

The North West Dolomite Aquifers, South Africa: A Stalled Opportunity for Water Security and Development

Jude Cobbing



Groundwater issues addressed

- ✓ Groundwater over-abstraction
- Groundwater quality/human health
- Salinity issues/intrusion
- Land subsidence
- ✓ Ecosystem degradation
- ✓ Food security/livelihoods

Type of interventions

- ✓ Legal initiative/regulation
- ✓ Policy
- Technology application
- ✓ Local initiative



GRIPP
GROUNDWATER SOLUTIONS
INITIATIVE FOR
POLICY AND PRACTICE

The author: Jude Cobbing is a Research Fellow at Nelson Mandela University, Port Elizabeth, South Africa.

Acknowledgements: The author would like to thank Karen G. Villholth (Principal Researcher, International Water Management Institute [IWMI], and Coordinator of the Groundwater Solutions Initiative for Policy and Practice [GRIPP]) and Alvar Closas (Researcher - Groundwater Management and Policy, and currently Acting Head of the IWMI Middle East and North Africa [MENA] office) for their support while reviewing previous drafts of this report; Barbara Schreiner (Pegasys Institute, South Africa) and Stephen Foster (Visiting Professor at University College London and Past President of the International Association of Hydrogeologists [IAH]) for their review of this report; and Mahen Chandrasoma (Senior Production Editor, IWMI) for providing editorial support. Prof. Maarten de Wit (Nelson Mandela University), the South African Water Research Commission, interviewees, and staff from the Department of Water and Sanitation (DWS) in Mahikeng, Hartbeespoort and Pretoria are also thanked for their contributions, guidance and support. This issue of the GRIPP Case Profile series builds on the study conducted by Cobbing (2017).

Cobbing, J. 2018. *The North West dolomite aquifers, South Africa: a stalled opportunity for water security and development*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 22p. (Groundwater Solutions Initiative for Policy and Practice (GRIPP) Case Profile Series 03). doi: 10.5337/2018.223

/ aquifers / groundwater management / groundwater level / groundwater extraction / water resources development / water governance / water users associations / water quality / water supply / water institutions / dolomite / public health / legal aspects / regulations / policy making / municipal authorities / local authorities / hydrogeology / stakeholders / farmers / costs / South Africa /

ISSN 2520-2405 (Online)

ISSN 2520-2391 (Print)

ISBN 978-92-9090-874-6

Copyright © 2018, by IWMI. IWMI encourages the use of its material provided that the organization is acknowledged and kept informed in all such instances.

You are free to copy, duplicate or reproduce, and distribute, display or transmit any part of this paper or portions thereof for non-commercial purposes without permission, and to make translations, adaptations or other derivative works under the condition that the work must be attributed to but not in any way suggesting endorsement by GRIPP, its partners, IWMI or the authors.

Front cover photograph: Center pivot irrigation, Grootfontein, North West Province, South Africa (*photo*: Theo Rossouw).

About the Groundwater Solutions Initiative for Policy and Practice (GRIPP) Case Profile Series

The GRIPP Case Profile Series provides concise documentation and insight on groundwater solution initiatives from around the world to practitioners, decision makers and the general public. Each case profile report covers a contemporary intervention (innovation, technology or policy) or a series of applied groundwater management-related approaches aimed at enhancing groundwater sustainability from an environmental and socioeconomic perspective at local, national or international level. Integrated analysis of the approach, background, drivers, stakeholders, implementation, experiences and outcomes are discussed with a view to illustrating best practices, factors that could lead to success or failure, and wider applicability.

Abstract

English

The karst dolomite aquifers of the North West Province in South Africa are among the most important in the nation. They serve as key water sources for municipal water supply and irrigation, and are also ecologically important in supplying springs that feed important rivers. Over-abstraction and consequent falling groundwater levels jeopardize water supply security, with increasing costs and risks to sustainable development. Better aquifer and conjunctive water management would improve water supply security and lower costs, with wider benefits to many sectors. This GRIPP Case Profile discusses these challenges and management experiences through the examples of two representative North West dolomite aquifers - the Grootfontein and Steenkoppies aquifers. These aquifers are relatively well understood hydrogeologically, and modern South African water law mandates sustainable use. Yet, underperforming collaboration between stakeholders using and managing the aquifers at various levels, and poor support from the national authority have led to an entrenched suboptimal equilibrium where stakeholders are reluctant to change behavior, despite awareness of the negative outcomes. Neither prescriptive local nor top-down organization has been effective. The synthesis argues for prioritized input from a legally mandated and capacitated convening authority (the national Department of Water and Sanitation) to catalyze and support effective local stakeholder groups and other governance initiatives. It calls for a renewed effort by this convening authority and other stakeholders, emphasizing mutually beneficial or “win-win” outcomes.

French

Les aquifères karstiques dolomitiques de la province du Nord-Ouest, en Afrique du Sud, font partie des plus importants du pays. Ce sont des réserves d'eau essentielles pour l'approvisionnement en eau des municipalités et l'irrigation. Ils sont également importants du point de vue écologique, dans la mesure où ils alimentent des sources qui se déversent dans de grands cours d'eau. Les prélèvements excessifs et la baisse du niveau des eaux souterraines qui en résulte mettent en péril la sécurité de l'approvisionnement en eau, avec des coûts et des risques croissants pour le développement durable. Une meilleure gestion conjointe des aquifères et des eaux améliorerait la sécurité de l'approvisionnement en eau, réduirait les coûts et produirait des avantages plus importants pour de nombreux secteurs. Cette étude de cas GRIPP examine ces problèmes et ces expériences de gestion à travers les exemples de deux aquifères dolomitiques du Nord-Ouest - l'aquifère de Grootfontein et celui de Steenkoppies. Ces aquifères sont relativement bien compris du point de vue hydrogéologique, et la législation sud-africaine moderne relative à la gestion des eaux exige qu'ils soient exploités de manière durable. Pourtant, la collaboration peu efficace entre les parties prenantes qui exploitent et gèrent les aquifères à différents niveaux et le faible soutien de l'État ont conduit à une véritable situation d'équilibre sous-optimal, dans laquelle les parties prenantes sont réticentes à changer de comportement ; bien qu'elles soient conscientes des répercussions négatives de tels agissements. Ni les actions des organisations locales et encore moins celles de l'État n'ont été efficaces. Le document de synthèse plaide en faveur d'une contribution prioritaire de la part d'une autorité coordinatrice, légalement mandatée et habilitée (la Direction nationale de l'eau et de l'assainissement) afin de motiver et soutenir des groupes d'acteurs locaux efficaces et d'autres initiatives de gouvernance. Il préconise que de nouveaux efforts soient consentis par cette autorité coordinatrice et les autres parties prenantes, en mettant l'accent sur l'obtention de résultats mutuellement avantageux ou « gagnants-gagnants ».

Spanish

Los acuíferos cársticos en la provincia noroccidental de Sudáfrica destacan entre los más importantes del país. Además de ser fuentes esenciales de agua para el sistema municipal de suministro y riego, poseen un importante valor ecológico abasteciendo manantiales de los que se nutren grandes ríos. Prácticas como la sobreexplotación, con la consiguiente reducción de los niveles de agua subterránea, ponen en peligro la seguridad del suministro de agua, acarreando costos y riesgos crecientes para el desarrollo sostenible. Una gestión más eficaz y coordinada de los recursos hídricos y de los acuíferos mejoraría la seguridad en el suministro del agua y reduciría los costos, con beneficios más amplios para muchos sectores. En este “GRIPP Case Profile” se analizan estas problemáticas y experiencias de gestión a través del ejemplo de dos acuíferos cársticos representativos de la región sudafricana noroccidental: Grootfontein y Steenkoppies. El conocimiento acerca de estos acuíferos en términos hidrogeológicos es relativamente amplio, además la legislación contemporánea en Sudáfrica en materia del agua exige un uso sostenible. Sin embargo, la escasa y deficiente colaboración entre los grupos de interés que utilizan y gestionan los acuíferos a distintos niveles, así como el escaso apoyo de las autoridades nacionales, han dado lugar a un equilibrio insatisfactorio, en el que las partes interesadas se muestran reticentes a cambiar su proceder a pesar de tener conciencia de las consecuencias negativas del mismo. Ni una organización local prescriptiva ni un enfoque verticalista han resultado eficaces. En la presente síntesis se aboga por dar prioridad a una autoridad convocante legalmente autorizada y capacitada (es decir, el Departamento de Agua y Saneamiento nacional) para que catalice y apoye a los grupos de actores locales relevantes y a otras iniciativas de gobernanza. Exhorta a que dicha autoridad convocante y los otros grupos de interés hagan un esfuerzo renovado, haciendo hincapié en resultados satisfactorios y beneficiosos para todos.

Afrikaans

Die karst dolomiet waterdraers van die Noord-Wes provinsie in Suid-Afrika is van die belangrikste waterdraers vir die nasie. Hulle dien as waterbronne vir munisipale watertoevoer en besproeiing en is ekologies belangrik om bronwater te voorsien wat belangrike riviere voed. Oor-onttrekking en daaropvolgende val van grondwatervlakke stel die watervoorraadsekuriteit in gevaar, met verhoogde kostes en risiko's vir volhoubare ontwikkeling. Beter waterdraer- en samewerkende waterbestuur sal watervoorraadsekuriteit verbeter en laer kostes, wat groter voordele vir baie sektore inhou. Die GRIPP-geval profiel bespreek hierdie uitdagings en bestuursondervindinge deur middel van twee verteenwoordigende Noord-Wes dolomiet waterdraers as voorbeelde - die Grootfontein- en Steenkoppieswaterdraers. Hierdie waterdraers word relatief goed hidrologies begryp, en die moderne Suid-Afrikaanse Waterwet gee 'n mandaat vir volhoubare gebruik. Tog word samewerking tussen belanghebbendes wat die waterdraers gebruik en bestuur op verskeie vlakke ondermyn, en swak ondersteuning van nasionale outoriteit het gelei tot 'n gevestigde suboptimale balans waar belanghebbendes traag is om hulle gedrag te verander, ten spyte van bewustheid van die negatiewe uitkoms. Voorgeskrewe plaaslike sowel as organisasie van bo was nie effektief nie. Hierdie samevatting bepleit geprioritiseerde insette van 'n wetlike mandaat en bemaatigde sameroeper outoriteit (die nasionale Departement van Water en Sanitasie) om effektiewe plaaslike belangegroepe en ander bestuursinisiatiewe saam te voeg en te steun. Dit vra vir hernude pogings deur hierdie bestuursoutoriteit en ander belangegroepe, wat die gesamentlike voordeel of wen-wen uitkoms sal benadruk.

1. Introduction

Among South Africa's most important aquifers are the dolomites of the North West Province, which are found in the northern part of the country (Barnard 2000; Meyer 2014) (Box 1; Figure 1). North West dolomite groundwater contributes to the water supply of many towns and settlements, including Itsoseng, Lichtenburg, Mahikeng, Ottoshoop, Ventersdorp and Zeerust. It also supports lucrative commercial irrigated agriculture, and numerous springs, wetlands and rivers (Holland and Wiegman 2009).

Box 1. The North West dolomite aquifers.

The 2.7 billion-year-old North West dolomites belong to the Malmani Subgroup, part of the Transvaal Supergroup (Johnson et al. 2006). They cover a 5,000 km² swathe of North West Province, from the border with Botswana in the west to the outskirts of Johannesburg in the east. Weathering and karst development makes them some of South Africa's most important aquifers. The formations are tectonically deformed and are intruded by igneous dikes of varying ages. These dikes, together with other discontinuities, separate the dolomites hydraulically into a "patchwork quilt" of semi-independent units or 'compartments', which form a basis for groundwater assessment and management (RSA 1977; Vegter 2001). The dolomites have poor primary hydraulic properties, but fracturing, karst weathering and other secondary features make them prolific aquifers, and they support individual borehole yields of up to 80 liters/second (about 7 megaliters/day) or higher (Barnard 2000; Meyer 2014). Transmissivities may be 10⁴ m²/day or higher, and porosities are between about 2% and 10% (van Tonder et al. 1986). The weathering and tectonic history mean that aquifer properties can change by several orders of magnitude over distances of meters or less. It complicates borehole siting and the prediction of groundwater flow patterns, and also makes them vulnerable to surface contamination. Aquifer thicknesses are limited by lithology and weathering, and are generally less than 100 m. Under natural circumstances, many compartments drain via impressive springs (known in South Africa as "eyes"), some of which give rise to important rivers.

The North West dolomite aquifers were relatively unexploited before the 1960s, although natural spring flows and wetlands had been used for millennia. Rural electrification, modern drilling techniques and more sophisticated borehole siting methods brought a boom in groundwater pumping in the 1960s and 1970s. Today, some North West dolomite aquifer compartments support extensive groundwater abstractions for irrigated agriculture, water supply to towns and settlements, and for industrial use. In places, over-abstraction of groundwater has reduced spring flows or dried up springs and wetlands altogether. Falling water levels have increased water supply costs and reduced the reliability of wellfields. In many cases, over-abstraction continues *despite* adequate scientific understanding of the aquifers and their hydrogeological functioning, as well as legal policies clearly hinging on sustainability principles and approaches (Box 2). The multiple categories of groundwater users and South Africa's predisposition towards surface water development and management produce complex groundwater governance challenges.

This GRIPP Case Profile examines two North West dolomite aquifer compartments in more detail: the Grootfontein aquifer in the west near the city of Mahikeng, and the Steenkoppies aquifer in the east closer to Johannesburg (Figure 1). The objectives are to: (i) identify common challenges and contemporary experiences in addressing the increasing pressure on these water resources through groundwater and broader water management; and (ii) through this, identify shortcomings and ways forward for more sustainable use of these aquifers. The institutional characteristics and processes around their management suggest multi-disciplinary lessons for groundwater governance in a highly dynamic South Africa, as well as elsewhere.

Box 2. South African water law, groundwater management and the wider political context.

South African water law changed fundamentally following the first democratic elections in 1994. With the passing of the Water Services Act in 1997 and the National Water Act in 1998, groundwater is now recognized as an integral part of the water cycle, and as a public asset vested in the Department of Water and Sanitation (DWS) (RSA 1997, 1998; Lazarus 1998). Water for the environment and basic human needs takes legal priority over other uses. Management of water services is the responsibility of the local sphere of government (i.e., municipal level), and municipalities are designated as Water Services Authorities responsible for domestic water supplies. The new laws specify organizations such as Catchment Management Agencies (CMAs) and Water User Associations (WUAs) to promote a fairer, more equitable and more decentralized system of water governance. The law recognizes basic human needs and environmental requirements, and minimum volumes of safe drinking water are provided free of charge to those who cannot afford to pay (Muller 2008).

South Africa's water legislation is 'progressive', but implementation has been weak (Seward et al. 2015). An objective of the major restructuring of the South African water legislation in the mid-1990s was the transfer of power and agency from a white minority to a democratically elected government representing all South Africans. The required conversion of riparian rights to time-bound authorizations to use water relies on law enforcement and the application of regulatory tools, but in practice, this has been slow (Schreiner 2013). Old patterns of behavior have consequently persisted, including over-exploitation of groundwater for farming and other commercial purposes, and a sustained belief in private ownership of the resource (Beckh 2013).

In a study that included interviews with groundwater experts in South Africa, Knüppe (2011) found that poor groundwater management in the country is associated with: an insufficient appreciation of the resource; shortcomings in knowledge and information, and sharing of same; centralized system structures; and an inadequate recognition of the significance of aquifer-dependent ecosystems and services.

Slow progress in the implementation of water management decentralization as set out in the legislation has contributed to the challenges of water administration in South Africa. The National Water Act makes provision for the establishment of CMAs, the transformation of existing irrigation boards into WUAs, and the establishment of an agency to manage the national water resource infrastructure. However, integration between decentralized government bodies and central administration is limited, hindering cooperation between levels and across sectors (Knüppe 2011).

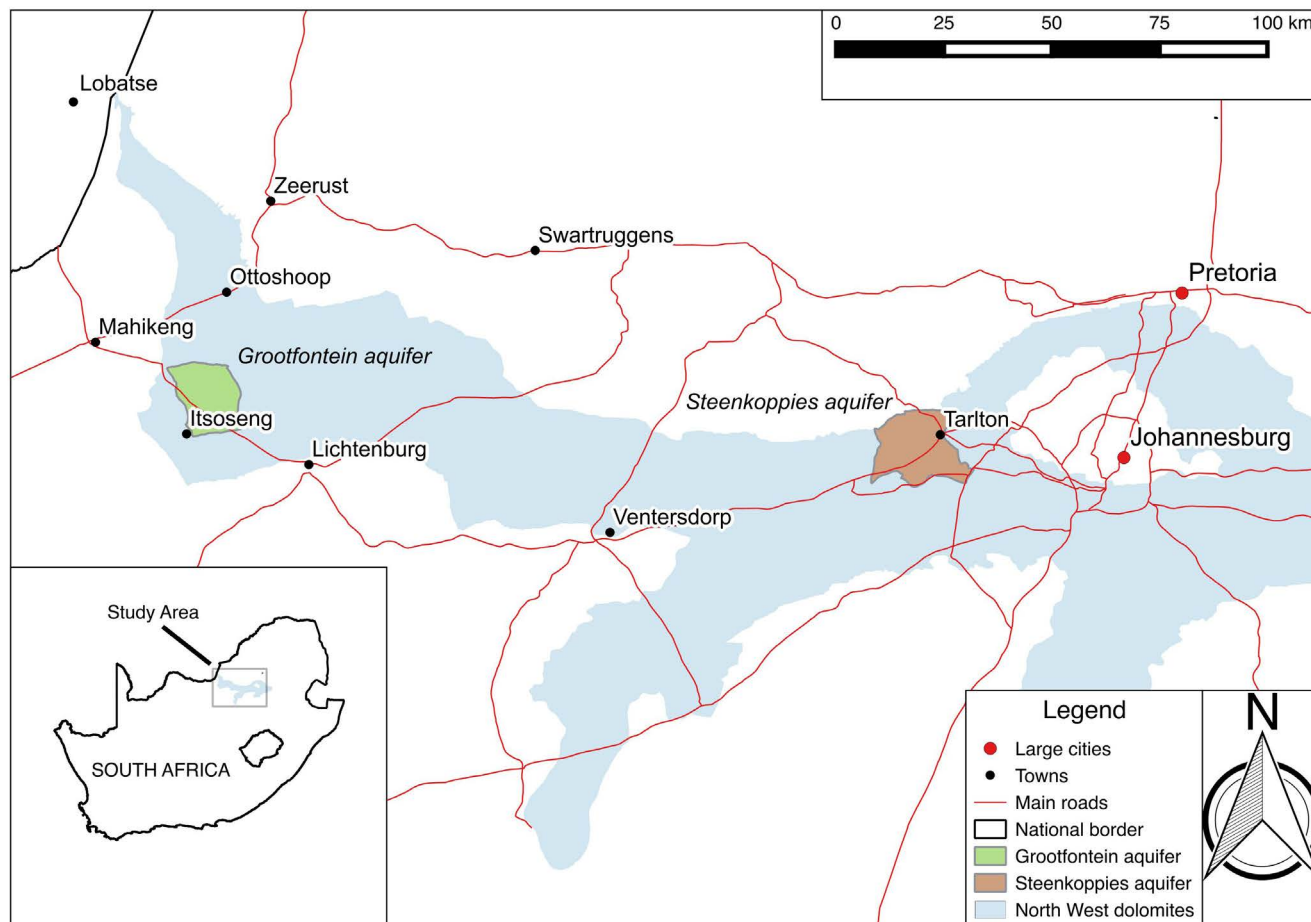
The history of governance in South Africa has been one framed by hierarchy (Picard and Mogale 2015). This is reflected in an apparent reluctance by DWS towards devolving duties and responsibilities from the national office to the regional branch offices (Seward et al. 2015; Schreiner 2013).

Under the new water laws, it was expected that the authority to allocate licenses "would be transferred to the level of the CMAs [...] however, it has proved very difficult to set up CMAs, and there are only two CMAs in South Africa to date, none of which has been given the full powers of licensing" (Movik and de Jong 2011: 68).

In addition, the intended systems have failed to evolve due to factors that include an absence of scholarship focused on the necessary socioeconomic data to support effective management of groundwater resources, and lack of technical and professional expertise at all management levels (Colvin and Saayman 2007; Knüppe 2011; Seward et al. 2015).

According to van Koppen and Schreiner (2014a), the burdensome license application process and associated costs disproportionately affects small-scale and remote water users. Moreover, the acceptance of inherited water rights from the old system (so-called "Existing Lawful Use") as lawful under the Water Act presents a challenge for policy. According to van Koppen and Schreiner (2014b: 70), this has reproduced "the immense inequalities in access to water and the profoundly discriminatory pre-1998 race, gender and class-based water use authorization system." During the consultation period after 1994 leading up to the drafting of the National Water Act, established water users (e.g., large-scale commercial white farmers) did not want to lose their water rights and access to land (only 13% of the land was accessible to black South Africans at the time).

Figure 1. Locations of the Grootfontein and Steenkoppies aquifers.

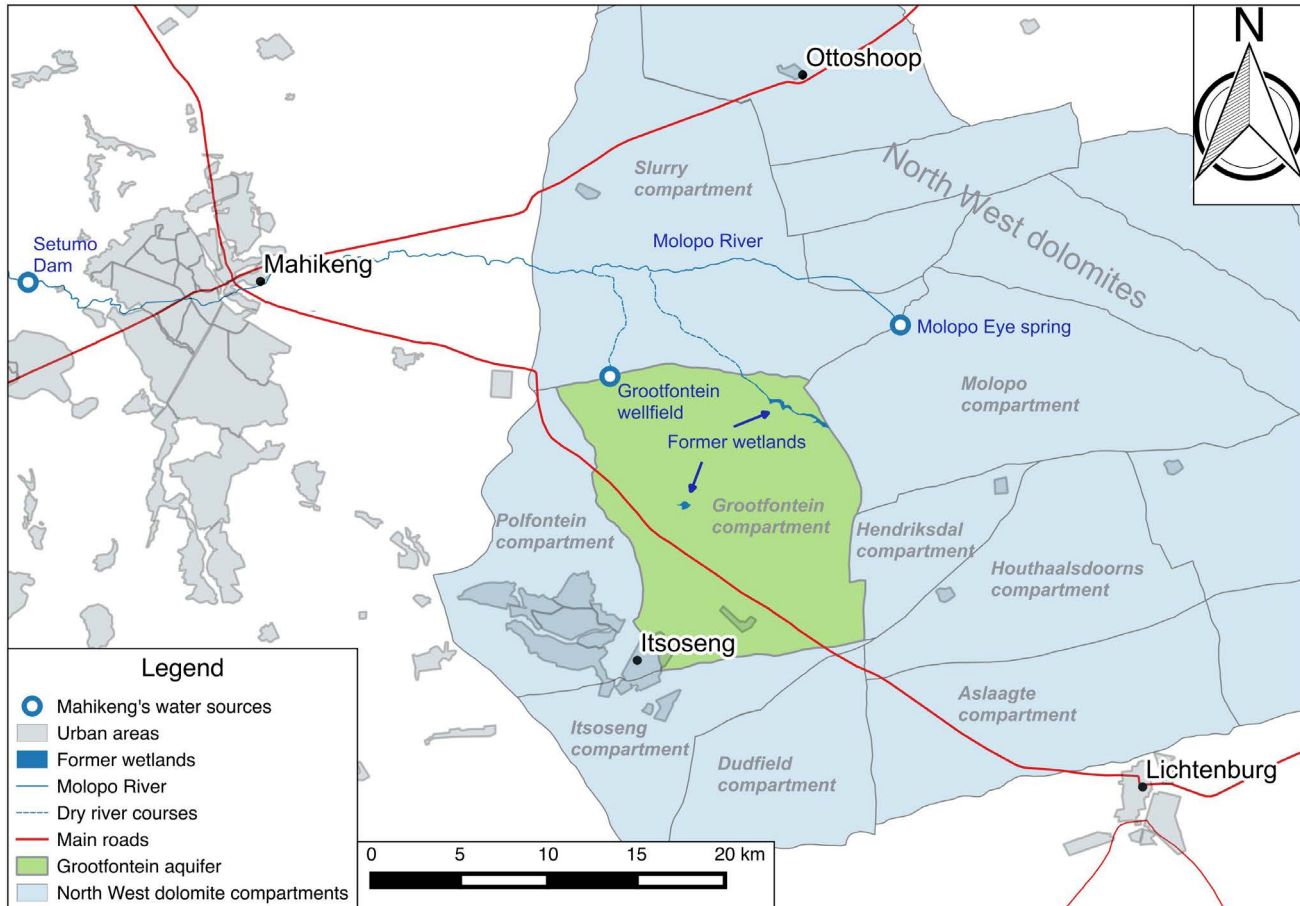


2. The Grootfontein case

The Grootfontein aquifer is located at the western edge of the North West dolomites and covers an area of about 240 km² (Figure 2). Fertile soils in the area and the availability of reliable electricity supplies contributed to large increases in groundwater irrigation in the 1950s. During the late twentieth century, the new urban area of Mmabatho (now part of Mahikeng) became the capital of the “homeland”¹ of Bophuthatswana and, like Mahikeng, was supplied by Grootfontein groundwater (RSA 1977). Because of its political importance and the large urban reliance on groundwater, the Grootfontein aquifer has been intensively studied (Cobbing 2017). At least 16 hydrogeological research reports by DWS or its predecessor, the Department of Water Affairs and Forestry (DWA), have focused on the aquifer since the 1960s (e.g., dating back to Bredenkamp [1964] and Temperley [1965]; see Cobbing [2017] for more details). Grootfontein was also the subject of some of South Africa’s earliest analogue and numerical groundwater models, and of pioneering isotope studies (e.g., van Tonder et al. 1986).

¹ Under apartheid, “homelands” or Bantustans were territories set aside for black South Africans. Some were declared “independent” by the apartheid government, who had a vested interest in their viability.

Figure 2. Map of the Grootfontein aquifer.



Source: Boundaries after Holland and Wiegman 2009.

The city of Mahikeng, capital of the North West Province, has a population of about 70,000 people and requires about 18 Mm³/year of water at present. About 20% of this requirement (about 3.7 Mm³/year) comes from a wellfield situated at the northern end of the Grootfontein compartment. The balance comes in roughly equal proportions from the Setumo Dam on the ephemeral Molopo River downstream of Mahikeng and from a large spring in another dolomite compartment (Molopo) to the north of Grootfontein called the Molopo Eye (Figure 2). At least 60% of the city's water supply is from groundwater.

The Grootfontein aquifer met most of Mahikeng's water needs up until the 1980s, first from the natural spring that drained the aquifer (the Grootfontein Eye), and when the spring dried up, from a wellfield drilled around the old spring site. Increasing demand and declining yields from the Grootfontein wellfield meant that the Molopo Eye and later the Setumo Dam were incorporated into Mahikeng's supply.

Today, Mahikeng receives about 3.7 Mm³/year of water from the three remaining Grootfontein wellfield boreholes, and irrigating farmers abstract about 13.6 Mm³/year from the Grootfontein aquifer (Cobbing 2017). Smaller users, including several businesses, a prison, a large hospital and extensive peri-urban residential areas, pump approximately 1.5 Mm³/year. Total abstractions (18.8 Mm³/year) compare with the average annual recharge to the Grootfontein aquifer of no more than 10 Mm³/year, indicating a long-term groundwater deficit (Cobbing 2018). This has caused groundwater levels to drop. The water level near the old spring (i.e., around the wellfield) is today more than 28 m below ground level (Cobbing 2018). Former groundwater-dependent wetlands have also disappeared (Figure 2). On average, across the compartment, groundwater levels have fallen by about 0.4 m/year since the 1970s (Cobbing 2018).

Both the city of Mahikeng and irrigating farmers are concerned about the falling water levels – some wells have run dry, and there is a risk of this happening to others. As a response, Mahikeng has invested in upgrades to the Mmabatho Water Treatment Works at the Setumo Dam to increase the supply capacity from this dam (DWS 2014) and to compensate for increasing uncertainty at Grootfontein. Irrigating farmers are reluctant to invest in agriculture for the long-term and have several strategies for coping with water supply uncertainty, such as investigating other forms of income, which affect their livelihoods, economic contribution and long-term outlook (Cobbing 2017). For the farmers and for most of the “smaller” groundwater users (households and small businesses), there is no immediate alternative water source to Grootfontein groundwater.

In the short term, Mahikeng could give up the Grootfontein aquifer and replace it by increasing the capacity of the Mmabatho Water Treatment Works. Some planners even see a pipeline for surface water from another catchment as a long-term solution, even though surface water resources in nearby catchments are already fully allocated (DWA 2013). However, groundwater from Grootfontein is cheaper than water in Setumo Dam, and much cheaper than water pumped from elsewhere (DWS 2014). Grootfontein, if managed well, would represent a considerable and important reserve of water that could be temporarily over-pumped if other sources failed, or be used to store water during times of surplus as part of a managed aquifer recharge (MAR) scheme. In addition, Grootfontein groundwater only needs precautionary chlorination when compared with the more complex treatment process at the Mmabatho Water Treatment Works, which requires chemicals, human resources, energy and spares. This treatment process has broken down in the past (DWS 2014) and may do so in the future, with significant cost implications for businesses and the public sector.

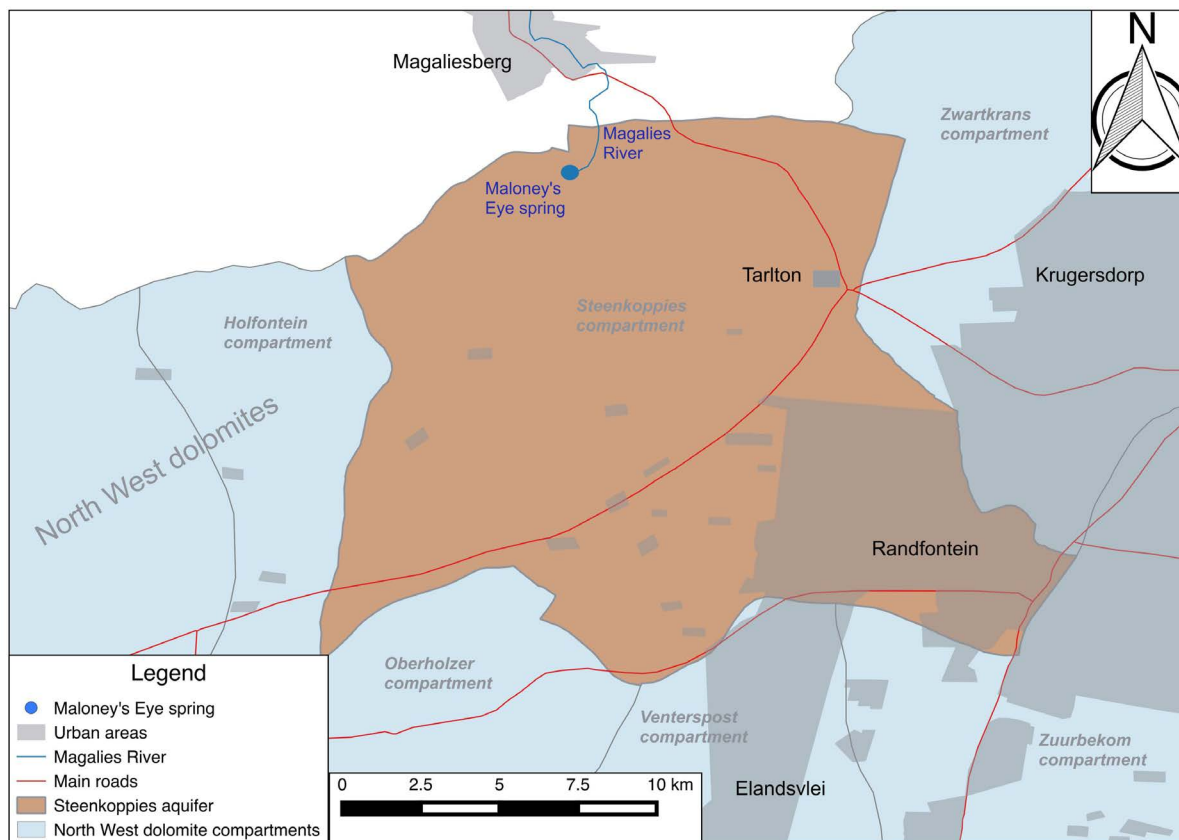
As mentioned, over-abstraction at Grootfontein also has environmental impacts. The disappearance of the Grootfontein Eye and its associated wetlands has reduced flow to the Molopo River. This situation is unfortunately not unusual in the dolomites in South Africa: several other large dolomite springs draining other dolomite compartments have diminished or dried up as a result of over-abstraction from the surrounding aquifer, including the Lichtenburg Eye, Maloney’s Eye, Kuruman Eye and Polfontein Eye. Dewatering of entire dolomite compartments closer to Johannesburg for mining purposes has destroyed several other springs and wetlands, and caused problems of subsidence and sinkholes (Adler et al. 2007). Despite clear indications of these impact chains, the varied and complex linkages between social-ecological systems dependent on dolomite groundwater and regional economic consequences are still poorly understood (Cobbing and de Wit 2018).

3. The Steenkoppies case

The Steenkoppies aquifer compartment is situated in the central part of the North West dolomites and covers an area of about 311 km² (Holland 2009) (Figure 3). Groundwater irrigation from the aquifer supports a valuable local agricultural economy, including vegetable cultivation, cut flowers for export, and plant nurseries. It supports the largest producer of carrots for export in Africa. The annual irrigated agricultural turnover from the compartment exceeded USD 66 million in 2013 (Vahrmeijer et al. 2013). Farms and businesses dependent on groundwater employ more than 4,000 people, with significant backward and forward linkages into other sectors of the economy (Vahrmeijer et al. 2013).

The Steenkoppies aquifer drains naturally at its northern end at a large spring known as Maloney’s Eye, which is the source of the perennial Magalies River. Downstream uses of this river include small-scale irrigation and market gardening, fish farming, trout fishing, and other activities dependent on the ecological functioning and scenic beauty of the river. More than a century of spring flow records show that Maloney’s Eye has a long-term average flow rate of 0.46 m³/s (about 14.3 Mm³/year) (1908 to 2009) (Table 1). However, the spring flow has fallen since large-scale groundwater irrigation began in the 1970s (Table 1), particularly in the last 20 years or so when rising irrigation abstractions have been compounded by drought (Holland 2009). The diminishing flow from Maloney’s Eye has been explicitly linked to the expansion of irrigated agriculture rather than being due to drought alone (Holland 2009). In the 1990s, groundwater withdrawals for irrigation from the Steenkoppies aquifer were estimated to be about 19 Mm³/year (Barnard 1997), while withdrawals in 2009 were estimated to be 25-33 Mm³/year (Holland 2009).

Figure 3. Map of the Steenkoppies aquifer.



Source: Boundaries after Holland and Wiegman 2009.

Table 1. Summary of flow from Maloney's Eye (in Mm³/year).

Year	Minimum	Maximum	10 th percentile	90 th percentile	Median	Average
Pre-1975	10.63	22.04	11.48	18.95	14.13	14.56
Post-1975	1.58	32.64	6.34	26.81	12.02	14.01
Post-1999	1.58	16.05	3.37	14.82	7.98	8.93
1908-2009	1.58	32.64	9.46	20.85	13.81	14.35

Source: After Holland 2009.

The increased pumping and diminishing spring flows have caused problems over the years (Vahrmeijer et al. 2013). In 1994, DWAF temporarily halted abstractions from the Magalies River, following low flows in the river. Good rainfall between 1995 and 1997 provided a solution to the problem. In early 2004, some shallow boreholes in the Steenkoppies aquifer used for domestic supply dried up. Later that year, concerned water users downstream of Maloney's Eye formed the Magalies River Crisis Committee (MRCC) to address low flows in the river. In December 2004, DWAF took steps to curb unlicensed abstractions from the aquifer, including the start of a process to establish actual abstractions.

In early 2007, Maloney's Eye reportedly stopped flowing for the first time ever, following several years of drought (Holland 2009). The MRCC was reconvened, appealed to the South African Presidency to intervene, and began a lawsuit against DWAF to force a reduction in irrigation (Vahrmeijer et al. 2013). This led to a response by 21 major users of Steenkoppies groundwater, known as the "Tarlton Farmers" (Tarlton Farmers 2007), representing most of the groundwater use in the compartment. The Tarlton Farmers disputed that irrigation using groundwater was mainly to blame for low flows at Maloney's Eye and in the Magalies River. Further technical studies were commissioned, but these did not resolve hydrogeological disagreement on key parameters such as the exact area of the Steenkoppies compartment or its recharge (ERM 2007; Holland 2009).

Soon after convening, the Tarlton Farmers began negotiations towards establishing a WUA, with the assistance of the development aid organization DANIDA (Danish International Development Agency). A "Steenkoppies Aquifer Management Association" was formed, and a draft WUA constitution was prepared as a step towards formalization (Vahrmeijer et al. 2013). In 2008, DWAF published new restrictions on irrigation abstractions from the Steenkoppies aquifer, stipulating that all commercial irrigation abstractions should cease when the spring flow dropped below 2.9 Mm³/year. DWAF also requested all irrigators to report details of their abstractions. The Tarlton Farmers stated that such restrictions would have serious consequences for their activities, and that even reductions as low as 10% would need to be phased in slowly (Tarlton Farmers 2007). The Tarlton Farmers did install some flow meters as part of a pilot study, but it was reported that no restrictions on drilling or pumping were enforced, neither by DWAF nor anyone else (Vahrmeijer et al. 2013). The WUA was never legally constituted or approved.

At Steenkoppies, crises have tended to follow periods of drought, while periods of better rainfall have so far encouraged a return to "business as usual" (Vahrmeijer et al. 2013). The limited management attempts have been characterized by legal challenges, threats and disagreements that have tended to increase suspicion and mistrust. One farmer described this as "management by court order" and recognized that it was likely to lead to poor outcomes for all concerned. The environmental consequences of low flows in the Magalies River due to over-pumping of groundwater are serious, and so are the possible impacts on the livelihoods of all those who depend on the groundwater. These factors in turn deeply affect local economic and social conditions.

4. Analysis of North West dolomite groundwater management

In order to better understand the institutional context and options for integrated groundwater management in the North West dolomite areas, a combined stakeholder and institutional analysis was performed. The institutional framework proposed by the political economist Elinor Ostrom (Ostrom 2005) was used to investigate incentives, performance and interactions of stakeholders with an interest in and influence over groundwater. Ostrom's work on ordering and analyzing the institutional features of stakeholder collaboration and collective action in water resources management is well established and influential (e.g., Blomquist 1992; Garrick et al. 2017).

4.1. Stakeholders in North West dolomite aquifer management

4.1.1 Government departments

DWS is the primary government department responsible for South Africa's water resources. DWS is legal custodian of South Africa's water resources, according to the National Water Act of 1998 (RSA 1998) (Box 2). Among other powers, DWS can commission technical studies, issue legal directives, award or withdraw water licenses, and constitute local management bodies such as WUAs. DWS has its head office in the administrative capital Pretoria, main regional (provincial) offices in the nine provinces, and a network of smaller satellite offices. At Grootfontein, the wellfield is operated by DWS, where they have a small office. The DWS regional offices for North West Province are in Mmabatho and Hartbeespoort. DWS monitors groundwater levels across the North West dolomites and employs hydrogeologists in Pretoria, Mahikeng and Hartbeespoort.

Other government departments, such as the National Treasury, Department of Rural Development and Land Reform, Department of Agriculture, Forestry and Fisheries, and the Department of Mineral Resources, have indirect influence over

water allocation and management. For example, the National Treasury influences the final budgets for local government functions (and therefore to an extent, the scope and remit of these functions). As another example, the process of mine license allocation by the Department of Mineral Resources influences water demand and affects the debate over water allocation.

4.1.2 Municipalities

Many water-related functions are the responsibility of the local sphere of the South African government, consisting of district municipalities, which are subdivided into local municipalities (larger urban areas are designated as unitary metropolitan municipalities). The relevant local municipality in any given area is usually designated as the Water Services Authority (WSA) with the responsibility for the provision of domestic water and sanitation services for that municipality. The WSA has the power to appoint service providers such as water boards or private sector entities to carry out these tasks. In cases where the local municipality cannot carry out these functions, they are vested in the district municipality. In Mahikeng, the Ngaka Modiri Molema District Municipality is the WSA, but the Mahikeng Local Municipality has responsibility for certain tasks such as wastewater treatment. The Steenkoppies aquifer falls within the area of Mogale City Local Municipality, which is the WSA and forms part of West Rand District Municipality.

4.1.3 Water boards

Water boards are regional bodies that operate bulk water infrastructure such as dams, treatment plants and reticulation systems. They are managed as corporate entities but are wholly government owned. There are 15 water boards in South Africa, although this figure may change as further amalgamation of water boards takes place. Sedibeng Water Board is responsible for bulk water supply to Mahikeng and the surrounding area. It pumps and treats groundwater from the Grootfontein wellfield and operates the water treatment plant at the Setumo Dam. Sedibeng Water Board has considerable technical expertise, and financial and administrative capacity. In comparison with Grootfontein, the Steenkoppies aquifer is not used for bulk water supply by a water board.

4.1.4 Water User Associations and Catchment Management Agencies

The regional tier of water management in South Africa is the responsibility of Catchment Management Agencies (CMAs). CMAs are responsible for strategy implementation and the reconciliation of competing demands for water, including the involvement of local communities (DWA n.d.). Nineteen CMAs were originally envisaged to coincide with South Africa's major river basins (DWA 2004). Only two CMAs had been established by 2012, when a decision was taken to reduce the number to nine larger CMAs, still covering the territory of South Africa (DWA 2013). Once fully established, CMAs will take over some of the responsibilities of the DWS regional offices.

WUAs are envisaged in the National Water Act as cooperative associations of water users who collaborate to manage local water resources (DWA n.d.). Through better management or reallocation of water, WUAs ideally support poverty eradication and social transformation. Few groundwater WUAs have been approved by DWS, and today there is a process to disband existing WUAs and transfer their powers to the CMAs (DWA 2014).

In the North West dolomites, no groundwater WUAs have been approved and the relevant CMAs are not yet established. Organizations such as stakeholder operating forums (SOFs) and catchment management forums (CMFs) are expected to assume some of their responsibilities in the interim period.

4.1.5 Irrigation farmers

Irrigation farmers abstract the bulk of the groundwater from both the Grootfontein and the Steenkoppies compartments. Although grouped here as a single entity, irrigation farmers have a variety of backgrounds, socioeconomic and racial designations, and economic strategies. They include large-scale commercial farmers who may be heavy users of groundwater, smaller farmers using less groundwater (but still dependent on the resource), and part-time farmers whose main income source may not be from agriculture, but who might nevertheless rely on groundwater for domestic use and livestock watering. They may belong to different agricultural unions or none at all.

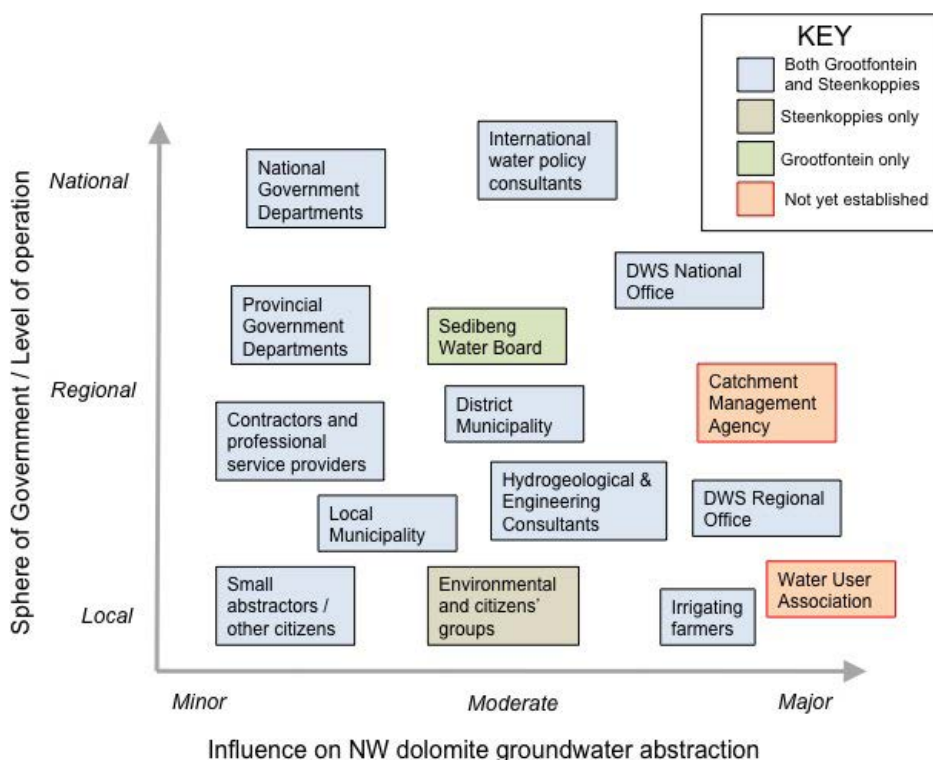
4.1.6 Other stakeholders

Other interested parties at Grootfontein and Steenkoppies with some influence over groundwater abstractions include the following:

- Private sector consultants, engineers and water supply experts, who shape or influence technical water supply choices and management approaches.
- Nongovernmental organizations (NGOs), citizens' organizations, workers' unions and environmental activists. One example is the MRCC.
- International water policy experts, development aid organizations and multilateral policy organizations. These stakeholders influence macro-policy on issues such as the structure and remit of water management organizations.

Figure 4 shows the various stakeholders in the use and management of the Grootfontein and Steenkoppies aquifers.

Figure 4. Organizations influencing groundwater use and management in the North West dolomites.



4.2. Assessment of current institutional features of collaborative management

South African water policy and institutional design favor democratic management and consultative decision-making, and have a broad set of interlinked institutions in place to support this (Figure 4; Box 2). Effective water resources management, addressing, for example, issues of groundwater over-abstraction (Box 3) is necessarily a participative and collaborative process across these institutions, and between individual stakeholders and stakeholder groups. Any stakeholder has some potential to facilitate or disrupt progress. Some institutional, social, cultural and historical factors incline stakeholders towards participation (centripetal), while others favor disagreement (centrifugal). Understanding the balance of these factors affecting water stakeholders and their behavior is a key task (Cobbing 2017).

Ostrom (2005) suggested six institutional prerequisites that, if present in a group of stakeholders sharing a common resource, “...enhance the likelihood of appropriators² organizing themselves to try to avoid the social losses associated with open access³ or rules that are not yet working well” (Ostrom 2005: 244). These “appropriator attributes” were used as the basis for an institutional analysis of groundwater management at Grootfontein and Steenkoppies aquifers (Cobbing 2017). Two important attributes relate to stakeholders having a “common understanding” of the resource, and high levels of “trust and reciprocity” (Ostrom 2005).

The appropriator attributes were investigated using stakeholder interviews⁴, a literature review and participant observation, backed up or triangulated by physical evidence in the dolomites (Cobbing 2017). For example, interviewees’ reports of lack of trust and reciprocity could be corroborated by poor attendance at formal stakeholder meetings convened to discuss water problems. Many of the issues pinpointed in the Grootfontein aquifer were also identified in the Steenkoppies aquifer. It can be shown that Ostrom’s appropriator attributes are mostly absent at Grootfontein and Steenkoppies, making local collaboration and institutional organization of stakeholders less likely (Cobbing 2017). Furthermore, stakeholders do not all agree on the physical characteristics of the resource (common understanding). For example, not all stakeholders at both case aquifers agreed on the aquifer boundaries, or even shared a common understanding of how groundwater existed in the aquifers and how it was replenished.

National policy uncertainty regarding the implementation of the envisaged WUAs has aggravated the problem. WUAs (or similar local organizations) would increase the likelihood of stakeholder collaboration (e.g., by specifying that all users be represented on the WUA board), and would act as a forum for breaking logjams, sharing data and other mutually beneficial functions.

Negotiations towards establishing WUAs at Grootfontein in the late 1990s and at Steenkoppies in the late 2000s were never completed. Representatives of DWS (and its predecessor DWAF) expressed concern that the emerging WUAs in the North West dolomites would replicate apartheid, racial, economic and gender hierarchies (Cobbing 2017). According to some stakeholders, this was, however, not communicated clearly by DWS to stakeholders. According to others, the trust and goodwill between stakeholders, necessary for a successful WUA process, were never present. Consequently, the attempts driven by stakeholder organizations such as the Tarlton Farmers (with support from some DWS and municipal personnel as well as outside agencies such as DANIDA) to formalize the WUAs dragged on for years without bearing fruit, unintentionally consuming resources and stoking cynicism. Interim organizations that are delinked from the WUA process (i.e., SOFs and CMFs) have not attracted wide support and have not been effective, partly because they are likely to be disbanded once the CMAs become effective (Cobbing 2017). Some suspect that DWS never supported WUAs because they imply loss of power, and others blame internal dysfunction at DWS.

Box 3. Addressing groundwater over-abstraction.

Irrigating farmers interviewed at Grootfontein confirmed that there are ways of significantly reducing groundwater abstractions without correspondingly large impacts on farm incomes. This could be done by changing crop types from thirsty, low-value crops such as maize to crops such as high-value vegetables or nut trees that have a higher value per unit of water used. Proper maintenance and application of irrigation equipment as well as electricity rationing or cost increases also tend to favor better use of irrigation water. Changing existing irrigation practices is feasible, but would most likely need to be agreed as part of a larger process of long-term trust building and collaboration (Cobbing 2017). Municipalities and water boards also expressed willingness to address leaks and “non-revenue” water, possibly as part of a larger program addressing the financial sustainability of local government. These findings suggest that mutually beneficial solutions and outcomes are possible, while hinging on coordinated policies and economic incentives.

² Appropriators here refer to those abstracting groundwater from the aquifers, as well as those with an interest in the abstractions and some agency in the process, but who might not themselves be abstracting groundwater (e.g., a local municipality).

³ Open access here refers to the relative ease with which stakeholders can access common-pool resources such as groundwater, and the relative difficulty in preventing such access.

⁴ Stakeholders from most of the groups shown in Figure 4 were interviewed (Cobbing 2017).

4.3. The current situation: A Nash equilibrium

The situation at Grootfontein and Steenkoppies can be described as a Nash equilibrium, a term originally used in game theory to describe situations in which “players” choose a particular course of action based on the anticipated actions of the other players, despite knowing that the outcome will ultimately be in no-one’s best interest (Nash 1950; Nasar 1998). Neither the major groundwater abstractors at Grootfontein (the irrigating farmers and DWS) nor the irrigating farmers at Steenkoppies see an advantage or incentive in unilaterally reducing their pumping rate under the current scenario. Instead, resources are diverted into insuring against the growing risk of water supply failure, at individual and municipal levels, with multiple internalized and externalized costs. Likely outcomes include conflicts between various stakeholders, an exodus of farmers, or a change in livelihoods in response to poor water assurance – exacerbated or moderated by drought or good rainfall, respectively. The Nash equilibrium is similar to a tragedy of the commons (Hardin 1968), but differs in the sense that the North West dolomite abstractors know that their collective actions imply higher costs for all in the present as well as in the future.

5. What is the solution?

Some see the solution in technical terms – e.g., simply punishing irrigating farmers who exceed their licenses, implementing managed aquifer recharge and compelling the municipality at Mahikeng to repair leaks in its water supply network. These are more difficult to achieve than they might appear, and a collaborative process in which all stakeholders gain has a better chance of success (Cobbing 2017). Such an approach would encompass technical (hydrogeological) and social (institutional) aspects of what is a “hydro-social” system (Cobbing and de Wit 2018). For example, sharing groundwater abstraction data, in the context of an agreed hydrogeological conceptual model, would build trust and reciprocity between stakeholders. Progress would be incremental, since the diverse technical and institutional issues influence each other in non-linear ways.

Two prerequisites for groundwater governance at Grootfontein and Steenkoppies are suggested below, which arguably apply in similar multi-stakeholder water governance contexts.

1. A shared forum is essential, if the problems are to be resolved democratically and amicably.
2. This forum needs to be supported by an overarching and effective entity with publicly mandated convening power.

These prerequisites are briefly discussed below.

5.1. Shared forum

Without all stakeholders meeting to discuss the issues, a common understanding cannot be built and it is unlikely that an agreement will be reached. Key tasks for such a forum include the following:

1. Agree that intervention is needed. Stakeholders must agree that the status quo is not in anybody’s interests, and that a better outcome for all is possible. The actions needed to overcome the Nash equilibrium can then be discussed.
2. Agree on a conceptual hydrogeological model. Interviews revealed that stakeholders do not all share the same conceptual model of the resource (Cobbing 2017). For example, there are disagreements about who is using the water, how much is being used, where the water comes from, and who is in breach of license conditions. Sharing summaries of existing hydrogeological data would help to resolve these issues. For example, a quarterly “state of the aquifer” report could easily be compiled from existing water level, rainfall and abstraction data, or a chart showing real-time water levels could be displayed near the aquifers or on a website.
3. Agree on the legal rights and responsibilities of all stakeholders (i.e., an institutional conceptual model). In both cases, stakeholders misunderstand each other’s mandate, powers and responsibilities. For example, some irrigating farmers consider the local and district municipalities and DWS to be essentially the same entity (i.e., the “government”). Conversely, irrigators are a more diverse group than often appreciated.

These tasks are among those that WUAs were intended to tackle (DWAF n.d.). WUA constitutions also encompass essential issues such as remit, venues, responsibilities, reimbursement of costs and deadlock-breaking mechanisms. There remains a need for an organizational and institutional template for these tasks.

5.2. Overarching entity

Given previous unsuccessful attempts at local self-governance, an overarching organization is needed to facilitate the negotiation process, breaking stalemates and nudging stakeholders forward, and with the technical, institutional and legal capacity to enforce agreements where necessary. In other words, an “external” (and impartial and professional) input is needed to break the Nash equilibrium. Such an entity would discourage walkouts, free-riding, the replacement of genuine decision-makers with junior deputies and other hindrances. To do this effectively, the entity needs an understanding of the various aspects of the hydro-social system, as well as a clear public and legal mandate. Essentially, the centripetal power of such an entity is needed to balance the centrifugal tendencies of multiple, diverse stakeholders in the South African context. The entity could also potentially provide well-managed funds, verifiable and transparent hydrogeological data, expertise and other practical support. From a legal, institutional and practical perspective, DWS is best suited to fulfil this role in South Africa (Cobbing 2017).

Evidence suggests that local-level groundwater governance in the North West dolomites breaks down without some kind of overarching institutional support, as confirmed by the cases, and from experience in the Tosca-Molopo area (Seward and du Toit van Dyk 2018). There are no examples of spontaneous, effective, representative grassroots groundwater governance in the North West dolomites emerging and enduring.

The need for overarching support for local groundwater governance is long established elsewhere in the world, even where stakeholders share similar incentives and overarching institutional frameworks. For example, an early study of the West Basin aquifer in California (Ostrom and Ostrom 1972) describes how legal sanction by an overarching publicly-mandated authority was needed to encourage and apply collectively agreed decisions and to discourage free-riding “holdouts” (Cobbing 2017). Community management of even basic groundwater supplies in Africa and elsewhere requires (public sector or NGO) support and should not be seen as a panacea in itself (Chowns 2015). The need for local participation in groundwater governance to be focused and facilitated by an authoritative water resource agency was recognized in a major study by an expert group including the World Bank and international agencies in 2016 (FAO 2016)⁵. Contemporary groundwater management literature aimed at the developing world rightly emphasizes local stakeholder participation, but the need for complementary interdisciplinary approaches and the vital role of the state are also acknowledged (e.g., Barthel et al. 2017). In the developed world, competing claims to water in complex institutional environments are overseen by public organizations such as the Environmental Protection Agency (USA) or the Environment Agency (UK). Such authorities do not necessarily usurp local multi-stakeholder governance, but can instead protect and guarantee it.

The National Water Act (RSA 1998) specifies both shared governance forums, and DWS as an overarching entity. Yet, a viable combination and integration of the two are rare in the North West dolomites, as well as in other South African groundwater governance contexts.

⁵ A component of this study, the Groundwater Policy and Governance Thematic Paper 5, states: “The national government can promote bottom-up approaches by playing an active role in the mobilization of people in local processes, providing funds and technical services for local initiatives, investing in infrastructure, building capacity and expertise among practitioners, and coordinating initiatives that span more than one local government.” (Varady et al. 2013).

6. Conclusions

The management of the North West dolomite aquifers is a complex or “wicked” problem, with nested institutional and technical features making up “hydro-social” systems. The problem is unfortunately often seen in more simplistic or zero-sum terms (e.g., as a narrowly technical matter, as a matter of legal enforcement, as a matter of convening local organizations, or as a simple lack of resources). While there is no easy recipe for success, evidence suggests that a shared local forum bolstered by a capacitated and well-organized DWS is essential. Such local forums have not emerged spontaneously, and previous half-hearted efforts to create them have failed. Today, South Africa is moving from WUAs to CMAs (DWS 2014), although the pace is slow. The situation requires a renewed effort by DWS, built on an understanding of the technical *and* institutional features of each local-level water governance context. The need for a capable, overarching, publicly-sanctioned entity is also likely to apply in other groundwater development contexts elsewhere in Africa, particularly where there are diverse groups of stakeholders and/or a higher volume of abstractions.

The exact form that a revitalized DWS would take, or the procedures and changes it would need to adopt to get there, are a complex set of matters largely beyond the remit of this research. Issues include coordination with other government entities, the nurturing and retention of skills, optimizing the level of autonomy given to professional staff, adequate budgeting for groundwater management, and stabilizing the turnover of senior staff, among others. These matters are generally discussed in the National Development Plan (National Planning Commission 2012), and with explicit reference to groundwater in the Groundwater Strategy (DWA 2010). However, a first step towards a recapacitated DWS is an acknowledgement of its pivotal role in the arrangements for groundwater governance, as well as recognition of the high price that is paid for the current levels of dysfunction.

The economic and environmental benefits of important aquifers such as Grootfontein and Steenkoppies directly influence employment, social cohesion, water security and state expenditure (National Planning Commission 2012). The value of these presumably outweighs the costs of better governance, especially in the longer term. The collaboration and negotiation required for governance of groundwater resources mirrors other situations in which virtuous circles are sought, but where trust and reciprocity must be kindled and maintained. South Africa, with its history of political negotiation and settlement, has considerable expertise here – expertise that could and should be extended to environmental management.

References

- Adler, R.A.; Claassen, M.; Godfrey, L.; Turton, A.R. 2007. Water, mining and waste: An historical and economic perspective on conflict management in South Africa. *The Economics of Peace and Security Journal* 2(2): 33-41.
- Barnard, H.C. 1997. *Geohydrological investigation of the catchment of Maloney's eye*. Dissertation submitted in the fulfilment of the requirements for the degree of Master of Science in the Faculty of Science, University of the Free State, Bloemfontein, South Africa. Unpublished.
- Barnard, H.C. 2000. *An explanation of the 1:500,000 general hydrogeological map, Johannesburg 2526*. Pretoria, South Africa: Department of Water Affairs and Forestry.
- Barthel, R.; Foster, S.; Villholth, K.G. 2017. Interdisciplinary and participatory approaches: The key to effective groundwater management. *Hydrogeology Journal* 25(7): 1923-1926.
- Beckh, C. 2013. Governance of groundwater ecosystem service trade-offs in Gauteng, South Africa – an institutional analysis. In: *Commoners and the Changing Commons: Livelihoods, Environmental Security, and Shared Knowledge: Fourteenth Biennial Conference of the International Association for the Study of the Commons (IASC), June 3-7, 2013*. Available at <http://dlc.dlib.indiana.edu/dlc/handle/10535/8886> (accessed on October 15, 2018).
- Blomquist, W, 1992, *Dividing the waters: Governing groundwater in Southern California*. San Francisco: ICS Press.
- Bredenkamp, D.B. 1964. *Verslag van hidrologiese opname in die Bo-Molopo Ondergrondse Waterbeheergebied*. Report No. GH 1283. Pretoria, South Africa: Department of Water and Sanitation.
- Chowns, E. 2015. Is community management an efficient and effective model of public service delivery? Lessons from the rural water supply sector in Malawi. *Public Administration and Development* 35: 263-276.

- Cobbing, J.E. 2017. *The Grootfontein aquifer as a hydro-social system*. Dissertation submitted in the fulfilment of the requirements for the degree of Doctor of Philosophy in the Faculty of Science, Nelson Mandela University, Port Elizabeth, South Africa. Available at <http://hdl.handle.net/10948/21349> (accessed on October 24, 2018).
- Cobbing, J.E. 2018. An updated water balance for the Grootfontein aquifer near Mahikeng. *Water SA* 44(1): 54-64.
- Cobbing, J.E.; de Wit, M.J. 2018. The Grootfontein aquifer: Governance of a hydro-social system at Nash equilibrium. *South African Journal of Science* 114(5/6): 53-59. <https://doi.org/10.17159/sajs.2018/20170230>
- Colvin, C.; Saayman, I. 2007. Challenges to groundwater governance: A case study of groundwater governance in Cape Town, South Africa. *Water Policy* 9(S2): 127-148.
- DWA (Department of Water Affairs). 2010. *Groundwater strategy 2010*. Pretoria, South Africa: Department of Water Affairs.
- DWA. 2013. *National water resource strategy: Water for an equitable and sustainable future*. June 2013, Second edition. Pretoria, South Africa: Department of Water Affairs.
- DWA. 2014. *National Water Policy Review (NWPR). Approved water policy positions*. January 31, 2014. Pretoria, South Africa: Department of Water Affairs.
- DWAF (Department of Water Affairs and Forestry). 2004. *National water resource strategy*. First Edition. Pretoria, South Africa: Department of Water Affairs and Forestry (DWAF).
- DWAF. n.d. *Water management institutions: Overview*. Pretoria, South Africa: Department of Water Affairs and Forestry. Available at <http://www.dwa.gov.za/documents/publications/WMIoverview.pdf> (accessed on October 15, 2018).
- DWS (Department of Water and Sanitation). 2014. *Third quarter performance evaluation report for Greater Mafikeng bulk water supply scheme*. Period October 1 to December 31, 2014. Chief Directorate: Bulk Infrastructure Programme. Pretoria, South Africa: Department of Water and Sanitation.
- ERM. 2007. *Steenkoppies aquifer management association – Hydrogeological review, Maloney's Eye catchment area*. Unpublished report by the consulting company ERM (Pty) Ltd.
- FAO (Food and Agriculture Organization of the United Nations). 2016. *Global diagnostic on groundwater governance*. Groundwater Governance: A Global Framework for Action. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Available at <http://www.fao.org/3/a-i5706e.pdf> (accessed on October 16, 2018).
- Garrick, D.E.; Hall, J.W.; Dobson, S.; Damania, R.; Grafton, R.Q.; Hope, R.; Hepburn, C.; Bark, R.; Boltz, F.; De Stefano, L.; O'Donnell, E.; Matthews, N.; Money, A. 2017. Valuing water for sustainable development. *Science* 358(6366): 1003-1005.
- Hardin, G. 1968. The tragedy of the commons. *Science* 162(3859): 1243-1248.
- Holland, M. 2009. *Geohydrology guideline development: Activity 25: Geohydrological assessment of the Steenkoppies dolomite compartment*. Report prepared for the Department of Water Affairs by Water Geosciences Consulting as part of DWA project number: 14/14/5/2: Implementation of dolomite guideline. Pretoria, South Africa: Department of Water Affairs.
- Holland, M.; Wiegmans, F. 2009. *Geohydrology guideline development: Activity 18 & 19: Desktop development of a dolomite hydrogeological compartment map and explanation booklet (report)*. Report prepared for the Department of Water Affairs by Water Geosciences Consulting as part of DWA project number: 14/14/5/2: Implementation of dolomite guideline. Pretoria, South Africa: Department of Water Affairs.
- Johnson, M.R.; Anhaeusser, C.R.; Thomas, R.J. (Eds.). 2006. *The geology of South Africa*. Johannesburg, South Africa: Geological Society of South Africa (GSSA); Pretoria, South Africa: Council for Geoscience.
- Knüppe, K. 2011. The challenges facing sustainable and adaptive groundwater management in South Africa. *Water SA* 37(1): 67-79.
- Lazarus, P. 1998. *Towards a regulatory framework for the management of groundwater in South Africa*. Water Research Commission Report No. 789/1/98. Pretoria, South Africa: Water Research Commission.
- Meyer, R. 2014. *Hydrogeology of groundwater region 10: The Karst Belt*. Water Research Commission Report No. TT 553/12. Pretoria, South Africa: Water Research Commission.
- Movik, S.; de Jong, F. 2011. Licence to control: Implications of introducing administrative water use rights in South Africa. *Law, Environment and Development Journal* 7(2): 68-78.
- Muller, M. 2008. Free basic water – a sustainable instrument for a sustainable future in South Africa. *Environment and Urbanization* 20(1): 67-87.

- Nasar, S. 1998. *A beautiful mind: The life of mathematical genius and Nobel Laureate John Nash*. New York: Simon and Schuster.
- Nash, J.F., Jr., 1950. Equilibrium points in n-person games. *Proceedings of the National Academy of Sciences of the United States of America* 36(1): 48-49.
- National Planning Commission. 2012. *National development plan 2030: Our future – make it work*. Pretoria: National Planning Commission.
- Ostrom, E. 2005. *Understanding institutional diversity*. New Jersey, USA: Princeton University Press.
- Ostrom, V.; Ostrom, E. 1972. Legal and political conditions of water resource development. *Land Economics* 48(1): 1-14.
- Picard, L.A.; Mogale, T. 2015. *The limits of democratic governance in South Africa*. Boulder, Colorado: Lynne Rienner Publishers.
- RSA (Republic of South Africa). 1977. *Supplementary report on the Upper Molopo Government Regional Water Supply Scheme (formerly called Government Water Supply Scheme for Mafikeng)*. White Paper prepared for the Secretary for Water Affairs. Pretoria, South Africa: Department of Water Affairs and Forestry.
- RSA. 1997. *Act no. 108 of 1997: Water services act*. Government gazette 390(18522), December 19, 1997. Cape Town: Republic of South Africa.
- RSA. 1998. *Act no. 36 of 1998: National water act*. Government gazette 398(19182), August 26, 1998. Cape Town: Republic of South Africa.
- Schreiner, B. 2013. Viewpoint – Why has the South African national water act been so difficult to implement? *Water Alternatives* 6(2): 239-245.
- Seward, P.; Xu, Y.; Turton, T. 2015. Using backcasting to explore ways to improve the national water department's contribution to good groundwater governance in South Africa. *Water International* 40(3): 446-462.
- Seward, P.; du Toit van Dyk, G.S. 2018. Turning the tide: Curbing groundwater over-abstraction in the Tosca-Molopo area, South Africa. Chapter 25 in: *Advances in groundwater governance*, (eds.), Villholth, K.G.; López-Gunn, E.; Conti, K.I.; Garrido, A; van der Gun, J. London: Taylor and Francis. Pp. 511-525.
- Tarlton Farmers. 2007. Submission by the Tarlton farmers to the Director-General, Department of Water Affairs and Forestry, regarding restrictions on the taking of water for all purposes except those contained in Schedule 1 to the National Water Act 1998, from the Steenkoppies Dolomitic Compartment (Quaternary Drainage Regions). Unpublished submission by water users in the Tarlton area.
- Temperley, B.N. 1965. *Groundwater conditions on Spring Valley Farm, Rooigrond near Mafikeng*. Report no. GH 1273. Pretoria: Department of Water Affairs and Forestry.
- Vahrmeijer, J.T.; Annandale, J.G.; Bristow, K.L.; Steyn, J.M.; Holland, M. 2013. Drought as a catalyst for change: A case study of the Steenkoppies dolomite compartment. Chapter 14 in: *Drought in arid and semi-arid regions*, (eds.), Schwabe, K.; Albiac-Murillo, J.; Connor, J.D.; Hassan, R.; Meza González, L. Dordrecht: Springer. Pp. 251-268.
- van Koppen, B.; Schreiner, B. 2014a. Moving beyond integrated water resource management: Developmental water management in South Africa. *International Journal of Water Resources Development* 30(3): 543-558.
- van Koppen, B.; Schreiner, B. 2014b. Priority general authorisations in rights-based water use authorisation in South Africa. *Water Policy* 16(S2): 59-77.
- van Tonder, G.J.; Janse van Rensburg, H.; Botha, J.F.; Bredenkamp, D.B. 1986. Die modellering van grondwatervlakke in die Grootfonteinkompartement in Wes-Transvaal. *Water SA* 12(3): 151-160.
- Varady, R.G.; van Weert, F.; Megdal, S.B.; Gerlak, A.; Iskandar, C.A.; House-Peters, L.; McGovern, E.D. 2013. *Groundwater policy and governance*. Groundwater Governance Project Thematic Paper No. 5. Groundwater Governance: A Global Framework for Action. Global Environment Facility (GEF); World Bank; United Nations Educational, Scientific and Cultural Organization – International Hydrological Programme (UNESCO-IHP); Food and Agriculture Organization of the United Nations (FAO); International Association of Hydrogeologists (IAH). Available at http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/Thematic_papers/GWG_ThematicPaper5_APr2013_web.pdf (accessed on October 16, 2018).
- Vegter, J.R. 2001. *Groundwater development in South Africa and an introduction to the hydrogeology of groundwater regions*. Water Research Commission Report No. TT134/00. Pretoria: Water Research Commission.

Groundwater Solutions Initiative for Policy and Practice (GRIPP)

The Groundwater Solutions Initiative for Policy and Practice (GRIPP) is an IWMI-led initiative designed to co-develop solutions to the challenges of sustainable groundwater development. GRIPP aims to strengthen, expand and connect current groundwater-related initiatives by forging new partnerships, sharing solutions, scaling-up successes and filling knowledge gaps. The initiative is targeted at the groundwater-dependent, food-producing regions of the world, particularly in low-income and emerging economies. Through dynamic partnerships, GRIPP informs, promotes and adapts tested technologies, and innovative policy and institutional approaches, in order to achieve the Sustainable Development Goals (SDGs) related to climate resilience, food security, livelihoods and sustainable water management. gripp.iwmi.org

International Water Management Institute (IWMI)

The International Water Management Institute (IWMI) is a non-profit, scientific research organization focusing on the sustainable use of water and land resources in developing countries. IWMI works in partnership with governments, civil society and the private sector to develop scalable agricultural water management solutions that have a real impact on poverty reduction, food security and ecosystem health. Headquartered in Colombo, Sri Lanka, with regional offices across Asia and Africa, IWMI is a CGIAR Research Center and leads the CGIAR Research Program on Water, Land and Ecosystems (WLE). www.iwmi.org

GRIPP PARTNERS



ISSN 2520-2405 (Online)
ISSN 2520-2391 (Print)
ISBN 978-92-9090-874-6

FIND OUT MORE Contact: Dr. Karen G. Villholth - iwmi-gripp@cgiar.org | Web: <http://gripp.iwmi.org>



IWMI is a CGIAR Research Center and leads the:



RESEARCH PROGRAM ON Water, Land and Ecosystems

International Water Management Institute (IWMI)
127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Mailing Address:
PO Box 2075, Colombo, Sri Lanka
Tel: +94-11 2880000 Fax: +94-11 2786854 E-mail: iwmi@cgiar.org
Web: www.iwmi.org