Blouberg	gw	1 252	1 252	66 609	1.88		1.88
Boland	sw	84 729		245 996	34.44		
Boland & Northwestern Cape Ranges	swgw	5 975		17 333	34.47		
Boland & Overberg Region	swgw	2 823		21 988	12.84		

SWSA name	Type	Area (ha)	Total PA (ha)	Total area in section (ha)	Protected SWSA area (%)	Whole area (ha)	Protected SWSA area (%)
Boland & Southwestern Cape Ranges	swgw	174 978		268 036	65.28		
Boland & Tulbagh-Ashton Valley	swgw	15 175	283 680	54 947	27.62	608300	46.63
Bo-Molopo Karst Belt	gw	9 850	9 850	526 763	1.87		1.87
Cape Peninsula and Cape Flats	gw	924		32 836	2.81		
Table Mountain & Cape Peninsula and Cape Flats	swgw	6 269	7 192	27 114	23.12	59950	12.00
Carnarvon	gw	1 570	1 570	65 860	2.38		2.38
Central Pan Belt	gw	1 881	1 881	336 773	0.56		0.56
Coega TMG Aquifer	gw	29 406		164 628	17.86		
Tsitsikamma & Coega TMG Aquifer	swgw	569	29 975	3 528	16.14	168157	17.83
Crocodile River Valley	gw	673	673	216 306	0.31		0.31
De Aar Region	gw	333	333	247 462	0.13		0.13
Eastern Cape Drakensberg	sw	16 530	16 530	1 081 419	1.53		1.53
Eastern Karst Belt	gw	6 898	6 898	198 390	3.48		3.48
Eastern Upper Karoo	gw	101 469	101 469	613 098	16.55		16.55
Enkangala Grassland	sw	66 509	66 509	858 216	7.75		7.75
Far West Karst Region	gw	8 042	8 042	138 207	5.82		5.82
George and Outeniqua	gw	2 173		15 635	13.90		
Outeniqua & George and Outeniqua	swgw	20 926	23 100	57 082	36.66	72718	31.77
Giyani	gw	1 218	1 218	43 788	2.78		2.78
Groot Winterhoek	sw	95 932		153 107	62.66		
Groot Winterhoek & Northwestern Cape Ranges	swgw	157 807		250 661	62.96		
Groot Winterhoek & Sandveld	swgw	11 151		42 352	26.33		

SWSA name	Type	Area (ha)	Total PA (ha)	Total area in section (ha)	Protected SWSA area (%)	Whole area (ha)	Protected SWSA area (%)
Groot Winterhoek & Tulbagh-Ashton Valley	swgw	51 358	316 248	72 959	70.39	519079	60.92
Kamieskroon	gw	7 242	7 242	331 419	2.19		2.19
Kouga	sw	44 178	44 178	61 311	72.05		72.05
Kroondal/Marikana	gw	9 209	9 209	79 515	11.58		11.58
Langeberg	sw	78 474		168 878	46.47		
Langeberg & Tulbagh-Ashton Valley	swgw	2 634	81 108	3 360	78.40	172238	47.09
Maloti Drakensberg	sw	3 866	3 866	10 851	35.63		35.63
Mbabane Hills	sw	45 820	45 820	1 001 481	4.58		4.58
Mfolozi Headwaters	sw	13 570	13 570	192 500	7.05		7.05
Mpumalanga Drakensberg	sw	40 954		720 482	0.06		
Mpumalanga Drakensberg & Northern Lowveld Escarpment	swgw	29 422	70 376	116 869	0.25	837351	8.40
Northern Drakensberg	sw	79 300	79 300	1 030 156	7.70		7.70
Northern Ghaap Plateau	gw	2 005	2 005	627 356	0.32		0.32
Northern Highveld	gw	259	259	134 523	0.19		0.19
Northern Lowveld Escarpment	gw	33 798		289 753	11.66		
Mpumalanga Drakensberg & Northern Lowveld Escarpment	swgw	29 422	63 220	116 869	0.25	406622	15.55
Northwestern Cape Ranges	gw	10 291		95 834	10.74		
Groot Winterhoek & Northwestern Cape Ranges	swgw	157 807		250 661	62.96		
Boland & Northwestern Cape Ranges	swgw	5 975	174 073	17 333	34.47	363828	47.84
Nyl and Dorps River Valley	gw	32 407	32 407	203 606	15.92		15.92
Outeniqua	sw	73 488		235 346	31.23		
Outeniqua & George and Outeniqua	swgw	20 926		57 082	36.66		

SWSA name	Type	Area (ha)	Total PA (ha)	Total area in section (ha)	Protected SWSA area (%)	Whole area (ha)	Protected SWSA area (%)
Outeniqua & Upper Keurbooms	swgw	3 458	97 873	8 069	42.86	300498	32.57
Overberg Region	gw	23 625	23 625	203 562	11.61		11.61
Phalaborwa	gw	12 975	12 975	43 289	29.97		29.97
Port Nolloth	gw	4 653	4 653	50 372	9.24		9.24
Sandveld	gw	2 349		358 442	0.66		
Groot Winterhoek & Sandveld	swgw	11 151	13 499	42 352	26.33	400794	3.37
Southern Drakensberg	sw	175 012		1 339 398	13.07		
Southern Drakensberg & Ixopo/Kokstad	swgw	62 205	237 218	676 849	9.19	2016247	11.77
Southern Ghaap Plateau	gw	801	801	654 209	0.12		0.12
Southwestern Cape Ranges	gw	443		6 872	6.45		
Boland & Southwestern Cape Ranges	swgw	174 978	175 421	268 036	65.28	274908	63.81
Soutpansberg	gw	2 236		127 100	1.76		
Soutpansberg	sw	2 736		104 348	2.62		
Soutpansberg & Soutpansberg	swgw	1 502	6 474	130 150	1.15	361598	1.79
Swartberg	sw	49 976	49 976	77 487	64.50		64.50
Table Mountain	sw	10 458		19 353	54.04		
Table Mountain & Cape Peninsula and Cape Flats	swgw	6 269	16 726	27 114	23.12	46467	36.00
Tsitsikamma	sw	49 465		239 682	20.64		
Tsitsikamma & Coega TMG Aquifer	swgw	569		3 528	16.14		
Tsitsikamma & Upper Keurbooms	swgw	50 539	100 574	78 098	64.71	321309	31.30
Tulbagh-Ashton Valley	gw	40 268		224 734	17.92		
Langeberg & Tulbagh-Ashton Valley	swgw	2 634		3 360	78.40		

SWSA name	Type	Area (ha)	Total PA (ha)	Total area in section (ha)	Protected SWSA area (%)	Whole area (ha)	Protected SWSA area (%)
Groot Winterhoek & Tulbagh-Ashton Valley	swgw	51 358		72 959	70.39		
Boland & Tulbagh-Ashton Valley	swgw	15 175	109 435	54 947	27.62	356000	30.74
Upper Keurbooms	gw	2 112		36 142	5.84		
Outeniqua & Upper Keurbooms	swgw	3 458	5 570	8 069	42.86	44212	12.60
Upper Sand (Polokwane) Aquifer System	gw	1 796	1 796	96 568	1.86		1.86
Upper Usutu	sw	162	162	619 058	0.03		0.03
Van Wyksdorp	gw	26 064	26 064	59 919	43.50		43.50
Vanrhynsdorp	gw	6 161	6 161	142 278	4.33		4.33
Ventersdorp/Schoonspruit Karst Belt	gw	4 346	4 346	287 518	1.51		1.51
Vivo-Dendron	gw	2 969	2 969	255 540	1.16		1.16
Waterberg	sw	14 855	14 855	103 310	14.38		14.38
West Coast Aquifer	gw	24 400	24 400	458 632	5.32		5.32
Westrand Karst Belt	gw	28 741	28 741	108 994	26.37		26.37
Willowmore	gw	189	189	28 919	0.65		0.65
Wolkberg	sw	6 667		56 467	11.81		
Wolkberg & Letaba Escarpment	swgw	6 622		94 841	6.98		
Wolkberg & Northern Lowveld Escarpment	swgw	31 616	44 905	110 137	28.71	261445	17.18
Zululand Coastal Plain	gw	96 450		275 760	34.98		
Total		2 744 845		21 560 984	12.73		

15. APPENDIX 7: COMMENTS AND RESPONSES REGISTER

15.1 Inception workshop

Project inception workshop: Identifying and delineating South Africa's strategic surface-water and groundwater source areas and mapping the areas they supply

Date and time: 11 September 2015, 09h30 for 10h00, ending 15h30

Venue: Ulwazi Room, Knowledge Commons, CSIR, Pretoria

Workshop Summary: Proceedings and key discussion points

Project summary

Managing and protecting water source areas is a cost-effective means of keeping contaminants out of drinking water and delivering a continued supply of good quality water to downstream users. South Africa's recently mapped surface-water source areas[17] make explicit that managing a relatively small fraction of land can greatly enhance national water security and human wellbeing, supporting growth and development needs that are often a far distance away. This project seeks to refine the map of surface-water source areas, and augment the map with strategic groundwater source areas.

Purpose of workshop

To review and refine the proposed approach with key end-users, seek agreement on the criteria for identifying Strategic Water Source Areas and to identify policy and planning processes that the project outputs could inform.

[17] In this project, the term 'water source area' refers to integrated water source areas that include consideration of both surface-water source areas and groundwater source areas. The term '***Strategic*** Water Source Areas' refers to a subset of water source areas that are considered of strategic significance from a national planning perspective. Criteria for identifying Strategic Water Source Areas will be developed as part of this project.

Agenda

09h30-10h00	Coffee	ALL
10h00-10h15	Welcome and introductions	Dr Stanley Liphadzi, WRC
10h15-10h30	Policy and practice insights	Chair: Kristal Maze[18], SANBI
10h30-10h45	Presentation on mapping methodology for surface-water	Jeanne Nel, CSIR
10h45-11h15	Presentation on groundwater methodology: groundwater conceptual framework	Helen Seyler, Delta-H
11h15-13h00	Discussion	ALL
13h00-13h30	Lunch	ALL
13h30-14h30	Agreement on approach For identifying *strategic* groundwater source areas For identifying *strategic* surface-water water source areas	ALL
14h30-15h00	Targeted policy processes at different scales Filling in cards of how YOU could use these products	ALL
15h00-15h30	Main uses, completion of meeting register and tea Years of relevant experience and in what Additional data not mentioned and contact person(s)	ALL
15h30-15h45	Other issues	ALL
15h45-16h00	Closure and way forward	Amanda Driver, SANBI

Welcome and introductions

Stanley Liphadzi (WRC) welcomed participants and a round of introductions was held. A brief introduction to the project then followed. Key points included:

- This project involves the same team that worked on the National Freshwater Ecosystem Priority project (NFEPA), which was part of a WRC project. The WRC is building on this project by integrating groundwater and surface water source areas. We are therefore making the links between freshwater conservation planning and management, and groundwater management. It is very exciting to be bringing in the groundwater community and strengthening the work started by NFEPA.

- The products emerging here will be designed, not just as a research tool, but a usable product that can assist with implementing change in our communities. The more we do these applied projects, the more we can attract funding for improving these projects.

- This is not only a tool for groundwater management, but will also make a start on exploring higher-level synergies between water and human wellbeing. For example, can we overlay the poverty map on water source areas and see how they overlap? What can we say about these water source areas in water accounts? What about employment or national development planning priorities? Can we use this to explore the connections between energy and water resources? How can these products be used to support government in realising the countries strategic objectives?

[18] Kristal Maze from SANBI, originally intended as the chair person, sent apologies, and Mandy Driver (SANBI) chaired.

- Diverse views are very good and we have that here with the representation we have achieved – at this workshop there are five national government departments, research institutions and NGO's represented. This sets the scene for a project with strong collaborative governance.

Workshop participants and apologies

Table 1 provides a list of participants in the workshop, as well as the ones that sent apologies. For a full list of invitees, see the registration list at the end of this document.

Table 1: Workshop participants and apologies

Workshop participants			Apologies		
Name	***Surname***	***Organisation***	***Name***	***Surname***	***Organisation***
Ayanda		DWS	Atwaru	Yakeen	DWS
Dean	Muruven	WWF	Boyd	Escott	Ezemvelo KZN Wildlife
Ernst	Bertram	DWS	Brent	Corcoran	Mondi
Faith	Seabi	DAFF	Chris	Moseke	DWS
Fanus	Fourie	DWS	Christo	Marais	DEA
Harold	Weepener	ARC	Graham	Jewitt	UKZN
Heidi	van Deventer	CSIR	Jill	Hooday	
Helen	Seyler	Delta-H	Johan	van Rooyen	DWS
Henry	Roman	DST	Kristal	Maze	SANBI
Hermien	Roux	North West READ	Magamase	Mange	DST
Hesma	Cockrell	DWS	Mark	Gush	CSIR
Isa	Thompson	DWS	Mike	Smart	DWS (RO, Groundwater)
Jacqueline	Jay	DWS	Sarah	Polonsky	DEA NRM
Jeanne	Nel	CSIR	Shanna	Ninamber	DST
John	Dini	SANBI	Tendani	Nditwani	DWS
Julian	Conrad	GEOS			
Jurgo	Van Wyk	DWS			
Kai	Witthüser	Delta-H			
Lindie	Smith-Adao	CSIR			
Lucia	Motaung	DEA			
Majola	Kwazikwakhe	DWS			
Mandy	Driver	SANBI			
Mariam	Dickinson	DEA			
Nadia	Sitas	CSIR			
Niccoline	Fourie	DEA			
Nicolette	Vermaak	DWS			
Niel	van Wyk	DWS			
Rochelle		DEA			
Sakhile	Mndaweni	DWS			
Salama	Moodeley	DWS			
Seef	Rademeyer	DWS			
Simangele	Sithole	Ezemvelo KZN Wildlife			
Stanley	Liphadzi	WRC			
Tichatonga	Gonah	DWS			
Wanda	Mthdoisi	DEA			
Wandile	Nomquphu	WRC			
Willem	Du Toit	DWS			

Summary of key points and decisions made

Table 2 summarises the key discussion points raised during over the duration of the workshop and decisions taken, where appropriate. The next section provides more detail of the workshop discussions.

Table 2: Key points and decisions

No.	Key discussion point	Decision
1	Will the project look at demand from industry and residential as well as agricultural use?	Yes. The project team will be mapping beneficiaries associated with key economic centres and will also make an attempt at agriculture.
2	Will significant urban runoff and treated waste (i.e. recycled water sources areas) be considered as strategic water source areas, e.g. Gauteng?	No, this project focuses on strategic water source areas that are considered key ecological infrastructure, which by definition only includes natural, functioning ecosystems and not human infrastructure source areas. We will not embed these areas in strategic water source areas, but it is an interesting dataset for users to consider with the outputs. There was a request to make this more explicit in the project summary and presentation of the maps – possibly a footnote indicating that urban runoff and re-use is a category of water source on its own that is not embedded in the strategic water source area maps that focus on naturalised runoff and recharge.
3	Should the surface water source areas, which used the 2005 National Water Resource Assessment, be updated with the 2012 National Water Resource Assessment data?	This was considered but the project team felt an update would be too time consuming and would not change the water source areas. It would also be better to consider a new rainfall surface for future updates.
4	Will the product be an integrated groundwater and surface water map?	That is what we are striving for; however, we will have to decide whether this makes sense once we have the draft maps of surface water and groundwater source areas.
5	Are we going to consider the suitability of groundwater sources to users, i.e. examine groundwater quality in terms of human impacts on groundwater?	No, we can address the vulnerability and risk but cannot assess small scale impacts due to the difficulties of including local information on a national map. However, we might assess broad impacts.
6	In ecosystem service assessments, CSIR has in the past removed areas that have naturally high recharge but poor quality water. Will we do the same?	No. We will take the viewpoint that it is useable if treated.
7	Will groundwater source areas be linked to groundwater dependent ecosystems as well as groundwater infrastructure?	No. We are not going to consider groundwater dependant ecosystems. Our focus is on water that is being used for socio-economic purposes rather than water that is being used by rivers to maintain ecosystems.
8	Will maps of recharge need to include Swaziland and Lesotho?	Yes, the GRAII recharge dataset covers Lesotho and Swaziland so the recharge in these areas can be shown.
9	Are transboundary dependencies (e.g. Swaziland, Lesotho, Botswana) going to be mapped?	The perspective of the project is South African, but where there are very strong transboundary dependencies, the team will try and include them – if there are data quantitatively; else to just highlight the dependency on the map, and specifically highlight the strategic risks of transboundary rivers and aquifers.

No.	Key discussion point	Decision
10	Will the map be linked to mandates?	The map will have many different use contexts. This workshop is a start at understanding the main use contexts, and then we will be developing guidelines that target specific audiences.
11	Will local scale data be integrated with national scale data in the approach?	Point is taken but it is not possible to process the two scales together. For example, a national scale map is inconsistent with a soil scale map.
12	Are we looking at existing demand or existing and future demand?	Both. We will most likely use the water reconciliation strategies as the data source for existing and future demand, and augment these with other data if necessary.
13	Will aquifer storage be included as a criterion for identifying strategic groundwater source areas (given that areas of high storage can indicate areas where managed aquifer recharge could be implemented)?	There was disagreement among the participants. Some felt it should be in because it captures areas such as the dolomites, and it provides for strategic application of the maps related to future potential groundwater use (i.e. where can we have high storage for future drought protection, high storage for Mean Annual Runoff). However, the team suggested that as the project is not concerned with groundwater resources quantification and planning, storage isn't used as a criterion, however map users will be able to compare the SWSA-gw areas with whatever datasets they see as necessary for a particular analysis, MAR being one of them.
14	Even though this is a national map, the real value of this dataset is going to be at a provincial or catchment level.	Yes, agreed
15	Who should be custodian of this map – responsible for its dissemination and updating?	DWS was considered, but participants – including DWS officials – felt that DWS had too many other implementation agendas that would take priority. The agreement eventually was that the WRC is collaborating with SANBI and WWF as the main data custodians of the results of the research, and that the WRC would be the custodian – and potentially disseminate through SANBI and WWF channels.
16	Who will update the dataset?	The WRC will fund the updates
17	The lack of surface and groundwater monitoring points was highlighted as a big problem.	Participants recommended that the monitoring stations are extended. This issue links back to DWS mandates.
18	The next NWRS update is 2018 and we are striving to have the map products ready for this process.	Yes, all participants agreed
19	How do we categorise strategic recharge areas?	It is the combination of groundwater supply and dependency, but we may need to have a separate method for urban and agricultural dependency since there are lots of situations where the use and recharge are very different – It is not straight forward.
20	Can we map groundwater recharge across South Africa through using soil permeability of groundwater and the recharge they allow, rather than estimate it through understanding rainfall versus recharge?	There is an honours student at Free State university exploring this concept as part of another research project (the study is not yet available). Agreed in principle that soil maps for spatially disaggregated recharge are required. The project team is aware of the study (Piet le Roux) with promising results, however the data are not ready for us to use, and it is a local study, not yet national.

Presentation on mapping methodology for surface-water

There was interactive discussion among workshop participants through the course of the presentation by Jeanne Nel (CSIR). Key points included:

Agriculture

- Heidi van Deventer (CSIR) asked if the project will look at demand from industry and residential, and if we will look at livestock and rural use. Jeanne Nel responded that the project is committed to mapping urban beneficiaries of key economic centres and then examining how to consider agricultural beneficiaries too, although we are still assessing data sources for doing so. The project team would like to use actual use data, but failing that a potential method is to model agricultural water use from land cover data. The project team will also assess using the census data (e.g. poverty levels, water borne diseases, etc.) to understand links between human benefits and each strategic water source area.

- A DAFF representative was concerned that agriculture is a priority area as agriculture needs to expand irrigation and grow according to the National Development Plan. Jeanne Nel responded that we will definitely be looking at agriculture, and a task team will be put together to deal with agricultural water use. This task team will approach ARC and DAFF to explore which datasets are best for our purposes.

- Niel van Wyk (DWS) also mentioned that DAFF is doing an Agricultural Policy Action Plan (ACAP). The contact person is Hein Lindeman. They are collecting agricultural use data that the project team will find useful.

Urban reuse of water

- Kai Witthüsser (Delta-H) asked why Johannesburg does not show up as a water source area because of urban runoff and treated waste water? Jeanne Nel responded that naturally Johannesburg is not a strategic water source area in terms of its water production in situ. The water supply to Johannesburg comes via Rand Water from Lesotho. The project team is only assessing natural strategic water source areas.

- Henry Roman (DST) made the point that if the water source from Johannesburg was cut off, there would be serious consequences to downstream beneficiaries – so should Johannesburg in this light not be considered a strategic water source area? Jeanne responded that we are currently only focusing on natural runoff – the key ecological infrastructure. Henry pointed out that the project summary was not explicit about the naturalised runoff focus and requested that it be made more explicit and to point out that non-natural urban runoff is a very important water source that is not captured by these strategic water source areas.

- Isa Thompson (DWS) stated that it is the denaturalised runoff which is associated with health problems. She suggested that this should be kept separate. Jeanne Nel agreed that this project is about ecological infrastructure. Jeanne Nel stated that it is a layer to overlay, not to embed in our strategic water source areas. Stanley Liphadzi also stated that in integrated water planning they are starting to look at “other resources” such as underground mine workings.

WR2012 data

- The current Mean Annual Runoff data are based on the Water Resource Assessment 2005 (WR2005). The updated WR 2012 is now available. Isa Thompson and the workshop participants requested that the project team consider updating the Mean Annual Runoff data to the WR 2012.

- The project team agreed to consider this, but said that because it is based on naturalised runoff, they do not expect big changes to the water source areas. Jeanne posed the dilemma whether this meant that the data should be updated with each Water Resource Project every 5 years. No decision was made on this, except later, WRC agreed to be custodian of the strategic water source data, responsible for its updating.

National priorities

- Dirk Versveld (Consultant) requested that we keep the products streamlined, and uncomplicated – that we should focus on the idea of national strategic water source areas and embed these in peoples mind, and after that they will be able to accept the more local priorities. Jeanne agreed and mentioned the Mountain Catchment Areas Map (1959) which had 101 priorities. This map didn't have as much uptake as the water source areas map possibly because there were too many priorities and it was too complicated. The project will aim to keep it simple so that it can be taken up into policy.

Integrated surface and groundwater source areas

- Will the product be an integrated groundwater and surface water map? Jeanne replied that this is what is intended, but that we will need to decide if this makes complete sense once we have the surface water and groundwater products. The workshop in June 2016 is aimed at the integration of surface water and groundwater products.

Policy

- Ethel Sinthumele (DMR) asked in relation to policy alignment and arrangement who is the owner of the data and it implementation? And who owns the final output? Is it aligned with certain policy or legislation? Is it providing a framework for protection, use management and control? Jeanne Nel replied that the products could be applied to decision-making within many different mandates (land use planning, mining, agriculture). The workshop is a start to understand the key implementation mechanisms, and then we will be developing guidelines with the relevant stakeholders on how to use it in their domain. Later on in the workshop, it was decided that the WRC will be custodian of the final products and responsible for their update. They would do this in collaboration with SANBI and WWF.

Impacts

- Kai Witthüsser suggested possibly overlaying the blue drop / dysfunctional sewage works with Strategic water source areas, to show links feeding into the Strategic water source areas (our conveyer belts of surface water sources). Agreed, but not a factor to inform the definition of the water source areas.

Presentation on groundwater conceptual framework

There was interactive discussion among workshop participants through the course of the combined presentation by Helen Seyler and Kai Witthüsser. Key points included:

Comments on Terms of Reference

- We discarded mountain and water tower terminology from proposal, as groundwater source areas are not restricted to mountain tops

Top down challenges with national recharge estimations

- A top down (map recharge, map recharge hierarchy, link to users) process will be followed as well as a bottom up process (i.e. mapping local use). The project team presented some of the top-down challenges:

- Challenge 1: Recharge is not a direct indicator of groundwater availability. When an aquifer is pumped, the abstracted water is met by a combination of reduced discharge (often baseflow), and enhanced recharge (often streamflow depletion), and groundwater storage is reduced (water levels will reduce). Groundwater availability is therefore dictated by the ability of pumping to "capture" natural discharge, and enhance recharge without continually depleting an aquifer. These elements can only be determined at an aquifer-scale. Nevertheless, the project requires an indicator for groundwater availability at national scale. Prior to pumping an aquifer is in a state of dynamic equilibrium in which natural recharge is equivalent to discharge. As these are equivalent, recharge can be considered a proxy for one of the factors influencing groundwater availability. As it does not consider enhanced recharge, which could increase groundwater availability, it cannot be a direct indicator. In the absence of a better dataset, recharge will be used as an input to identify groundwater source areas, and the complexities with its use will be documented

- Challenge 2: Available recharge dataset at national scale. National recharge datasets provide information on recharge derived from direct infiltration. This is only one mechanism by which recharge occurs. There is however no national dataset for indirect recharge from rivers ('losing rivers'). It has been acknowledged by DWS that there is "no reliable national recharge estimates" available. The best available national dataset (GRAII) is based on the Chloride method, which has an acknowledged accuracy factor of 5-10. Recent research has also shown the chloride content of rainwater varies by 3 factors seasonally. However, locally, more detailed recharge information is available, derived for aquifer scale or regional scale investigations. This data will be collated during the literature review (Deliverable 2), and the national groundwater recharge map will be enhanced where there is more detailed data available. For example, we may use the available data on recharge from the GRAII and adjust it to a moderated average of Vegter (1995). This researcher provides the first national estimate of groundwater recharge areas. Some of these areas correspond with surface water source areas, with the exception that they are slightly offset downhill from the mountains, and they also include the dolomites. The GRAII does not bring out the dolomites as clearly as Vegter (1995).

- Challenge 3: Time lags are geological – 1000 years for infiltration and recharge of aquifer. Abstracted groundwater may have been recharged several hundreds or even thousands of years previously. Land use and climate can vary greatly in those time periods. This is an important consideration in protection of current groundwater resources, as in some aquifer settings, whatever policy is implemented now may only benefit a user in hundreds of years' time

Overall comments on groundwater methods

- Eddie Van Wyk shows that CL varies seasonally by a factor of 3 which means that the recharge values will also vary.

- Kai Witthüser has collated all the available data, trying to find a compromise to improve the existing recharge maps. Data from for example All Towns, Scheme Operating Rules and DWS infrastructure database. Once they have done this, they can use similar methods that were used to identify surface-water source areas, based on percentage of catchment recharge per pixel.

- There is a need to link location of aquifer recharge with location of infrastructure, for example, the recharge in Outeniqua is used in Oudtshoorn. We also need to link groundwater dependency to strategic recharge areas. Importantly, this is bottom up process and at a much finer scale than a primary catchment.

- Groundwater dependent ecosystems are often dependent on indirect recharge from surface water. Jeanne: the project team will not be assessing groundwater dependent ecosystems.

- Some surface water and groundwater areas overlap while others don't. The team will need a manual process to link these.

- Will the GW source area include consideration of the suitability of groundwater sources for the users?

    - Generally not: we cannot consider local aquifer drawdown-induced quality issues (such as mobilisation of heavy metals on drawdown), as this is a local scale issue. Also, local surface-water quality challenges are not included in the surface-water source areas, so should not be included in groundwater. Poor groundwater quality is often used as motivation to not use the resource, however groundwater can be treated, just as it is generally accepted that all surface-water requires treatment.
    - The formations that generally give rise to poor groundwater quality are known and could be marked if the same is done for surface-water.
    - We can certainly address the vulnerability and risk to groundwater quality – but we cannot assess the impact that might come out from using that water. A national scale map can't inform local well field management issue.
- Ernst Bertram: GW drought vulnerability maps are available, done by the Council for Geoscience for the SADAC (Southern Africa Development Community) project. With methodology tested for South Africa. Ashton Maherry was on project team for downscaling drought vulnerability for South Africa.

- Are we including ecosystem services, or all ecosystems? Jeanne Nel, Kai Witthueser: Almost an entire project to look at surface / groundwater dependent ecosystems as groundwater users. Agreed that in terms of groundwater users we will consider baseflow (SW), but not groundwater dependent ecosystems – the focus of this project is directly on human beneficiaries.

- Dirk Versveld: Highlighted that whatever criteria we look at for surface-water, we use same for groundwater. He highlighted that (as per surface water), we want big message from groundwater: these are the key areas, key source areas, this is the 1st stage and 1st area – he advised the project team to not get lost in groundwater detail and complexity. The nice examples were the dolomites, and then examples such as the Outeniqua source area that gets used in the Oudtshoorn area. We need to develop a map that – when you look at how much groundwater is used across the country, it is exciting – stick to these big messages.

- Fanus Fourie: There is a hillslope flow – soils project of the WRC at University of Free State. They have looked at / mapped the soils of South Africa. One of the outcomes is the recharge to the soils. Could be useable for updating recharge maps. Agreed in principle that soil maps for spatially disaggregated recharge are required. The project team is aware of the (Piet le Roux) study with promising results, however the data is not ready (it is local not yet national).

- Julian Conrad and John Dini: in terms of identifying strategic water source areas, which takes more priority – if a large number of people are partially dependent on a resource compared to a small town totally dependent on it? The small towns (because their demand is small) that have failing water supplies are a local municipality management issue. These small town issues have capacity / governance issues not resource issues. The project should focus on areas on large population dependency

- Julian Conrad (GEOS): Mapping of groundwater recharge – how do you work out where the strategic recharge areas are? How to categorise it. Kai Witthüser answered we need to link it to socio-economic use because it may not have a high recharge – it is the combination of supply and dependency – may be a colour coding. Julian Conrad: May need to have a separate method for agriculture since there are lots of situations where the use and recharge are very different – It is not straight forward.

General discussion

An interactive discussion amongst the workshop participants followed the presentations. Key points that emerged from the discussion included:

- Hermien Roux (North West READ): Hermien Roux questioned whether the groundwater source areas will include consideration of the suitability of groundwater sources for the users?
    - Generally not: we cannot consider local aquifer drawdown-induced quality issues (such as mobilisation of heavy metals on drawdown), as this is a local scale issue. Also, local surface-water quality challenges are not included in the surface-water source areas, so should not be included in groundwater. Poor groundwater quality is often used as motivation to not use the resource, however groundwater can be treated, and it is generally accepted that all surface-water requires treatment.
    - The formations that generally give rise to poor groundwater quality are known and could be marked if the same is done for surface-water.
    - We can certainly address the vulnerability and risk to groundwater quality – but we cannot assess the impact that might come out from using that water. A national scale map cannot inform local well field management issue.
- John Dini (SANBI) asked about mapping groundwater source areas and linking it to the infrastructure to identify natural ecological supply areas? Our focus is on water that is being used

for socio-economic purposes rather than water that is being used by rivers to keep the biodiversity happy. Jeanne Nel pointed out that this project will stick with human uses and human dependencies. Hermien Roux: We need to make sure we identify groundwater dependent rivers for human use.

- Isa Thompson: Maps of recharge need to include Swaziland and Lesotho. The countries depend on each other for water resource management. Kai Witthüser: Agreed. There is SADC (Southern African Development Community) work that was done.

- Christine Colvin (WWF): If we are taking the utilitarian view of what are South Africans using, then it may take us over the border in Limpopo but this won't be extensive. We could entertain going across there is if there is data. Mandy Driver stated that the perspective of the project is South African, but where there are strong transboundary dependencies, the team will try and include them if there is data. Shashi catchment in Botswana is a major recharge of Limpopo River. Henry Roman asked that the team highlight the strategic risks of transboundary rivers and aquifers without mapping them.

- Niel van Wyk: We may supply a substantial amount of surface-water to Botswana directly from our source area. This will stress the importance of this source area. We will probably need to think about future water resource developments and include comments in this.

- Christine Colvin mentioned that she suspects that the approach for groundwater won't end up mirroring the surface water approach. She recommended an algorithm with ranking and weighting. The groundwater will be an algorithm of where it is being used and greatest potential for use. Then linking these to the key strategic areas that we would intuitively select. If we try and do a comprehensive numeric approach for groundwater across the country, we may miss the wood for the trees. Similarly, we should rather focus on the strategic transboundary issues.

- Stanley Liphadzi: In terms of the products and tools, the maps are the primary product, but also to start asking about what are the people and stakeholder uses of the map. He wants to see more people aspects connected with strategic water source areas. Can we have recommendations on rehabilitation, stewardship issues, etc. Nicolene Fourie (DEA) wants to link the map to mandates (Ethel Sinthumele, Stanley Liphadzi also explicitly mentioned this). Jeanne Nel responded that there will be both governance and ecosystem management guidelines as final products, i.e. an implementation manual similar to the one done for the National Freshwater Ecosystem Priority Areas project.

- Wandile Nomquphu (WRC): CSIR is mapping water resources for Limpopo Basin so there will be data available. Isa Thompson: There is lots of info available that the project team can use. It can be in a follow-up study if we cannot cover it in the scope of this project. Some dataset was produced by CSIR, not sure what it was.

Key messages

The workshop participants filled in cards related to their top three key messages (Figure 1; Table 3). These were grouped into six clusters:

1. Big picture messages around water as an important national resource, and linkages of surface and groundwater is not an additional resource

2. Groundwater and surface water budget – how much is there?
3. Governance and management: To inform policy discussion
4. Users and beneficiaries of water
5. Protection of water source areas and the stressors/impacts
6. Ecosystem services, payment, monetary issues

Figure 1: Key messages and clusters that were identified by workshop participants

Table 3: List of headline messages identified by workshop participants

1. Keep mines out of our important source areas
2. Mining should not take place in strategic WSAs
3. Vulnerability of GW to poor sanitation services / practices
4. Alien plants use the annual requirement of the whole of Ethekweni (400 mcm)
5. GW source protection
6. The link between GW supply / availability and ecosystem condition
7. All sources of water considered during development of an IDP
8. Manage aliens
9. Will the impact and spread of alien plants around the 19 blobs be taken into account
10. Protect SWSAs against development damage like mining

11. Payments for ecosystem services
12. Potential investment should be estimated – understand the value the source – ecosystem services
13. Contribution of GW in provision of ecosystem services
14. Monetary value of WSAs
15. Strategic value of GW

16. GW must be accepted as a source
17. Create a better understanding of the big water picture
18. Relation between use and source
19. Water is key to life and economy resources must be protected
20. Conservation and wise use of strategic water source areas
21. GW is not a limitless source
22. Every river is fed by GW
23. GW & SW are linked
24. GW is a national resource
25. Capacitate decision-makers
26. Low-yield aquifers can be strategic
27. The importance of knowing where water is coming from, before it is used for development, to make sure it is sustainable.
28. SW and GW are one resource

29. The number of people our WSAs support
30. Who uses South Africa's water
31. Sources are being damaged and demand is growing
32. The GW % supporting the country
33. Dependency of rural users on GW
34. Socio-economic importance of GW source areas
35. GW provides large parts of the country with water
36. ID the key large scale cross boundary (LM, DM, political, national, catchment) water transfers between use and source

37. Delineate no-go areas of development to protect all WSAs
38. GW needs focussed / systemic studies
39. Joint planning by 3 tiers of government
40. Clear policy brief and mandates for gov. departments
41. Proper management of SW and GW because of linkages
42. Clearly define a home or WSAs
43. Inclusion of aquifer geometry parameters like T and S parameters in geohydro-mapping
44. A map of palaeo pockets of groundwater
45. Politics and economics take science into account in decision making
46. Actual volumes of water contributed
47. Water sources need to be protected – increased stress from climate change, demand increase,
48. Protection of SWSAs and promote sustainable use

50. Strategic SDFs
51. Involvement of local gov in implementation processes
52. Clear interventions based on project findings
53. SGWSAs should be protected
54. Why inform decision makers – ID protection areas for main water resources
55. Why protect water resources – ensure water for use
56. Improve survey network of boreholes across the country
57. This project does not imply that areas not identified as WSAs should not be protected
58. Must conserve GW with SW
59. GW is not an ADDITONAL water resource
60. Is a sole source town significant – say with only a population of <50,000
61. Guidelines for strategic GWSAs
62. Equity associated with GW with respect to SIPS and the NDP
63. Improve GW data / map for SA is greatly needed
64. Strategic recharge / protection areas are crucial

65. Where is GW available
66. Where are the potential GW use areas
67. What % of available GW can be used.
68. Water is a scarce commodity and therefore should be strategically managed
69. GW is as important a resource as SW and should be utilised.

Recommendations on approach

The workshop participants split into groups (Figure 2) and identified the following for consideration in the approach. This was followed by a plenary report back and general discussion.

Group 1

- Inclusion of lithology related to storage and recharge
- Consideration of riparian zones
- Different guidelines for different aquifer types
- Springs and baseflow
- Soil water
- Groundwater quality
- There is a wealth of information available at the DWS library

Group 2

- To consider economic importance of aquifer, vulnerability of aquifer and future importance.
- Surface water and groundwater has a scale issue. We have identified a number of surface water areas. Groundwater is a strategic resource and if we go into too much detail we will lose the strategic nature of the product.

Group 3

- Suggest a data audit for rating the confidence of groundwater across the country. Where do you have good data and where not. This will advise on where to improve data and also gives you confidence in your mapping.
- Map different consumers across the country. For example total volume of water used per annum profiled into different types of consumers over the whole country.

Group 4

- Where are the large numbers of people and the infrastructure for accessing the resource?
- Map accessibility of groundwater sources
- The areas must be big enough for agricultural use
- Potential future requirements – does the source area have the potential to supply water into the future

Group 5

- Take out storage – use recharge as the primary factor
- Water quality would be ideal (but this = mission impossible)

  - Nitrate (agriculture) and fluoride (geology). What isn't tested for in NGA and is a problem is e-coli.
  - Most important use is agriculture – > 60% GW use is agriculturally
- Future development
  - NDP, Industrial & Spatial planning for future development, these need to take into account to protect an area for future use
  - Strategic Environmental Assessment are required for large (cross boundary) development plans
- Climate change projections
  - The Climate System Analysis Group modelled change in rainfall, CSIR (?) took this and modelled change in runoff. Aurecon were involved and took this into the systems model or future surface water availability. This should be included in the future projections.

Technical discussion on storage:

- Participants suggested it stays in because for example the dolomites
- Strategic application of what we are doing (future potential use) we need to consider storage. Where can we have high storage for future drought protection, high storage for Mean Annual Runoff
- Data is the challenge:
  - To determine aquifer storage we need a storage parameter – all our storage values are set to literature / standard values in NGA
  - 90% or our storage don't go beyond 60 m below group so we limit the storage to the upper 60 m
  - So it doesn't add information to consider it
- Project could simply use a criteria – low med high storage potential
- Use of aquifer storage must be a strategic outcome
- Ricky Murray generated maps of potential for ASR (Aquifer Storage and Recovery) – consider overlying these maps

Technical Discussion on Groundwater availability:

- Comment (Fanus Fourie): the key "need to know" is how much you can take out – wants to see national GW availability – i.e. utilisable groundwater exploitation potential.
- Comment (Helen Seyler): this brings us back to the presentation – the capture principle. Recharge is our only proxy for national water availability, and the only way to get more accurate than recharge only is a national numerical model – anything in between the two is application of "fudge factors" that bring you little real added value / certainty.

Figure 2: Workshop participants contributing to the approach

An interactive discussion amongst the workshop participants followed after the group report backs. Key points that emerged from the discussion included:

- Kai Witthüser responded to Group 1's recommendations on use of lithology, pointing out that these were good suggestions, but that there was a serious scale issue in incorporating these points. A national scale map is inconsistent with a soil scale map at a cm scale – cannot process the data on both of these. Point is taken but it is not possible to process the two together.

- Kai Witthüser – Do we want to consider potential aquifers that could be utilisable? Yes, everyone agreed. Henry: we took return flows out of surface water, why are we putting artificial recharge into the equation for groundwater recharge?

- Mandy Driver: Are we looking at existing demand or existing and future demand? And how far into the future are we looking at? Jeanne: Both

- Dirk Versveld: National Water Act talks about basic human needs and international obligations. We may well have to be looking at international obligations.

- Heidi van Deventer: Where are the pressures and what are they – are we wanting future pressures. And then add the climate change issue to this too.

- John Dini: If a large number of people are depend on a groundwater source, then demand is high. Which takes more priority – a large number of people partially dependent or a small number totally dependent. It's complicated. Harold Weepener thinks it's a matter of scale. Small towns are often a governance issue that municipality's truck in water because they haven't got groundwater pumped. They should not be in as priorities.

- Christine Colvin stated that having a simple high level map that people can hang their hat on is very important. We can have lots of data supporting it, but simple is good.

- Dean Muruven (WWF) commented that the project team needs to stay focused and go back to the outcomes of what they would like to achieve.

Targeted policy processes at different scales

Workshop participants were asked to complete cards on how they would use the maps/guidelines and tools (Table 3). They were then asked to complete another set of cards on which institutions or planning/decision-making processes are most relevant to the strategic water source area products (Table 4). This was followed by a plenary discussion on the critical core users of the products whose needs the products should be designed around. Finally, there was a discussion on the custodianship of the products.

Table 3: Main uses for the products as per your institution

Institution	Recommended use
ARC	Crop suitability studies for irrigated crops
DAFF	To locate areas of agricultural development based on water availability
DEA	Natural Resource Management
DEA	Ecological Infrastructure
DEA	Environmental Programs – working for water
DEA	SIP 19
DEA	Ecological Accounting
DEA	Policy & Programmes
DEA	Clearing of invasive alien plants are implemented in priority areas, e.g. rivers and dams, agriculturally significant areas, etc. The product will be used to: 1) realign priority areas; 2)strategic planning adjustment; 3)motivate budget requests and/or justify request; 4)use as a base for a new labour intensive projects
DEA	When commenting on EIA proposals, use maps to identify areas that need protection, NRM may use maps to identify rehabilitation projects, climate change modelling or predictions & scenarios
DWS	Water quality planning, possibly considering off-setting principles & rehab
DWS	Water quality planning, used to prohibit land use activities where necessary
DWS	Water quality management, benefits of strategic water source areas to be quantified to allow decision makers to compare with costs associated with development
DWS	Water quality planning, strategic water source areas provisioning dilution capacity to be dealt with in special way
DWS	1) future demands on water security; 2) potential areas for GW development
DWS	The products will be used in developing catchment management plans, i.e. included in scenarios included in setting objectives included in designing management interventions
DWS	Products may be included in policy and regulations which address the management of allowable water uses in sensitive areas
DWS	1)Evaluation of WULAs (Water use license applications); 2) Management of aquifers/GW; 3) Get idea where more studies/monitoring needed; 4) Protection of water resources; 5) GW awareness

Institution	Recommended use
DWS	1) I would imagine that this will be of value to young people joining DWS to orientate them into. the importance of our water resources; 2) Also those who are in DWS but not necessarily involved in the resources but have to take important decisions.
DWS	1) Consideration in future water schemes – maps would allow ease of location of high yield areas; 2) For flood management; 3) Areas for potential droughts, also easier identified by using maps; 4) For strategic management of water resources
DWS	1) ID 'no-go' areas; 2) Motivate the use of GW in specific areas; 3) Promote better management of GW
DWS	Planning for future integrated resource development
DWS	1) Enhance multi-country cooperative management and governance of the source in case of transboundary aquifers; 2) Assist in drawing up appropriate network programmes; 3) Assist in planning processes for sustainable supply purposes; 4) Ensure that DWS meets its international reporting obligations with accurate information & will help compiling state of water report as per White Paper Policy of 1997
DWS	Will greatly assist in focussing classification process
DWS	Licensing water abstraction; 2) Planning for future water resource development where growth requires water augmentation to ensure sustainable sources are targeted.
DWS: GI	Awareness of GW as strategic resource
DWS: NWRP	1) Feed it into SWR planning studies; 2) Use it in presentations; 3) Framing background for newcomers/ new staff; 4) policy guidance
EKZNW	1) Select priority areas for conservation (BD management); 2) Assessment of ecosystem goods and services provision; 3)Link between BD & water resources; 4) Influence conservation plans; 5) Climate change vulnerability assessment of KZN
GEOSS	Groundwater Strategic Source Areas – shape files/kml files will be used in EIAs or GIAs (GW impact assessments) extensively
North West READ	Aquatic ecosystem monitoring priority areas
North West READ	Conservation priority areas for BD plans
SANBI	Supporting DEA NRM programmes to incorporate strategic water source areas into the procrastination of their rehab & management interventions
SANBI	1) Use of maps in mapping EI relating to specific ecosystem services; 2) Policy advice relating to implementation of Chapter 5 of NWRS 2; 3) inclusion of maps in protected area expansion & stewardship strategies
WWF	Possibly use the maps to develop projects that enhance the management of these areas & support projects/research within these areas
WWF	Advocacy & lobby to have STRATEGIC WATER SOURCE AREAS incorporated at the highest level possible, so that they are conserved for South Africa's long term water security

Table 4: Institutions or planning/decision-making processes identified as most relevant to the strategic water source area products

Which institution(s)/ planning processes/policy do you think should use the maps/guidelines/tools?
National Planning Commission – portfolio on Water & Sanitation
DWS & DEA
CoGTA & Local government
Spatial development planners
Change the legislated process that is followed for SDFs and IDPS to integrate water resources at that level of development planning
Communication and awareness raising – give civil society tools to lobby
Integrate into development planning process from National to local level planning, e.g. IDP and SDFs
Use in disaster management for understanding areas that are at a higher risk in terms of drought & flood
Ensure the SIP19 is implemented/ formally recognised
Use in NRM projects to prioritise clearing, e.g. WfW & WoF
Use in SDG implementation – think of integrated indicators with food/water/energy nexus
WRC to continue funding research to refine the maps/update them
Inform the NWRS
Identify potential stewardship sites/water accounts/funds
Important layers in EIAs/SEA process
Mining applications
Ground water hydrologists: Inclusion of aquifer geometry parameters in geohydrological mapping
Communication and awareness raising – "Who uses South Africa's water "
Prioritise IAP clearing
All sources of water considered in IDPs
Prioritisation and limitation of prospecting areas
Strategic spatial development planning
Development of guidelines for strategic recharge areas
Enhance equity associated with groundwater through the SIPs and NDP

Discussion on the absolutely critical core users whose needs the products should be designed around

- Ernst Bertram: National integrated water information system is developed by DWS, which is a management information system. This map should go onto there to make management of DWS aware. We would need to talk to the team to structure the map in a way that they can put it on their website.

- Isa Thompson: DWS Western Cape has done exactly the same information platform that links all databases. How widely it is available she doesn't know as it is brand new but we could talk to Russel Neil in Cape Town (Western Cape deeds) about it. Provincial Environmental Affairs offices, water offices, rural development offices, human settlements – all need to be aware of this information and they should use it in all of their planning. The resolutions at which the national maps are available are extremely important – we need to have them electronically availability and go down to a fine scale to zoom in to your planning area. Even though it is a national map, at province level it is very important. The national departments are policy and regulators. The provinces do the implementation, except for national DWS which is the custodian of water, so the provinces are critical.

- Nicolene Fourie: The Operational Department in national DEA are the NRM users. The custodian is not the only user. The real value of this dataset is going to be at a provincial or catchment level. There is a requirement for it but she is concerned that we don't have data for planning at a lower level.

- Dirk Versveld: WfW and failure of Land Care programme could be reinvigorated with these areas.

- Christine Colvin: Catchment management agencies should be made aware of this as they are a key user. We need to make sure that there is an awareness of the strategic water source areas drawn in to their catchment management strategies. The Catchment Management Agencies are going to have delegated authority for assigning license and it is imperative that they know about this product.

- Christine Colvin: This needs to guide national development planning and as the next planning commission is established, we need to make sure that we get our map in there. And to make the nexus trade-offs spatially explicit.

- Dirk Versveld: Parliamentary portfolio or oversight committees have good potential.

Who are the ultimate custodians of the guidelines?

- Ernst Bertram: He is groundwater information and the groundwater component should land up in the section that he directs.

- Nicolene Fourie: Custodianship should come with funding. Must be given over with a strategic management plan up to 2030 or whatever the time horizon is.

- John Dini: Obvious policy hook is the NWRS that has a map of the strategic water source areas in Chapter 5. From a custodian point of view DWS is the custodian as the ground has been laid. But we also need to think of things like Protected Areas in DEA. The language in the NWRS s not that DWS does everything, but that there is an environmental competence.

- Isa Thompson: DWS has too many other priorities. She would like to see the WRC or CSIR taking custodianship to ensure that the necessary research keeps going.

- Wandile Nomquphu stated that the WRC is collaborating with SANBI and WWF as the main data custodians of the results of the research.

- Heidi van Deventer: We need to think differently about custodianship. Housing is not the problem, it is the updates. Nothing is comparable over time. Who needs to fund the update of product – are we improving on methods or keeping consistency for time monitoring? How do we do updates?

- Nicolene Fourie: CSI (Custodian of Spatial Information Act) have guidelines on attribute information that can be linked to rivers.

- Who is going to house the product; who is going to fund updates? Wandile Nomquphu responded that the WRC will fund the updates.

Other issues and closure

- Isa Thompson: Recommendations for next phase need to address: Extending the international boundaries and include water quality. It might not be on updating the maps, but rather collecting information so that we can add these layers.

- Participants recommended that the monitoring stations are extended. Nicolene Fourie said that this issue links back to Water Affairs mandates.

- Isa Thompson: Next NWRS update is 2018 and then we need to make sure that these maps get into there.

- Wandile Nomquphu: There is an update on the Lynch et al. (2004) data, where they have used a different approach to the gridded approach. We hope that this can be integrated into the strategic water source area maps.

- Christine Colvin mentioned that groundwater could consider having guidelines for recharge areas, storage (aquifer) areas, and use areas. Each is going to have different management issues. The recharge areas are going to be land management issues (surface guidelines). The storage areas are about abstraction, mines, fracking, sanitation, etc. (subsurface guidelines).

Participant register for project inception workshop

Surname	Name	Organisation	Email	Work number	Cellphone number	Years of Relevant Experience	What relevant experience	Signature
Adams	Shafick	WRC	shaficka@wrc.org.za	(012) 330 0340				
Bertram	Ernst	Department of Water and Sanitation (DWS)	BertramE@dws.gov.za	(012) 336 7863	082 806 0691	42	Groundwater	
Bragg	Christy	EWT	christyb@ewt.org.za	(021) 788 5661	082 332 5447			
Cockrell	Hesma	Department of Water and Sanitation (DWS)	CockrellH@dws.gov.za	(012) 336 7936	0827537816	14	Groundwate /NQ	
Coetzee	Henk	Council for Geoscience	henkc@geoscience.org.za	(012) 841-1398				
Colvin	Christine	WWF	ccolvin@wwf.org.za	(021) 657 6639	0834629619	23	Groundwater / IWRM	
Conrad	Julian	Concultancy: GEOSS	julian@geoss.co.za	(021) 8801079		23	Groundwater / GIS	
Dini	John	SANBI	J.dini@sanbi.org.za	(012) 843 5221				
Driver	Mandy	SANBI	m.driver@sanbi.org.za	(021) 799 8838	083 468 8257	13	spatial biodiversity planning & policy	
du Preez	Johann	UFS	dpreezpj.sci@ufs.ac.za	(051) 401 2514	082 376 4404			
Du Toit	Willem	Department of Water and Sanitation (DWS)	DuToitW2@dws.gov.za	(015) 290 6388	082 808 8386	44	Groundwater	
Edwin	Mametja	DAFF	edwinmam@daff.gov.za	(012) 846 8692	079 804 3786			
Fourie	Nicoline	DEA	nfourie@environment.gov.za	(012) 310-3756		23	GIS water	
Fourie	Fanus	Department of Water and Sanitation (DWS)	FourieF@dws.gov.za	(012) 336 7303	082 801 5598	18	Groundwater planning	
Gonah	Tichatonga	DWA	GonahT@dws.gov.za	012 336 7191	073 881 1466	7	GROUNDWATER	
Holland	Martin							
Holness	Stephen	SANParks	sholness@nmmu.ac.za	(041) 508 5414	082 887 3735			
Houdet	Joel	ACTS & Concultancy: Integrated Sustainability Services	J.Houdet@acts-net.org	(011) 275 0159				
Jay	Jacqueline	DWA: Department of Water and Sanitation (DWS): RDM Office	JayJ@dws.gov.za	(012) 336 7443	082 328 3491	6	WRM	
Kershaw	Pamela	Control Biodiversity Officer Grade B: Biodiversity Planning	pkershaw@environment.gov.za	(012) 399 9585				
Khan	Ahmed	DWA	KhanA@dws.gov.za	(021) 441 2729.				
Liphadzi	Stanley	WRC	stanleyl@wrc.org.za	(012) 330 0340	(012 330 0340)	10	Ecosystems	
Lukey	Peter	DEA	plukey@environment.gov.za	012) 310-3710	083 415 2963			
Madikizela	Bonani	WRC	bonanim@wrc.org.za	(012) 330 9021	083 290 7238			
Mahomed	Reyhana	CSIR	rmahomed@csir.co.za	(012) 841 3598				APOLOGIES
Mange	Magamase	DST	Magamase.Mange@dst.gov.za					
Maze	Kristal	SANBI	K.Maze@sanbi.org.za	(012) 843 5234				
Meiring	Cobus	Natural bridge communications	cobus@naturalbridge.co.za		083 626 7619			
Mjadu	Nomvuzo	DAFF	patriciamj@daff.gov.za	(012) 846 8597	076 349 6365			
Mndaweni	Sakhile	Sanitation (DWS)	MndaweniS@dws.gov.za	(012) 336 8764	0836549001	15	GROUNDWATER	
Mohapi	Ndileka	DWA	MohapiN@dws.gov.za	(012) 336 8234				
Moodley	Salona	DWA	moodleys2@cwa.gov.za		(084) 4234400			
Moodley	Salona	DWS			844 234 400	7.5	Water Resources Planning	
Morokane	Molefe	DMR	molefe.morokane@dmr.gov.za	(012) 444 3831				
Motaung	Lucia	DEA	LMotaung@environment.gov.za	012399 9588		6.5	wetlands	
Motebe	Nancy	DWS	MotebeN@dws.gov.za		012 336 8309			
Muruven	Deon	WWF	DMuruven@wwf.org.za	(021) 657 6639	072 118 0279	9	Water quality	
Naidoo	Shane	DWA: WR Classification	naidooshane@dws.gov.za	(012) 336 6707				
Nditwani	Tendani	DWA: Department of Water and Sanitation (DWS)	NditwaniT@dws.gov.za	(012) 336 8189	082 888 5113			Apology
Ndou	Cyril	DAFF	CyrilND@daff.gov.za	(012) 309 5708	082 805 5913			
Nyamande	Tovho	DWA	NyamandeT@dws.gov.za	(012) 336 7521				
Parsons	Roger	Parsons and Associates	roger@pasgs.co.za	028 273 8676	083 310 6504			
Pietersen	Kevin	SLR Consulting	kpietersen@slrconsulting.com	021 851 3348	083 290 7253			
Rademeyer	Seef	Department of Water and Sanitation (DWS)	RademeyerS@dws.gov.za	(012) 336 8358	0828092338	41	WATER RESOURCE PLANNING	
Roman	Henry	DST	Henry.Roman@dst.gov.za	012 843 6436	076 412 4031	15	Water Quality, Treatment	
Roux	Harmien	North West READ	hroux@nwpg.gov.za	(018) 389 5665	082 466 5988	15	Aquatic Ecology, Biomonitoring	
Roux	Dirk	SANParks	dirkr@sanparks.org	(044) 871 0109	082 496 2144			
Sami	Karim	WSM Leshika	tshwane@wsmleshika.co.za		012 997 6760			
Seabi	Faith	DAFF	tsume08@daff.gov.za	012 319 7444	0825071108	10	Pedologist	
Seaman	Maitland	UFS: Centre for Environmental Management	seamanmt.sci@ufs.ac.za	(051) 4013958				
Seyler	Helen	Concultancy: Delta-H	helen@delta-h.co.za		082 043 8076			
Sithole	Simangele	Ezemvelo KZN Wildlife	Simangele.Sithole@kznwildlife.com	(031) 312 3726	(073)765742769	1.5	Water Quality, Ecosystem Services	
Slabbert	Nadene	DWA: Department of Water and Sanitation (DWS)	SlabbertN@dws.gov.za		082 801 7692			
Steyn	Susan	DAFF	SusanSte@daff.gov.za	(021) 944 1401				
Thompson	Isa	DWA: Department of Water and Sanitation (DWS)	ThompsonI@dws.gov.za	(012) 336 8647	082 805 2158	42	Water resource planning	
Titus	Rian	Private	rtitus@telkomsa.net					
Tshitwamulomoni	Stanley	DEA	StanleyT@environment.gov.za	(012) 399 9587	082 643 0623			
van Vuuren	Lani	WRC	laniv@wrc.org.za	(012) 330 0340				
van Wyk	Niel	DWA: Department of Water and Sanitation (DWS)	vanWykN@dws.gov.za	(012) 336 8327	082 808 5651	30	Water resource planning	
Vermaak	Nicolette	Department of Water and Sanitation (DWS)	VermaakN2@dws.gov.za	(021) 941 6267	730 121 932	7	Groundwater	
Versfeld	Dirk	Concultancy	dirki@iafrica.com	(021) 424 1787	082 377 4084			
Viljoen	Pieter	Department of Water and Sanitation (DWS)	ViljoenP2@dws.gov.za	(012) 336 7514	082 808 0497			
Vivier	Koos	Concultancy: Exigo3	kvivier@ages-group.com	(012)7512460	827 766 987			
Weepener	Harold	ARC	WeepenerH@arc.agric.za	012 3102505	0642095936			
Weston	Barbara	DWA: Resource Directed Measures (RDM)	westonb@dws.gov.za	(012) 336 8221	083 631 0801			
Witthüser	Kai	Concultancy: Delta-H	kai@delta-h.co.za			18		
Dickinson	Mariam	DEA	mdickinson@environment.gov.za	012 392 1150	071 285 7861	14	AQUATIC ECOLOGY, INVASIVE TERRESTRIAL AND AQUATIC WEEDS	

Surname	Name	Organisation	Email	Work number	Cellphone number	Years of Relevant Experience	What relevant experience	Signature
Maherry	ASHTON	CSIR	amaherry@csir.co.za	021 888 2599	0822974981	11	Groundwater	[illegible]
Smith-Adao	Linda	CSIR	lsmithadao@csir.co.za	021 888 2475		11	Ecosystems	[illegible]
Sinthumule	Ethel	DMR	ethel.sinthumule@dmr.gov.za	082 [illegible] 2275	012 444 3896	15	ground & surface	[illegible]
Nomquphu	Nandile	WRC	nandilen@wrc.org.za	012 3309069	0723069659	19	Groundwater & Surface	[illegible]
Zenzile	BAYANDA	DWS	zenzileb@dws.gov.za	012 336 7309	082 895 0574	24	Groundwater & Surface	[illegible]
Versfeld	Dirk	Dirk Versfeld cc CSIR Project Team	dirkv@iafrica.com	021 4261787	0823771084	40	Catchment Areas Water Resource Planning	DB Versfeld
Van Deventer	Heidi	CSIR	Hvdeventer@csir.co.za	012 841 2507		in what?	Geography RS mgt	[illegible]
SITAS	NADIA	CSIR	NSitas@csir.co.za	021 888 2573	0799705504	5	ecosystem services / social-ecological syst gov.	[illegible]
Nel	Jeanne	CSIR	jnel@csir.co.za	021 8882484	0721206442	10	Surface water	[illegible]
VAN WYK	JURGO	DWS: WQP	jurgo@dws.gov.za	012 998-3100	082 809 [illegible]	22	Water Quality Planning & management	[illegible]
~~DRIVER~~	~~MANDY~~	~~SANBI~~	~~m.driver@sanbi.org~~	~~021 7998838~~	~~0834688287~~	~~18~~	~~spatial biodiv plng & policy~~	[illegible]
MAJOLA	KWAZIKWAKHE	DWS	MajolaK@dws.org.za	012 336 7105	0837913575	12	Groundwater/Hydrogeology	[illegible]
MOTAUNG	LUCIA							
Wanda	Nthabisi	DEA	Nwanda@environment.gov.za	012 399 9883	084 349 4314	0	ecosystem	[illegible]
Dini	John	SANBI	j.dini@sanbi.org.za	012 8435221	0834207988	11	ecosystems	[illegible]

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15.2 Second stakeholder workshop

Draft map review workshop: Water Research Commission project (K5/2431) for identifying and delineating South Africa's strategic surface-water and groundwater source areas and mapping the areas they supply

1 Description of the draft map review workshop

1.1 Purpose and agenda

The draft map review workshop was held at the CSIR in Pretoria on 26 July 2016. The purpose of the workshop was to review and refine the draft maps of strategic water source areas for groundwater and to discuss the most useful format for management guidelines for strategic water source areas. The agenda for the workshop is provided in Table 1.

Table 1: Agenda for the draft map review workshop

09h00-09h30	Coffee	ALL
09h30-09h50	Welcome	Wandile Nomquphu, WRC
09h50-10h00	Brief overview of progress and agenda for the morning	Jeanne Nel, CSIR
10h00-10h30	Presentation on mapping methodology for strategic groundwater source areas	Helen Seyler, Delta-H
10h30-11h30	Regional break-out groups to review and refine draft maps of strategic groundwater source areas; tea will also be served during this time	ALL
11h30-11h45	Proposed approach for developing management guidelines for strategic water source areas	Lydia Cape, CSIR
11h45-12h20	Discussion on approach and proposed decisions on way forward	ALL
12h20-12h30	Closure	ALL
12h30-13h30	Lunch	ALL

1.2 Key discussion points and decisions from the draft map review workshop

The groundwater methodology, involving the establishment of factors and criteria, was presented along with the resulting draft groundwater source areas. Breakaway groups were convened to discuss the methodology and resulting areas. Table 2 summarises the key discussion points or comments raised over the duration of the draft map review workshop and decisions taken, where appropriate. The majority of comments received were for particular areas to be refined, or added or removed. Apart from comments on perhaps adjusting the threshold for criteria 4, there were few methodological comments received and the general approach applied for definition of groundwater source areas was supported.

Stakeholder comments (both verbal and written directly onto the draft maps) will assist in shaping the final source areas.

Table 2: Key points of discussion at the draft map review workshop and the decisions recorded

Key discussion point/comment	Decision/response
Presentations	
We should not remove any of our existing surface water source areas. An example was made of the northern portion of the Groot Winterhoek.	Participants agreed
Will we include the source areas at a regional economy scale?	No, although these are important, the process needs to be run at CMA level. The focus in this project is on a simple map with a few areas that are our national assets.
Are we going to be communicating this map to national planning? Messaging is very important.	Yes. In the inception meeting a number of key messages were recorded that participants thought would be important to communicate.
Why was aquifer storage not considered as a criterion?	Indicators were selected that could illustrate groundwater availability, for which storage (alone) is not useful. Storage can be considered as an overlay map to indicate areas where there is a high storage potential and high availability.
Should we explore having separate maps for groundwater use and recharge?	No. After some discussion and confusion on this, it was made clearer that use was only mapped and considered as an indicator, in order to provide another proxy for groundwater availability, i.e. where there are favourable recharge / permeability / storage properties for groundwater, it is used.
How did we deal with the inaccuracies of the WARMS database in terms of not registering all groundwater use (sometimes 50% off)?	The geographical coordinates were verified using a farm cadastral layer. An estimated 80% of coordinate issues were eliminated. We are also undertaking expert review of the groundwater source areas to detect whether we have gaps in our identified areas owing to the data limitations.
Are we going to take future use into account?	Yes. The idea is to look at the reconciliation strategies of the 26 urban areas of economic importance (from the NWRS) and determine future water sources, where known and listed.
We should also consider using the groundwater control areas. Most of them are in but some on the west coast are not.	Agreed that the groundwater control areas will be used as a proxy for areas with potential for future groundwater use (which was their original intention).
Did we include water quality considerations into the identification of groundwater source areas?	No, water quality should not be used as an automatic exclusion factor especially at this national scale. Poor quality groundwater can be treated, just like surface-water of poor quality.
The overlap of groundwater recharge with all the strategic surface water source areas is great and only strengthens our message about groundwater and surface water supporting each other. Why is the overlap there?	High recharge becomes high discharge in the form of baseflow. However, the point was also made that non-overlapping regions such as the dolomites and springs are not baseflow contributors but are very important sources and highly vulnerable to pollution.

Key discussion point/comment	Decision/response
Delineation of areas concerning the fuzzy boundaries was mentioned. This is an issue when it comes to the management guidelines and legal requirements.	Keep boundaries fuzzy. We cannot get out definitive boundaries in this national project.
Each source area will most likely require a tailor made protection strategy, depending on the level of use/protection we would like to afford it. But the more customised, the longer the time.	Participants agreed that generic is less time consuming
A list of permissible activities and excluded activities will be very useful. Two approaches to this: top down – in which we write generically for all source areas, or bottom up in which we look at impacts in each and then possibly pull out generics later.	We could possibly have an iterative approach
Report back on map review in regions	
Western Cape/arid interior	
There was a suggestion that we consult the Vegter names for strategic groundwater source areas, where they overlap with Vegter	Agreed
The town dependency map is a product of its own right. The analysis has highlighted towns solely dependent on groundwater, but this alone isn't considered a reason to incorporate their supply as strategic (ground)water source areas.	The towns identified will be highlighted, with a 'sole source' dataset product from the project
Extend Lower Swartland source area (no 17) to the coast to contain confined Peninsula aquifer. Re-name to Sandveld	Agreed
Extend Uitenhage Springs source area (no 24) to the coast to include confined aquifer. Rename to Coega Artesian Basin (double check with what Ricky Murray calls the resource unit)	Agreed
Add Cape Flats as a new source area because of future use	Agreed (in line with approach for mapping and including future use in GWSAs, as the CFA is considered a potential future resource for CCT)
Source areas with numbers 14-16 should be combined. Re-name to Central Cape Fault Mountains and their valleys.	Will be considered
Comment made within group that it is considered okay not to have Oudtshoorn on at national scale	Agreed
Langebaan Road Aquifer (no 22) and Atlantis Aquifer System (no 23) source areas should be combined. Re-name to West Coast Aquifers.	Groupings for all Sandveld Group aquifers will be considered, (perhaps Atlantis rather be grouped with CFA)
How the project relates to activities such as fracking and uranium mining in areas such as Beaufort West should be considered	Will be considered
List places such as Kamieskroon, Garies and Bitterfontein area (which meet all GWSA critiera) as regional importance	Agreed
It was noted that the Garden Route Southern Cape area has high recharge, BF and is a SWSA. There is not high use, so it didn't come up as GWSA. However: the SWSAs are to be considered combined waterSAs, hence it is protected by being a WSA	Agreed
Naming: 21 rename to cape peninsula (north)	Will be considered

Key discussion point/comment	**Decision/response**
Western Cape/arid interior (Additional comments received from DWS RO 18 August 2016)	
Regarding regional vs national: the distinction requires some consideration, as even areas that may not be large, (i.e rural towns) become of national importance when water resources are impacted and water supply infrastructure requires large investment from national government	Will be considered
The impacts on WSAs should include plotting vulnerability to overuse. Perhaps consider plotting high transmissivity (can drill strong borehole) and low recharge areas (wont replenish)	Vulnerability to overuse will be considered
Criteria 4, the pink blobs, are fairly arbitrary and false, for example why did Middelberg translate into a GWSA yet Beauford West didn't.	Alternative approaches for Criteria 4 will be tested
Suggest the Hex aquifer is a GWSA – nationally economically important, and a significant groundwater resource	Will be considered
(How) will climate change be considered in the mapping of GWSA, and the impacts on GWSA? i) Although not currently used in many places where criteria 1 and 2 are met, the TMG has huge value for future drought resilience due to high storage. Should it be GWSA to protect future use? ii) show a map where hotter / drier in impacts map as this is where GW is even more important to protect	Will be considered
Eastern Cape/ KZN	
Consideration of the streamflow reduction activities on groundwater from afforestation (e.g. illegal woodlots in northern KZN) was suggested as a potential criterion and very important to consider in the areas around St Lucia and Bushbuckridge. [And this has not yet been considered in use of WARMS]. Should these areas be added? High groundwater use. Sugar cane is also a streamflow reduction activity in KZN.	In the reference group meeting, it was decided that streamflow reduction areas would not be included as a criterion, but rather as an information layer in assessing impacts on the areas, and developing management guidelines.
Re-name the Ciskei Coastal Region source area (no 18) to Great Kei	Agreed
Extend Eastern Upper Karoo source area (no 12) to Graaff-Reinet area because of groundwater development	Will be considered
Participants agrees with source areas 19 (KZN Coastal Foreland) and 28 (Richards Bay GW Fed Estuary). Double check STATSSA groundwater use data.	Will be considered

Key discussion point/comment	**Decision/response**
Planning should include stress information, which relates to considering how to package the information	Project team disagrees with mapping groundwater stress as use / recharge on quaternary catchment scale as this can be misleading when aquifer boundaries do not coincide with quaternary boundaries. More often than not, the stress level indicated is over-exaggerated for example in areas where an alluvial aquifer within the quanternary catchment is sourcing water from aquifer in neighbouring catchment and hence can sustain groundwater use >> recharge within quaternary. Generating this simplified information leads to mis-information in the public domain. Consideration of groundwater stress is part of the DWS Water Resources Classification projects.
Add area between Kokstad and Matatiele as a new source area because of recharge from rivers. Relook the commercial irrigation	To be considered
Participants agrees with no Zululand Coast SWSA because Richards Bay get transfers	Agreed
Area between St Lucia and Mozambique (Isimangaliso) is stressed and not (yet) a GWSA. It should be considered a GWSA based on the high availability and future groundwater supply for the largely rural population. Groundwater in the area requires protection. Risks include salinisation of boreholes around St Lucia, illegal woodlots / afforestation.	Will be considered
Eastern Cape/ KZN Additional comments received from Sue Janse van Rensburg South African Environmental Observation Network	

Zululand coastal plan which incorporates lake St Lucia but also the surrounding "rural" area. The areas is in general poor, but with rapid population expansion and associated increases in timber. This is also an area hardest hit in KZN re the drought. I would have thought that the area from Mapelane all the way to Kozi bay would have come out as a strategic water resources areas, requiring appropriate management and protection if the methods are robust. Comments below: • The lake is drive by surface and ground water. I was surprised that the "Hluhluwe head waters" catchments did not extend all the way down to the lake as an important catchment. • In the surface water presentation the make the following case for removing Pondoland Zululand coastal area... "Zululand and Pondoland Coast – more pertinence to strategic groundwater source areas" but then it is completely absent in the ground water presentation as a key area. • Do the criteria capture enough regarding the biodiversity requirements for water? Can we risk excluding an entire system that is a world heritage site on which peoples livelihoods depend? • Given the fact that the entire Zululand coastal plain (north of Richards Bay) is pretty much solely dependent on ground water, combined with the very rapid legal and illegal timber expansion compromising these resources, I am trying to understand why it did not come out as significant? Could be an artifact of the input data not being current enough to capture the extent of current and potential extraction of ground water reducing activities in the area (including mining all the way up to Nhlabane now, just south of Mapelane. • its one of the more politically contentious issues in the province with respect to water user licences • Are climate models being taking into account in calculating recharge in future scenarios? Indications are we going to be getting drier ... everywhere... If there is no rain to recharge the sandy aquifer it becomes problematic have we have seen in the past two years in that area... here I speak to the presentation on human rights linked to water.	Will be considered

Key discussion point/comment	Decision/response
Northern region/Dolomite	
It was pointed out that the draft groundwater source area blobs required additional groundwater resource units (e.g. Thabazimbi Alluvium, no 27) delineated around each of them. Also, consider having buffers to reflect zones of certainty in delineations (i.e. certainly a GWSA, less certain, etc.)	Project team considers this to complicate the messaging. Simply crisp messages of GWSA and not GWSA, with the boundary fuzzy rather than exact, was decided as the best way forward.
The town dependency criterion is very important and it was felt that it should be up-weighted	Use was mapped only as a proxy of availability. Town dependency on groundwater means that the GW resource deserves/requires protection by very nature of being the only source, and doesn't need to also be a GWSA. These areas will be highlighted as another project product.
Comment: Source areas 3 (Letaba Escarpment), 25 (Giyani Basement Aquifer System) and 26 (Upper San (Polokwane) Aquifer) are groundwater dependent.	Noted
Transboundary aquifer at area near Zeerust	Delta-h was part of a previous project mapping the transboundary dolomites in the area, and the mapping showed that the resource does not actually extend across boundary. Delineation to be updated, and this note be included in report
Central Pan Belt source area (no 20): consider Caledon transfer scheme, double accounting?	To be considered
Add area around Brandvlei, Van Wyksvlei and Carnarvon, sole source of groundwater	Noted
Criteria 4 applies a High density of GW towns, which the participants and project team felt was inappropriate	Criteria 4 since updated
Add area around Britstown, De Aar and Hanover	To be considered

1.3 Key permissible and non-permissible activities in groundwater source areas

Participants were asked to record, on cards, the key activities that they thought were permissible and non-permissible in the groundwater source areas (Table 3). They were not restricted to a particular sector or impact.

Table 3: A s)ummary of permissible and non-permissible activities identified by the break-away groups (following on next page)

Permissible Activities	Non-Permissible Activities	Special Recommendation Activities
MINING		
Underground mining (No surface mining)	Limit any mining activities in ground water source areas	Cost benefit analysis in mining activities, residual cost should not outweigh the residual benefits
	Limit industrial development in ground water control areas and coastal aquifers	Consideration should be given to the economy when prohibiting mining. When mining does occur there should be no harm to aquifers (underground mining rather than opencast).
	Limit mining, fracking, sand mining	Coal Mining Carbon footprint: carbon emissions and carbon dumping and said impact on climate change and water source quality
	bulldozing of riverine areas and dredging of wetlands	
	All mining to be kept to Class I (Minimally used)	
	Prohibit Mine dewatering	
	No category C mining (Gold, Coal and Platinum)	
	Prohibit activities generating Acid Mine water	
AGRICULTURE and FORESTRY		
Subsistence farming	Limit the use of insecticides/pesticides/fertilizers in agricultural activities	Ensure good Agricultural management focusing on soil conservation
Legal agricultural activities	Strictly controlled agriculture and forestry	Agricultural use should implement best practices (Chicken, Dairy)
Increase aggroforrestation	Avoid activities that reduce stream flow (irrigated agriculture and forestry plantations)	Allow for low intensity agriculture
	Prohibit Nitrate producing Agriculture (Fertilisers, Pig Lots and Cattle Manure)	
	over stocking	
	alien invasive vegetation	
OTHER TYPES OF LAND USES		
Solar and Wind Power Generation	Limit tourism in mountains (limit construction development)	Eco-tourism utilising the biodiversity economy
Eco-Tourism	Limit erecting housing developments as well as poor sanitation in close proximity to water sources.	
	No informal settlements	Set conditions within which informal settlements can occur
	Limit greywater use in gardens as it pollutes ground water	
WATER MANAGEMENT AND MONITORING PRACTICES		
Permeable paving within infiltration basins for storm water runoff (WSUD)	Minimise ground water abstraction	Restore hydrological functions of degraded landscapes

Artificial recharge activities at suitable water areas	Limit rain water harvesting as it reduces runoff and recharge	Clearing of alien plants
		Maintain healthy functioning riparian zones and wetlands
		Detail the monitoring of water use is required: looking at water levels and water quality
		Highest level of protection should be given to water filling stations
		Unpack existing legislature constraints looking at water control areas, closed catchments and closed rivers

1.4 Participant register for second project workshop

ATTENDANCE REGISTER

Draft map review workshop: Identifying and delineating South Africa's strategic surface-water and groundwater source areas and mapping the areas they supply

Date and time: 26 July 2016, 09h30 for 12:30

Venue: Ulwazi Room, Knowledge Commons, CSIR, Pretoria

Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Bayanda	Zenzile	DWS	ZenzileB@dws.gov.za	021 941 6000 012 336 7304	25 yrs	Government	[illegible]
Cape	Lydia	CSIR	LCape@csir.co.za	021 888 2429 0726574719	6 yrs	Environmental Assessment & Management	[illegible]
Colvin	Christine	WWF	ccolvin@wwf.org.za	(021) 657 6639			
Conrad	Julian	Concultancy: GEOS	julian@geoss.co.za	(021) 8801079	26	G/water	[illegible]
Dini	John	SANBI	J.dini@sanbi.org.za	(012) 843 5221	12	Ecological infrastructure	[illegible]
Dippenaar	Matthys	University of Pretoria	Matthys.Dippenaar@up.ac.za				
Escott	Boyd	Ezemvelo KZN Wildlife	Boyd.Escott@kznwildlife.com	073 366 5008 033 845 1257	6	Cons Plan / GIS mapping [illegible]	[illegible]
Fourie	Melissa	Centre for Environmental Rights NPC	mfourie@cer.org.za	021 4471647	13	Environmental law	[illegible]

Nicolene Fourie sent apologies - ill

Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Hesma	Cockrell	DWS	CockrellH@dws.gov.za	(012) 336 7936			
Holland	Martin	Delta-H	martin@delta-h.co.za	0826919958			
Jay	Jacqueline	DWS	JayJ@dws.gov.za	(012) 336 7443	9	RDM, WQP	
le Maitre	David	CSIR	DIMaitre@csir.co.za	021 8882407	15	Groundwater dep. ecos.	
Maherry	Ashton	Private	amaherry@gmail.com		12	GWater	
Mahomed	Reyhana	CSIR	rmahomed@csir.co.za				
Maze	Kristal	SANBI	K.Maze@sanbi.org.za				
Mkhonza	Amanda	Centre for Environmental Rights NPC	amkhonza@cer.org.za	(021) 4471647	Less than one year	Environmental law	
Muruven	Dean	WWF	DMuruven@wwf.org.za	(021) 657 6639	0	IWRM	
Nel	Jeanne	CSIR	jnel@csir.co.za				
Nomquphu	Wandile	WRC	wandilen@wrc.org.za	012 3309047			
Pollard	Sharon	AWARD.	sharon@award.org.za				
Roux	Dirk	SANParks	dirk.roux@sanparks.org	(044) 8710109			

Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Seyler	Helen	Delta-H	helen@delta-h.co.za	0826438075	10	Hydrogeology	
Silberbauer	Mike	DWS	SilberbauerM@dws.gov.za	(012) 808 9605	15	Water Quality	
Sithole	Simangele	Ezemvelo KZN Wildlife	Simangele.sithole@kznwildlife.com	033 845 1469	3	"	
Smith-Adao	Lindie	CSIR	lsmithadao@csir.co.za	(021) 888 2475	12	Fluvial geomorph [illegible]	
Thompson	Isa	DWS	ThompsonI@dws.gov.za	(012) 336 8647	40	water resource planning	
van Deventer	Heidi	CSIR	HvDeventer@csir.co.za	(012) 841 2507	20	GIS/RS	
van Wyk	Jurgo	DWS	jurgo@dws.gov.za	0828092420	20	WQ	
Vermaak	Nicolette	DWS	VermaakN2@dws.gov.za	0219416267	8	DWS	
Versfeld	Dirk	Dirk Versfeld cc	dirki@iafrica.com				
Walsdorff	Annick	CSIR	awalsdorff@csir.co.za				
Witthüser	Kai	Delta-H	kai@delta-h.co.za	0725061340	18	[illegible]	
Jezile	Vuyokazi	DWS	jezilov@dws.gov.za	0219416175	3	DWS	
RIDDELL	EDDIE	SANPARKS	eddie.riddell@sanparks.org	0828891564	5	HYDRO PROCESSES + [illegible]	
LENYIBI	KEOBAKILE	DST	keobakile.lenyibi@dst.gov	012 8436439			

Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
RADMANN	LUKAS	UNIVERSITY OF PRETORIA	LUKAS.RADMANN@gmail.com	0297064063	—	student	[signature]
VAN WYK	NIEL	DWS NWRP	vanwyk@dws.gov.za	[illegible]	30	water resources	[signature]
Fundzo	Hlalanathi	DWS	fundzoH@dws.gov.za	083 236 8585	9	water	[signature]
~~DE VILLIERS~~	~~PIETER~~	~~DPSS~~	~~[illegible]~~	~~[illegible]~~			

15.3 Final stakeholder workshop

Water Research Commission project (K5/2431): Identifying and delineating South Africa's strategic surface water and groundwater source areas and mapping the areas they supply – Final Project Workshop

1. Project summary

Managing and protecting water source areas is a cost-effective means of keeping contaminants out of drinking water and delivering a continued supply of good quality water to downstream users. South Africa's surface water source areas[19] demonstrate that wise management of a relatively small fraction of the land can greatly enhance national water security and human wellbeing, supporting growth and development needs that are often distant from the source. This Water Research Commission project refined the definition of strategic water source areas for surface water (SWSA-sw) and augmented it with strategic water source areas for groundwater (SWSA-gw).

2. Purpose and agenda of the workshop

The final project workshop was held at the CSIR in Pretoria on 24 October 2017. The purpose of the workshop was to promote implementation of the SWSAs through:

(a) Agreement of which of the two definitions of the boundaries for the SWSA-sw to select as the final dataset;

(b) Presentation of the final SWSA-gw based on feedback from the previous workshop;

(c) Review of the draft management guidelines for strategic water source areas; and

(d) Discussion of key project messages and key content and format of the knowledge dissemination document, policy and other project outputs.

[19] In this project, the term 'water source area' refers to integrated water source areas that include consideration of both surface-water source areas and groundwater source areas. The term '***Strategic*** Water Source Areas' refers to a subset of water source areas that are considered of significant from a national planning perspective. Criteria for identifying Strategic Water Source Areas have been developed as part of this project.

Table 1: Agenda for the final project workshop

09h00-09h30	Coffee	All
09h30-09h50	Welcome, purpose of the workshop, ground rules and the agenda for the morning	Wandile Nomquphu, WRC; Christine Colvin, WWF
09h50-10h10	Brief overview of the WRC project	David Le Maitre, CSIR
10h10-11h00	Presentation and discussion on the rationale for the two proposed definitions of the boundaries for the SWSA-sw	David Le Maitre, CSIR
11h00-11h30	Presentation and discussion on a comparison of the two SWSA-sw definitions focussing on the impacts (e.g. land cover, mining and invasive alien plants) and protection status	Lindie Smith-Adao, CSIR
11h30-12h00	Reach consensus on the final set of SWSA-sw	All
12h00-12h30	Presentation on the SWSA-gw	Helen Seyler, Delta-H
12h30-13h15	Lunch	All
13h15-14h00	Review of the draft management guidelines, including the use of the map products	Annick Walsdorff, CSIR; Samir Randera-Rees, WWF
14h00-14h30	Presentation on the progress on legal protection mechanisms	Saul Roux, CER
14h30-15h00	Discussion on key content and messages for inclusion in the knowledge dissemination document and other project outputs	All
15h00-15h15	Closure	All
15h15-15h30	Coffee	All
15h30-16h00	Final sign-off on the SWSA-sw and SWSA-gw	WRC Reference Group members

3. Key discussion points and decisions from the workshop

The rationale for the two proposed definitions of the boundaries for the SWSA-sw was presented along with a comparison of their impacts (e.g. land cover and mining) and protection status. Breakaway groups were then convened to discuss the former (Figure 1). In addition, the final SWSA-gw were shown. Presentations on the draft management guidelines, legal protection mechanisms and key messages for inclusion in the project outputs followed.

3.1 Feedback from the presentations

Table 2 summarises the key discussion points or comments raised and decisions taken, where appropriate. The majority of the comments received were related to the draft management guidelines and the final SWSAs. Stakeholder comments (both verbal and written) will assist in finalizing the project outputs.

Table 2: Key points of discussion during the presentations at the final project workshop and the decisions recorded

Key discussion point/comment	Decision/response
Finalizing the boundaries of the SWSA-sw	
Methodology: In the original dataset the default settings in ArcMap were used. Kernel density instead of the focal mean was applied We need to use a cut off of 0.24 (50 MAR %) if we want similar data as was produced by Jeanne Nel. If we make it 0.14 the MAR change to between 43-49%. Do we still want to capture 50% MAR or less?	There was a concern with using the kernel density method at the escarpment. Method explained in detail in the technical report. Participants agreed to 50% MAR or more. The recommendation was to use the 014 density and 8 km radius.

Key discussion point/comment	Decision/response
Is the boundaries legally defensible?	After some discussion it was made clear that we do not have to make it legal in this WRC project. Also, we cannot make the mistake to just think about legal protection. Management of these areas are also important. There are a suite of tools that can deal with the protection and management of the SWSA-sw. It was agreed that we cannot make these national areas to complicated.
Final SWSA-gw	
There was a request not to use the term "ecological use of groundwater". People think it is the ecological reserve.	Noted, report has been amended
Why is there not a lot more overlap between SWSA-sw and SWSA-gw?	Groundwater team responded because high use and recharge were used, because initially people felt the SWSA-gw would be useful if they can protect areas where groundwater is relied upon. If only high recharge was used as criteria, the areas would largely overlap, and the benefit to groundwater is potentially lost.
There was a question over "What are the real risks to groundwater?", and whether these are captured in the impacts analysis that has been completed, and whether a groundwater area will be protected from these impacts via definition as a SWSA-gw?	The groundwater team and participants discussed the various scales at which groundwater protection is required, what kind of protection is needed at these scales, and how the SWSA-gw fit in. Groundwater protection is key at local scale, at borehole / wellfield capture zone level. This is the most appropriate response to contamination issues – and is required across the country, especially in all sole supply towns (not only SWSA-gw). However, at the national scale, the SWSA-gw provides a prioritisation of areas. Both these themes will be integrated into NGS by the project team.
There are a lot of illegal boreholes and they are not registered	Noted
Some parts of the country in the arid areas have heavy pollution	Noted
WARMS data is known to be inaccurate and does not incorporate huge numbers of villages reliant on groundwater, for example in Limpopo area. How were these areas considered?	The groundwater team used the DWS All Towns data, which includes water supply to all population (towns, villages, village clusters). The team went through the entire dataset and linked it with the spatial datasets in order to generate the data for domestic groundwater use used in the identification of SWSA-gw (in addition to WARMS data used).

Key discussion point/comment	Decision/response
If the data change do our source areas change?	The SWSA-gw may benefit from an update in the future if data changes significantly. However, the team feel the boundaries are unlikely to change significantly at national scale as they are based on several smoothed criteria: if one changes slightly the outline is unlikely to be affected. Areas may change if disaggregated to a local context, based on aquifer boundaries. This will be described in the report.
SWSA-sw impacts	
It was suggested that the mining impacts are under-reported on, given the project team considered coal areas only. It was suggested that the same analysis be done for all mineral provinces in the WRC Mine water atlas (not using the aggregated mining risk though, as this includes several uncertainties).	Completed for final report
Have a re look at the protection data	Agreed. Since then completed.
Draft management guidelines and stewardship	
Some of the areas are in Swaziland, how will they work with us?	Project team responded that we must first manage and protect the areas that are located in South Africa. Originally, 12% of the surface area (i.e. this included Lesotho and Swaziland) represent more than 50% of the MAR. But this was changed so that we can sort out our own areas first.
It was mentioned that in the inception workshop key messages were documented which should be returned to for the final reporting, to make sure these are incorporated	Completed for final report
Is housing not part of the guideline document?	The planning frameworks could include the housing issue. Christine Colvin mentioned rural housing and appropriate sanitation. While David le Maitre noted that it depends on the local scale, areas are different.
How does the guideline document deal with current and future practices?	Christine Colvin mentioned that best practice currently address current issues. Cumulative impact is very important. Annick Walsdorff replied that existing and new developments/land uses are considered.
It was suggested that the "guidelines" be renamed as a framework for implementation / use of SWSA	Agreed – Completed for final report
Should there be forbidden land uses, no future licences?	CMAs should look at the local scale. Cumulative impacts, management actions should be in place. Let's look at the areas and implement what we have already.
In the case of incompatible land uses, can you point to threats and explain why	To be considered
The term protection, people think about the protection Act. The project team should use management and protection	Agreed
KZN had a spatial management plan, there was no water management	Noted

Key discussion point/comment	Decision/response
We are trying to manage current SWSAs, but also to protect future ones. Water focussed governance is needed	Noted. A recommendation was made that in the future we need to put the source areas in water legislation such as the Water Act
Province people work in a regulatory environment, what must they do? These people need specific information	Noted
Does the guideline document look at what private people can do to help?	Christine Colvin mentioned stewardship with private people (e.g. insurance companies). There is also water stewardship offsets with wetlands.
When the project is done, do a pilot to engage with the people, CMA's never implement on the ground.	This is currently happening and the pilot studies are on the way
Benefit shed questions, link municipality use directly to SWSA-sw	Water funds through the private sector. Smaller medium sized businesses are important here
Legal protection mechanisms	
General: • Legal review, busy the last two years. • Focussing on key mechanisms. • CER work with WWF	Noted
Amendments of the Water Act, right steps must be in the master plan	Three different options were submitted to DWS
We must be more proactive, we cannot wait for DWS to Gazette the SWSAs. We need the information at DWS.	Participants agreed that the water community must be involved
A question was raised over why the SWSA-sw are being formalised by WWF (CER) through incorporation in NWA, and not the SWSA-gw	Christine Colvin answered that they started this process to formally recognise SWSA-sw before the areas for SWSA-gw were defined, and are committed to completing this step in the near future. Furthermore, (earlier in the day) the project team highlighted that because of the methods used to define SWSA-gw, and the fact that the boundaries are based on several criteria and empirical, they may not be able to be legalised in their current format. This will be described in the final report.
Is there any action from DWS to formalise the areas? Do the groundwater areas need a similar project like at CER? Can there not be an agreement that in the next 5 years something must be done?	Refer to response above, and Helen Seyler replied that we need these areas in the national groundwater strategy
Can we overlay the classification (e.g. class 1) data over the SWSA-sw?	Fanus Fourie responded that the SWSA areas are being considered in current / new classification projects
There are best practices that should be followed in all areas, non source areas also. We need stricter implementation actions	Agreed
It was noted that you licence water use, impact is land use	Jurgo van Wyk mentioned that the Water Act is not focussed on land use

3.2 Feedback from the breakaway groups

The workshop participants split into five groups (Figure 2) to discuss and get agreement of which of the two definitions of the boundaries for the SWSA-sw to select as the final dataset. They identified the following for consideration in the final project outputs.

Group 1

- Tighten the definition of strategic
  - Downstream economic activity
  - National water security
- Keep the 50% MAR
- There are other mechanisms for protecting the other areas that are not included as SWSAs
- Boundaries, cannot regulated what is not defined
  - Soft boundary core 8 "buffer"
- Need to consider groundwater before making decisions on what to include

Group 2

- Focus on mining
  - Aggregated mining data is a problem. Overlay with other useful data layers.
  - Acid mine drainage, mines in SWSA would need to be handled differently
- Use management tools to manage SWSAs. For example, if you are in a SWSA you would be directed to the relevant information.
- Cumulative impacts
- When it comes to the boundaries, have less SWSA-sws and keep it simple
- Economic importance, vulnerability of aquifer, economic importance and future importance.

Group 3

- We agree with the final areas, they need to be legalized
- Spatial delineation
  - Use all three radii
  - Have main core and buffer areas
- Going forward we need to consider each SWSA individually
- We need to get a stronger message across for these areas
- It is important for DWS to stand by the chosen map, to take ownership of the work and have a clear message
  - There must be a vision of where to take this work
  - There was a suggestion for the minister to gazette the map as an informant with informal legal status
  - Include in the National Water Resource Strategy (NWRS) and Master plan
- Map should inform the classification of water resources

- We need finer scale mapping for NEMA 24 (2A) process

Group 4

- We need to stick to 50% MAR but considering climate change (i.e. paper by Helen Dallas et al., which predict a drying out of the country) if it gets drier than this value must change.
- Broad scale national map, we need to move to the fine scale map
- Let's use 6, 8 and 10 for the degradation
- As our data improve this can change
    - We should move from science to implementation
    - All relevant departments must be involved, from local to national
    - This should include stewardships
- Biodiversity planners should examine these areas at a finer scale, they have access to local data
- We need a data custodian for these areas

Group 5

- Use 6, 8 and 10; core 8 buffer
- It is vital that we have stakeholder engagement from the start
    - Bottom up and not top down approach
- Sand mining
    - Currently not national map
    - Growing impact
- Adaptive management
    - Monitor mitigation methods
- Ecological services
    - Who pays for water?
    - Downstream users benefit
- There is uncertainty around CMAs

Figure 1: Workshop participants contributing to the final project outputs

3.3 General discussion

An interactive discussion amongst the workshop participants then followed. Key points that emerged from the discussion included:

- Message of 50% MAR is very important
- Use 6, 8, 10 data in a scoring system and protect the core
- Saul Roux suggested a workshop to prioritize the mechanisms
- SALGA, how do to integrate into SDFs
- Areas must be used at the local scale, practitioners must check if it is in an area
- Case study needed for groundtruthing the boundaries
- Areas need to be included in appropriate legal frameworks
- Messaging needs to be very clear
- Sources for water, need a catchy name
- No “no go” areas but this is the way that we are going the manage these areas
- At the institution level, use as tools for the departments and CMAs to bring into IDPs
- Need to proceed with fine scale mapping but should not hold up broad scale process
    - Provincial conservation planners have more local knowledge, engage with them
- We need to institutionalize the source areas in to DWS
    - DWS needs to be the champion
    - Needs to go to DG
    - Use the Master Plan as a vehicle, Trevor Belzer
- DEA also a key regulator
- MOU needed between the key departments
- It is important to include areas in the Master Plan, NWRS, Water Act, etc.
- These areas should be a standing item on the Provincial Infrastructure Coordination Committee’s agenda
- Where does the money for management comes from, DWS must take the lead here
- Stakeholders need to be involved and consulted beyond this project
    - Who are they?
- Identify compatible land uses, make noise about them

4. Participant register for final project workshop

ATTENDANCE REGISTER

Final Project Workshop: Identifying and delineating South Africa's strategic surface-water and groundwater source areas and mapping the areas they supply

Date and time: 24 October 2017, 09h30 – 15h30

Venue: Ulwazi Room, Knowledge Commons, CSIR, Pretoria

Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Bahadur	Umesh	DEA	ubahadur@environment.gov.za				
Colvin	Christine	WWF	ccolvin@wwf.org.za	0836624619	20	IWRM + GW	[signature]
Conrad	Julian	Consultancy: GEOS	jconrad@geoss.co.za				
Dini	John	WRC	johnd@wrc.org.za				
Driver	Amanda	SANBI	M.Driver@sanbi.org.za	0834688257	15	spatial biodiversity planning products & their implementation	[signature]
Fanus	Fourie	DWS	FourieF@dws.gov.za	0828015598	20	Groundwatr	[signature]
Holland	Martin	Consultancy: Delta-H	martin@delta-h.co.za				Apologies
Kamineth Bahadur	Abigail	SANBI	A.Kamineth@sanbi.org.za	012 843 5103		Lists a subset of skills [illegible]	[signature]
Kennedy	Mandaza	DWS	mandazak@dws.gov.za	012 336 7670	10	Water	[signature]

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Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Kwazikwakhe	Majola	DWS	MajolaK@dws.gov.za	012 336 7105	13	Hydrogeology	[signature]
le Maitre	David	CSIR	DlMaitre@csir.co.za	021 888 2407	30+	Environment & Water	[signature]
Mathe	Shirley		Shirley.Mathe@dmr.gov.za				
Michael	Braack	DEA NRM	Mbraak@enironment.gov.za	0716246514	20	EPWP Land degradation	[signature]
Ncubuka	Mamasangane Betty		MNcubuka@environment.gov.za				
Ndileka	Mohapi	DWS	MohapiN@dws.gov.za				
Nomquphu	Wandile	WRC	wandilen@wrc.org.za				
Nyiko	Mangoro	Inkomati-Usuthu CMA	magoron@iucma.co.za				She apologized.
Oosthuizen	Antoinette	CSIR	aoosthuizen@csir.co.za	0832968014		Comms	[signature]
Ramatsekisa	Rudzani	DMR	RUDZANI-RAMATSEKISA@DMR.GOV.ZA	012 444 3848			[signature]
Randera-Rees	Samir	WWF	srandera@wwf.org.za	084 853 3644	4 3	Environment & Water	[signature]
Roux	Saul	CER	sroux@cer.org.za				
Sawunyama	Tendai	Inkomati-Usuthu CMA	sawunyamat@IUCMA.co.zı	0826093043	15+	Hydrology	[signature]

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Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
Seyler	Helen	Consultancy: Delta-H Water	helen@delta-h.co.za				
Sinthumule	Ethel	DMR	Ethel.Sinthumule@dmr.gov.za				
Smith-Adao	Lindie	CSIR	lsmithadao@csir.co.za	021 888 2475	14	Regional conservation planning	
Stafford	Louise	TNC	louise.stafford@TNC.ORG				
Tau	Mahlodi	SANBI	M.Tau@sanbi.org.za				
van Deventer	Heidi	CSIR	HvDeventer@csir.co.za	012 841 2507	21	RS/GS wetl	
van Wyk	Jurgo	DWS	jurgo@dws.gov.za	082 8095820	23	WQM	
van Wyk	Niel		nieljvw@gmail.com	082 8085651	35	Water	
Versfeld	Dirk	Dirk Versfeld cc	dirki@iafrica.com	0823771084	40	Water Forestry	
Viljoen	Pieter	DWS	ViljoenP2@dws.gov.za	012 336 7574	30	WRM	
Viole	Photolo Kefiloe	DWS	PhotoloK@dws.gov.za				
Walsdorff	Annick	CSIR	AWalsdorff@csir.co.za	0833909009	16	Environment	
Witthüser	Kai	Delta-H	kai@delta-h.co.za				

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Surname	Name	Organisation	Email address	Telephone number	Years of relevant experience	What relevant experience (i.e. sector)	Signature
JAY	JACKIE	DWS	JayJ@dws.gov.za	0823283491	10	WRM	
ATWARU.	YAKEEN	DWS	ATWARUY @ DWS.Gov.za	082 894 1679	10	WRM	
Conrad	Julian	GEOSS	jconrad@geoss.co.za	021 8801079	27	G/water	
Witthüser	Kai	Delta H	kai@deltah.co.za	0725061343	20	G. water	
Lindley	David	WWF	d.lindley@wwf.org.za	083 222 9153	20	wetlands	
Roux	Sally	CER	sioux@cer.org.za	0827779990	7	ENVIRONMENTAL LAW	
Mbona	Namhla	SANBI	n.mbona@sanbi.org.za	0128435294	12	Wetlands planning	
Nzimande	Mthobisi	SANBI	m.nzimande@sanbi.org.za	012 843 5257	5	Biodiversity planning	
Netshishivhe	Shonisani	SANBI	s.netshishivhe@sanbi.org.za	0128435031	4	Biodiversity	

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