Official Journal of the World Water Council
Water Policy

Water Policy Vol 23 No 4, 819 doi: 10.2166/wp.2021.016

Implementation of groundwater protection measures, particularly resource-directed measures in South Africa: a review paper

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ABSTRACT

This review paper on groundwater protection measures in South Africa focuses on the actual implementation of groundwater protection measures, in particular, the resource-directed measures (RDM) as described in Chapter 3 of the National Water Act (NWA). Significant catchment-wide implementation of RDM has taken place in a phased manner throughout various catchments since 2012. By 2015, approximately R380 million had been expended on the catchment-wide implementation of the water resource protection measures over a period of 15 years. Considerable effort went into refining the RDM methodology, taking into account the groundwater component of the overall resource. In this paper, we contend that RDM, in its present form, will not make a significant contribution to groundwater resource protection and security in the country. This is a major concern because the Groundwater Strategy of the Department of Human Settlements, Water and Sanitation (DHSWS) had declared the protection of groundwater as a national priority. This paper also examines institutional and governance arrangements (or lack thereof) as well as providing recommendations to support the effective implementation of groundwater protection provisions as prescribed by South Africa's water legislation.

Key words: Effective implementation, Governance, Groundwater protection, Institutional arrangements, Resource-directed measures, Water legislation

HIGHLIGHTS

- Groundwater protection measures and its significant catchment-wide implementation to date.
- Resource-directed measures methodology.
- Groundwater Reserve determination.
- Water resource classification and resource quality objectives.
- Implementation of water resource legislative and scientific measures.

1. INTRODUCTION

South Africa falls into the high water stress class (total withdrawals 40–80% of total renewable supply) and has less water per person than countries widely considered being much drier such as Namibia and Botswana (Gassert *et al.*, 2013). Many catchments in the country are fast approaching the point at which all of the available freshwater resources are fully utilized. Increasing urbanization, industrialization and climate change place enormous pressure on the scarce water resources in terms of management and allocation. Ensuring a sustainable water balance requires a multitude of strategies which include water conservation, water demand management, increased use of previously under-utilized resources such as groundwater, desalination of seawater, water re-use, rainwater harvesting and treating acid mine drainage. The National Water Act (NWA), Act 36 of 1998 in South Africa provides for the protection of water resources through three main measures namely: (1) classification of water resources; (2) determination of the reserve; and (3) setting the resource quality objectives (RQOs) for the selected class. These together form the resource-directed measures (RDM) described in detail in Chapter 3 of the Act.

The Water Resource Classification System (WRCS) was formally established in September 2010 whereby water resources are categorized according to specific classes that represent a management vision of a particular catchment. The WRCS takes into account social, economic, ecological and the environmental landscape in a catchment in order to assess the costs and benefits associated with utilization versus protection of a water resource. It also defines three water resource classes reflecting a gradual shift from resources that will be minimally used to those that are heavily utilized. The classification of water resources represents the first stage in the protection of the resources and determines the quantity and quality of water required for ecosystem functioning as well as maintaining economic activity that relies on a particular water resource.

To investigate options to increase the utilization of groundwater, a strategic review assignment was initiated by the Water Research Commission (WRC) of South Africa. This review evaluates progress with the implementation of groundwater protection measures in South Africa in the past decade.

2. GROUNDWATER RESOURCES AND DEVELOPMENT IN SOUTH AFRICA

Because of the old geological formations in South Africa and the African continent as a whole, South Africa's groundwater occurs mainly in hard-rock aquifers. The distribution of various aquifers according to a classification of major, minor and poor, described in detail by Parsons (1995), is shown in Table 1. Most recent scientific

Table 1. | Aquifer classification system (after Parsons, 1995).

Aquifer system classification	Coverage of country (%)	General location
Major aquifers	18	Primary aquifer systems along the coast Dolomitic systems in parts of Gauteng, Mpumalanga, the Northern Cape and North West Provinces Rocks of the Table Mountain Group bordering the Cape coast Parts of the Karoo Supergroup Cities and towns receiving water from major aquifer systems are Pretoria, Mmabatho, Atlantis, St. Francis Bay and Beaufort West
Minor aquifers	67	Minor aquifers occur widely across South Africa with variable borehole yield and water quality. They supply many smaller settlements, e.g. Nylstroom, Williston, Carnarvon, Calvinia, Kenhardt and Richmond
Poor aquifers	15	Poor aquifers occur mainly in the dry northern and western parts of the country. The generally low borehole yields of poorer quality are, however, still of critical importance to small rural communities

estimates place groundwater in South Africa in the same league (volumetrically) as the stored surface water resources (DWS, 2017).

The total volume of available renewable groundwater in South Africa is approximately 10,000 million m^3/a (or 7,500 million m^3/a under drought conditions) (DWS, 2017). The current use is between 2,000 and 4,000 million m^3/a. Therefore, there is potential to considerably increase the use of groundwater in South Africa. In contrast, the assured yield of South Africa's surface water resources is approximately 12,000 million m^3/a, but more than 80% of this is already allocated (DWS, 2017). Although most (but not all) large-volume water users rely on surface water, the majority of small water supplies, which are critical to livelihoods and health, depend on groundwater (DWA, 2010a).

Groundwater sources played a major role in the rapid advancement of South Africa towards achieving the Millennium Development Goal (number 7c) for domestic water supply. Access to safe drinking water sources in the country increased from 61% in 1996 to over 95% in 2015 (DWA, 2013). A major advance towards improved development and management of groundwater resources has been that groundwater was registered for the first time, in terms of the provisions in the NWA. It presents the first step towards authorizing the use of groundwater and more than 20,000 users (using >10 m^3/day) were registered. This information, as summarized in Table 2, is available on the Water Authorization and Registration Management System (WARMS) database of DHSWS.

Groundwater is becoming increasingly important for urban water supply. Twenty-two percent of towns in South Africa use groundwater as the sole source and another 34% in combination with surface water (Braune *et al.*, 2014). Irrigation still presents by far the largest volumetric use of groundwater in the country. Like in many other parts of the world, this has mainly happened as a result of private development. Mines are often in remote areas, and the provision of an adequate water supply is one of the key challenges of the whole operation.

A major concern is that the most strategically important groundwater service, that of domestic water supply, is being poorly managed at the local level. A key reason for this problem is that the intended devolution of water resources management to catchment management agencies (CMAs) and supporting management institutions, in particular, Water User Associations (WUAs), has not taken place in any significant way. Inexperienced and non-capacitated municipalities, already struggling with their water supply function, also have to develop and manage their local groundwater resources, without comprehensive direction, control and support from national government (Adams *et al.*, 2015).

3. GROUNDWATER RESOURCE PROTECTION AND RELEVANT LEGISLATION

Protection of groundwater resources against pollution and over-use has become vitally important since its much-increased role for domestic water supply. The highest vulnerability to poor management is found in the highly

Table 2. | Status of groundwater use in South Africa (DWS, 2017).

Economic sectors	Registered groundwater use per sector (%)
Agriculture: irrigation	59
Agriculture: watering livestock	6
Water supply services	13
Mining	13
Other (industry, recreation, aquaculture, power generation)	3
Schedule 1 (smaller unregistered user)	6

transmissive and often shallow dolomitic aquifers and coastal aquifers. Groundwater levels and spring flow have dropped significantly due to over-use for irrigation in major Karst aquifers. Increasing salinity levels in strategically important coastal aquifers are pointing to an onset of seawater intrusion. Vulnerability to supply failure as a result of lack of monitoring is particularly high in the ubiquitous, low-yielding fractured aquifers. Increasing nitrate levels are observed in groundwater in several regions and may be as a result of human activity such as agriculture, industry and domestic effluent. The DHSWS initiated an integrated roll-out of protection measures through its National Water Resource Strategy (NWRS) (first edition). An early Groundwater Protection Strategy was largely neglected until recently, because it had been developed before the more systematic focus on integrated approaches.

3.1. National Water Resource Strategy

The first NWRS of South Africa was established in 2005. This strategy is an implementation strategy for the NWA, provides a 'general guide' on the priorities for water use and puts provision for water resource protection measures (inclusive of groundwater) at the head of a list of priorities. After the establishment of the first NWRS, DHSWS should have embarked on a process to address the knowledge gaps through well-coordinated processes of strategy development. Unfortunately, since 2005, this has never happened.

In 2009, a revision of the NWRS commenced, outlining the process to identify (through a gap analysis) those key strategic areas that require attention. Through the gap analysis, it became evident that crucial areas of water resource management were only superficially addressed or not addressed at all. Examples of these are water conservation and demand management, groundwater management, water quality management and coping with global warming and climate change. Relevant sub-strategies for these areas still need to be developed and/or finalized and aligned. Various identified shortcomings have since been addressed in the second edition of the NWRS, including regular reference to groundwater and in 2017, a separate, widely consulted, National Groundwater Strategy (NGS, 2017).

3.2. Resource-directed measures and source-directed controls

Protection principles are contained in Chapter 3 of the NWA. The Reserve, the Classification System and RQOs are protection-based measures (aimed at protecting both surface and groundwater resources) that together form the RDM (Xu *et al.*, 2003; Wentzel, 2008; Dennis *et al.*, 2013). RDM is a water resource management strategy with the objective of ensuring sustainable utilization of water resources. The purpose of RQOs is to establish clear goals with regard to the quality of the relevant resources and present a balance between the protection requirements and the need to develop and use the resource. The following classes are used: 'Protected', 'Good', 'Fair' and 'Severely Modified'. The groundwater component of the Reserve is the part of the groundwater resource that sustains basic human needs (BHN) and in some instances contributes to ecological water requirements (EWR). To be able to quantify the groundwater component of the Reserve, the volume of groundwater needed for BHN and contributing to EWR needs to be quantified. The EWRs of the resource in question must consider groundwater contribution to baseflow in rivers; wetlands; springs; and other groundwater-dependent ecosystems.

Another strategy exists for managing impacts of land-use activities on water resources, which is referred to as the source-directed control (SDC) strategy (e.g. land-use controls providing licences for water use and waste disposal). As shown in Figure 1, RDM should be implemented in conjunction with the SDC strategy to ensure that an integrated and balanced approach is taken in water resource utilization decision-making that looks at the social, economic and environmental requirements.

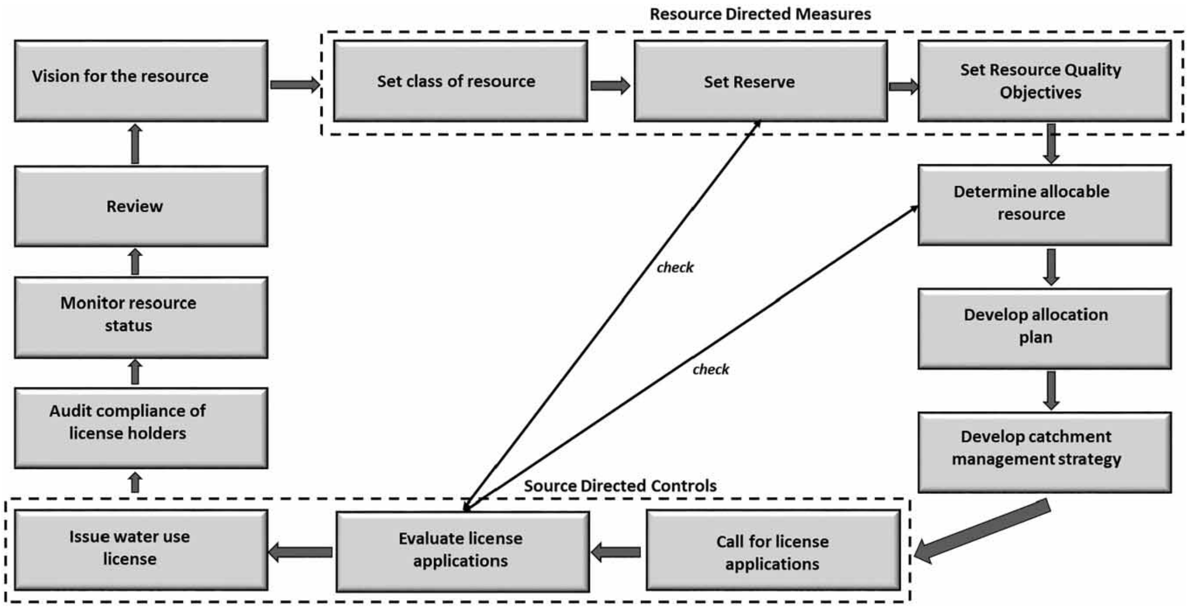

Fig. 1. | Role of resource-directed measures and source-directed controls in integrated catchment management.

3.3. RDM determinations factored into planning

Critical water resource protection challenges in South Africa are well recognized and documented. There is a worsening of water quality in many water resource systems with a deterioration of reservoirs and ecosystems, and especially rural communities face growing risks of water shortages and the health impacts of contamination (CSIR, 2010; DWA, 2010b). Key initiatives to address these water resource protection measures have been considered by a number of role players. For instance, the Integrated Water Quality Management Strategy of the DHSWS commenced in 2015 (DWS, 2016). However, a fragmented and isolated approach in responding to these water challenges is still evident despite efforts by DHSWS to realize a more holistic response based on an IWRM approach (Figure 2).

4. PROGRESS WITH GROUNDWATER RDM IMPLEMENTATION IN SOUTH AFRICA

4.1. National Water Resource Strategy

In doing all the necessary forward strategic planning for the comprehensive management of South Africa's water resources, the DHSWS has revised the NWRS and subsequently prioritized its implementation. The second edition of the NWRS serves as a strategic guideline document for all water-use stakeholders, and it addresses various issues affecting access to the resource in particular. Accordingly, the following NWRS sub-programmes have since received priority attention:

- The National Integrated Water Information System (NIWIS) to improve decision-making and improve access for the public.
- Water allocation reform: the validation and verification of existing lawful users.
- A structured water-use licence process with a maximum turnaround time of 30 days.

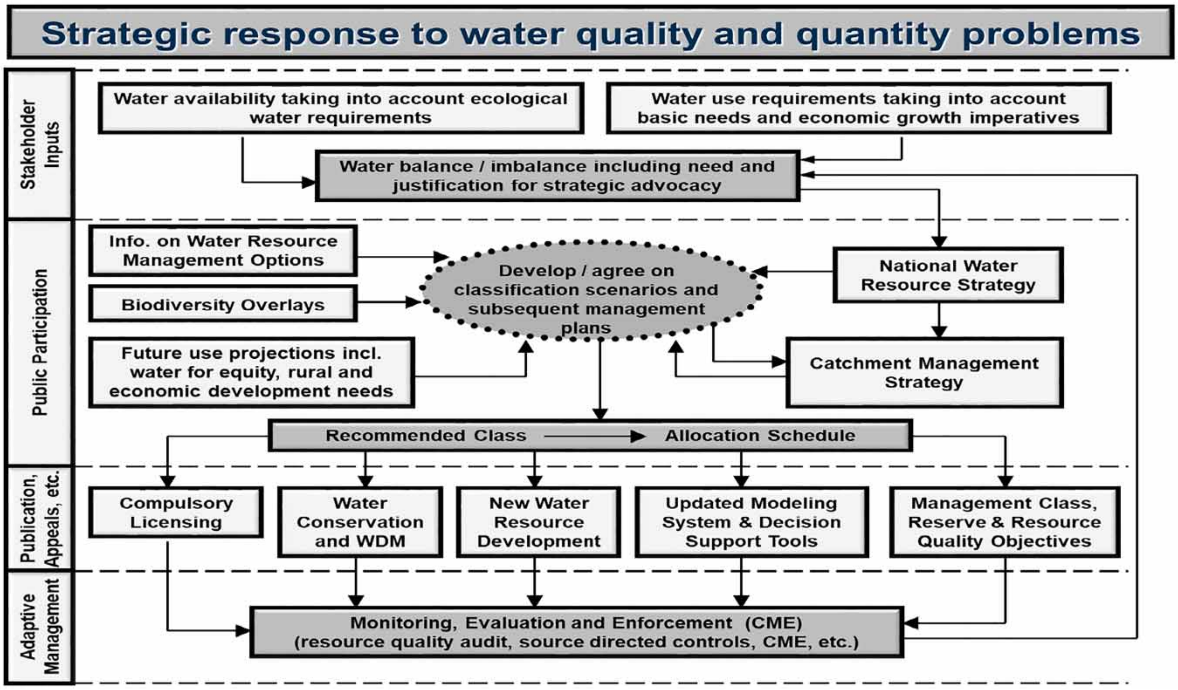

Fig. 2. | Strategic response to water quantity and quality problems.

4.2. Planning mechanisms

A first national assessment of available groundwater resources was initiated in 1995 through the publication of groundwater resources of South Africa (Vegter, 1995). Regional mapping, undertaken by the Department of Water Affairs at a scale of 1:500,000, followed, leading to a series of 21 hydrogeological maps covering the country by 2003. Importantly, a follow-on assessment phase, i.e. Groundwater Resource Assessment (GRA 2) in 2005, led, for the first time, to the inclusion of a groundwater component in the regularly updated Water Resources of South Africa.

Over the years, groundwater (quantity and quality) as a domain function has been well incorporated into the strategic planning function of DHSWS. However, operational plans at provincial and local levels are still lacking coherent implementation of groundwater protection measures, despite this function being an integral part of water resource planning. Planning attention should be focused not only on specific water supply issues but also on region-wide and national issues relating to vulnerable groundwater resources. Efforts to implement groundwater protection measures should therefore not only be considered within a strategic IWRM context (Figure 2) but also aim to advance a set of large-scale practical and effective science-based integrated scientific, engineering and technological (SET) solutions to counter groundwater problems evident at both source and resource throughout the water value chain (Figure 3).

4.3. Integration with SDCs

To date, it would appear that, in general, decisions regarding water resource utilization are not integrated and that RDM and SDC are being applied in isolation. The DHSWS has, however, established a function in its Regulations branch that is focused on environmental regulation, hence SDC could be concerned with implementing

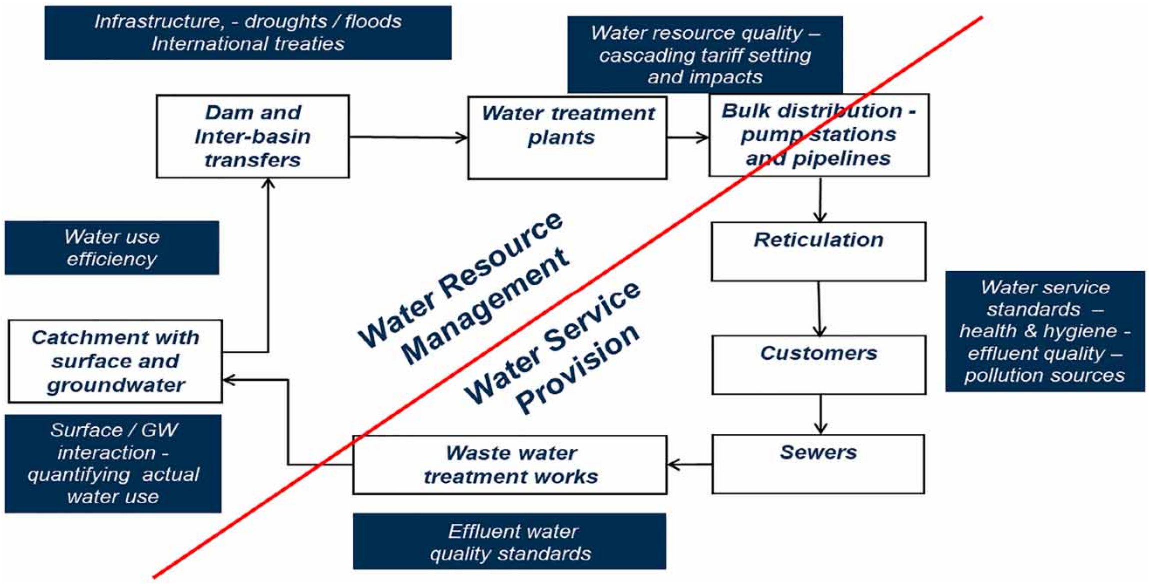

Fig. 3. | SET considerations throughout the water value chain to enhance the implementation of groundwater protection measures.

groundwater protection measures, while the determination and refinement of these protection measures are being determined by the RDM function that is performed within the Planning and Information Branch of DHSWS.

4.4. Implementation of groundwater RDM

4.4.1. Initial focus on Reserve determination

Before the classification of water resources was systematically introduced in various catchments, the key RDM process was Reserve determination in support of water-use licensing. Table 3 provides an indication of 'Groundwater Reserves' that have been assessed relative to the number of 'Surface Water Reserves' in a particular period up to 2013/2014. The major effort this presents can be seen in Figure 4, which depicts the cumulative number of 'Groundwater Reserves' determined up to 2014 in each of the nine Water Management Areas (WMAs).

The figure also shows the different levels of detail to which the Reserve has been determined in each WMA, i.e. Desktop, Rapid, Intermediate and Comprehensive. A Desktop level approach, mainly a planning instrument, uses results from previous flow determinations to generalize on the percentage of mean annual runoff and its seasonal distribution required for rivers held at the different ecological categories. The Rapid method can take up to

Table 3. | Summary of reserves completed (DWS, 2015a, 2015b).

Period	Groundwater reserves	Surface water reserves
Up to May 2011	1,306	1,468
2011/2012	94	1,128
2012/2013	1,141	161
2013/2014	21	53

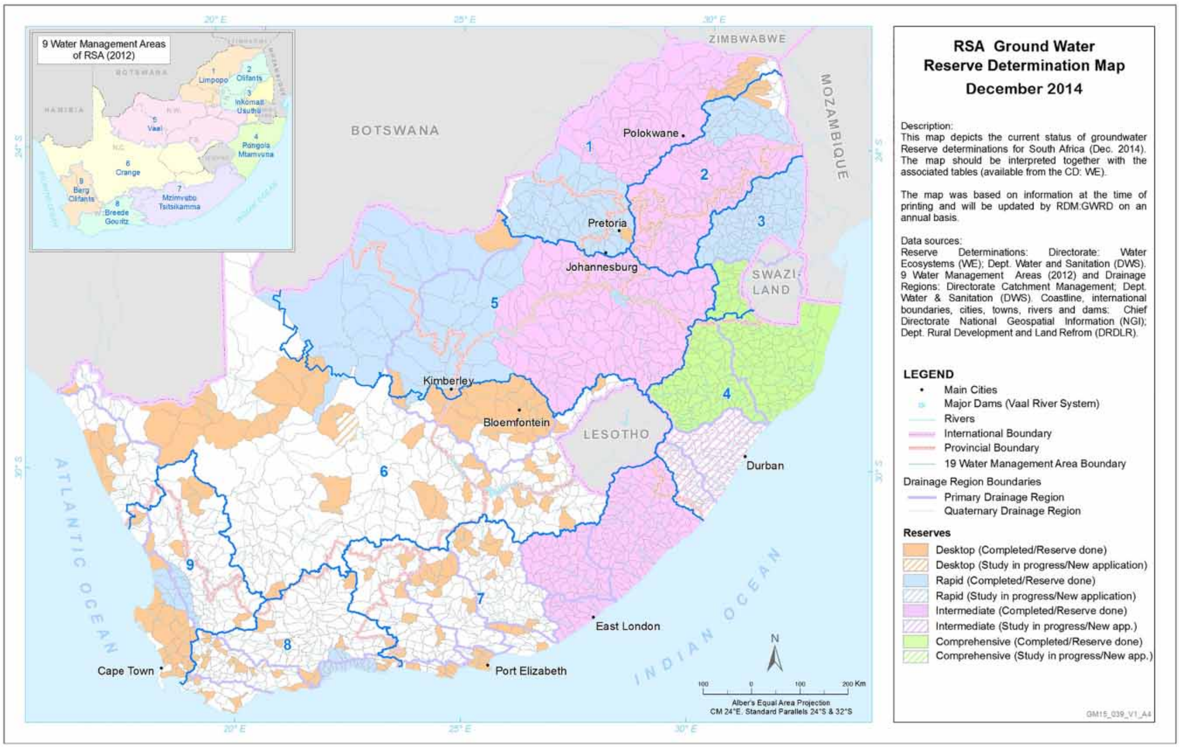

Fig. 4. | Status of groundwater Reserve determination – 2014 (Motebe, 2015).

14 days and may be used in water-use licence evaluations. Intermediate and Comprehensive level approaches can take between 2 and 6 months and are mainly used where potential water conflict is high, or where there is high ecological importance or sensitivity (King & Pienaar, 2011). This breakdown of the different levels of detail in a particular year (e.g. 2012/2013) is shown for illustration purposes in Table 4.

According to Figure 4, comprehensive 'Groundwater Reserves' have at this stage only been undertaken for the Pongola-Mtamvuna WMA and parts of the Inkomati-Usutu WMA. Intermediate determinations have been done for large parts of the Limpopo, Olifants, Vaal WMA and Mzimvubu-Tsitsikamma WMAs. Large portions of the Orange, Breede-Gouritz and Berg-Olifants WMAs have at this stage only patches of desktop determinations, with some Rapid and Intermediate Reserves along the coastal areas. A further important breakdown received from DWS regarding its implications for groundwater resource protection, namely the focus of the 'Groundwater Reserve' determinations:

- 80% *ad hoc* water-use licence-related (protection of linked surface water);
- 20% protection of groundwater resources.

A conclusion that can be drawn at this stage of Reserve implementation is that groundwater resources *per se* are not yet protected by these extensive measures, as the decisions for water-use licences are entirely informed by surface water ecological Reserve requirements. Moreover, the BHN Reserve for groundwater is a very small volume that can only be controlled if relevant RQOs are set.

Table 4. | Summary of groundwater Reserve determinations completed between October 2012 and September 2013 (DWA, 2014).

Drainage region	Desktop	Rapid	Intermediate	Comprehensive	Total
A	13	53	68	–	134
B	3	23	114	–	140
C	18	20	149	–	187
D	31	14	–	–	45
E	5	10	–	–	15
F	8	–	–	–	8
G	27	6	–	–	33
H	13	–	–	–	13
J	7	3	–	–	10
K	10	19	–	–	29
L	7	–	–	–	7
M	6	–	–	–	6
N	9	–	–	–	9
P	7	–	–	–	7
Q	8	–	–	–	8
R	–	–	30	–	30
S	–	–	58	–	58
T	–	–	106	–	106
U	–	–	–	–	0
V	–	–	–	86	86
W	–	–	–	117	117
X	–	93	–	–	93
Total	172	241	525	203	1,141

4.4.2. Roll-out of classification and RQOs

There has been considerable progress in the catchment-wide roll-out of RDM since 2014 (see Table 5). It is further reported that the high confidence Reserves were conducted in the Gouritz, Mvoti and Usuthu catchments, with the EWR for both surface and groundwater Reserves been specified (Atwaru, 2016). Significant also is the WRC contribution towards initiating the classification of significant groundwater resources, as legally prescribed by the NWA. All six groundwater studies mentioned below were undertaken with support from the WRC, and the reports were readily accessible. Approximately R380 million has been expended on RDM implementation of which an estimated third had gone to groundwater protection measures.

4.4.3. National monitoring

The DHSWS as the sole custodian of water resources in the country is mandated to monitor and manage these resources in a manner that supports socio-economic development without compromising the ecological integrity of natural systems. Chapter 14 of the NWA calls for the establishment of monitoring and information systems to monitor, record, assess and disseminate information on the quantity and quality of water resources.

Table 5. | Roll-out of RDM in catchments.

Area	RDM implementation[a]	Groundwater progress
Upper Vaal Middle Vaal Lower Vaal	Proposed classes of water resources were gazetted on 19 September 2014	WRC GRDM study (Hobbs *et al.*, 2013)
Crocodile (West) Marico		WRC Maloneys Eye study (Wiegmans *et al.*, 2013)
Mokolo & Matlabas		WRC Case study for Manual (Dennis *et al.*, 2013)
Mvoti–Umzimkulu Classification Project	Water resource classes proposed for Mvoti and Umkhomazi catchments Groundwater, Wetlands, River and Estuary RQO determination Public meeting planned for October 2015	DWS (2015a, 2015b)
Olifants-Doorn	Water resource classes gazetted October 2014 Legal notices containing both classes and RQO were published for a further 60-day consultation RQOs are currently legally reviewed	GEOSS Technical Report (DWA, 2012a)
Olifants and Vaal RQO Project	Draft RQOs have been determined Now prepared for gazetting for 60-day public commenting period	DWS (2015a, 2015b)
Incomati Classification and RQO Project	Draft water resource classes and RQOs have been determined Public meeting March 2015 RQOs prepared for gazetting for 60-day public commenting period	DWS (2015a, 2015b)
Letaba Classification and RQO Project	Draft water resource classes and RQOs have been determined Public meeting June 2014 RQOs prepared for gazetting for 60-day public commenting period	WSM Leshieka Report (DWS, 2014)

[a]Interdepartmental Inland Ecosystem Liaison Committee Meeting (April 2015).

In line with the progressive decentralization of water resources management as foreseen by the NWA, monitoring and assessment should also address these different levels of management.

Beside data acquisition, good progress has been made with data management and storage, and information generation and dissemination. The relevant national information systems are fully in place. Quarterly reporting takes place in two of the regions and an annual National State of Water Resources Report was initiated in 2007 and has appeared regularly since 2011/2012. There are currently (2015) 1,954 active groundwater monitoring stations (compared to 1,631 for surface water). In 2008, there were 1,836 active stations. While monitoring of rivers and dams has started around a hundred years ago, only a few groundwater-level records are longer than 40 years. The map of national groundwater-level monitoring stations (see Figure 5) still shows large blank areas and investment into groundwater monitoring is about 15% of that for the surface water network (DWAF, 2004).

The groundwater quality monitoring programme started in 1994 (see Figure 6) to determine the time series and spatial trends in the groundwater quality on the national scale. Monitoring points are sampled twice a year, that is before and after rainfall season (October and April). By 2014, there were 311 active monitoring points.

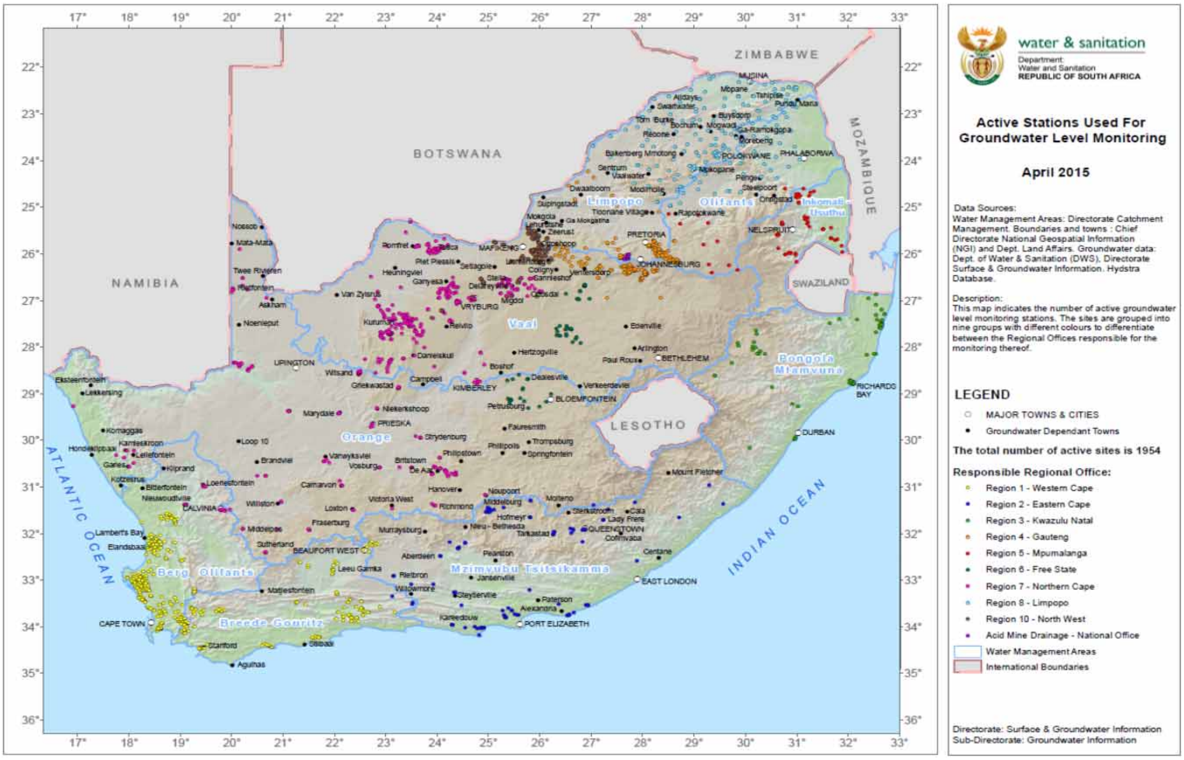

Fig. 5. | Active groundwater level monitoring sites – 2015.

Some of the strategic actions foreseen in terms of more systematic and integrated monitoring envisaged in the 5-year Monitoring Plan (DWAF, 2004), namely an integrated monitoring plan for each WMA and an overall monitoring governance model involving key stakeholders, are starting to be realized in some of the regions.

In the Limpopo Region, an Integrated Regional Monitoring Committee has been established. The purpose of the different networks has been spelled out. They are a mix of:

- National level (largely unimpacted areas) and
- Regional level (protection and regulation focus).

The observation network is expanded every year by means of a special drilling programme (the Region has its own drills for this purpose).

In the Western Cape Region, both baseline (unimpacted) and management support monitoring are undertaken. This includes, *inter alia*, focus on aquifers with large irrigation abstraction, with seawater intrusion potential and with contribution to river base flow. Both regions undertake systematic reporting on a quarterly basis.

One special off-shoot from this monitoring programme, which has been completed in two time slots (1999–2000 and 2007–2008), is the hydro-chemistry sampling/analysis of the National Dolomitic Eyes of South Africa. The intention to monitor aquifer-dependent ecosystems has not been put into practice yet. The integrated and user-focused monitoring of water resources, as foreseen in the 5-year monitoring plan, has not yet taken off, largely because integration was to take place at the catchment level, whereas the

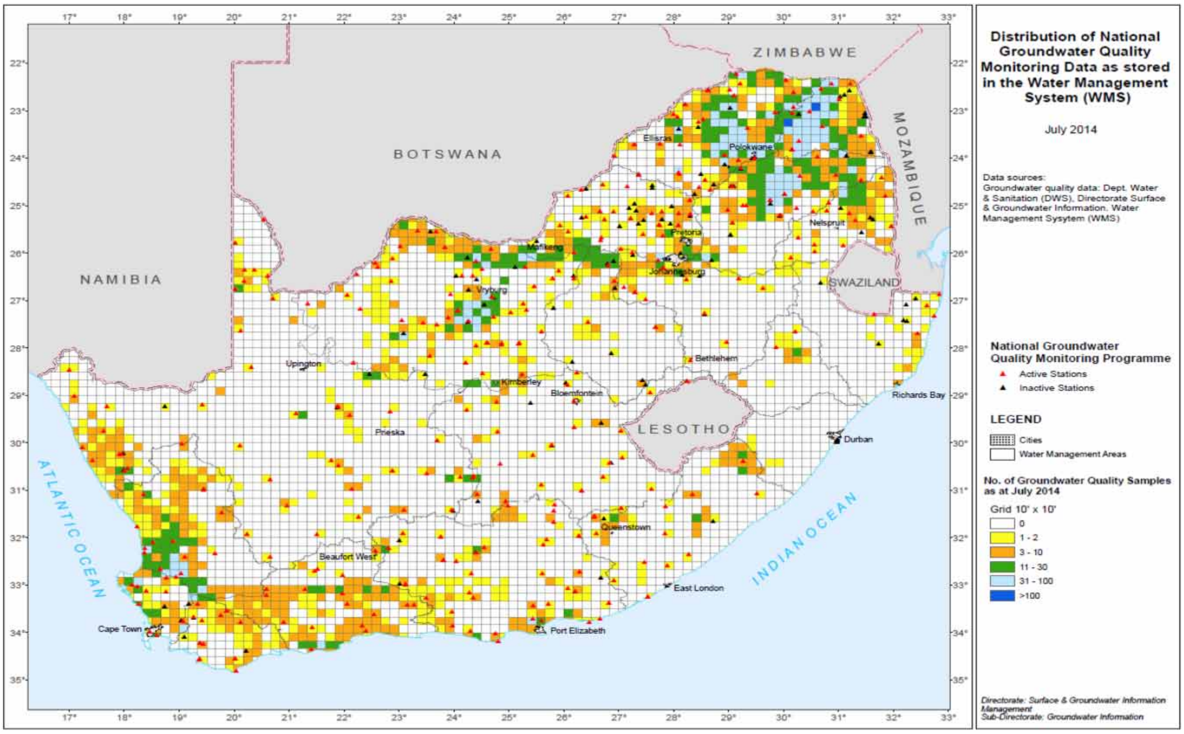

Fig. 6. | Active groundwater quality monitoring sites – 2013.

CMAs that were to lead this process are only just starting to be established. This is also the reason why the groundwater resources monitoring is poor in some regional offices of the DHSWS and strong in others. A good development is the publication of an annual report on the State of Water Resources, based on the various monitoring programmes (DWA, 2012b). The Department is presently undertaking a project review to achieve the optimization of the water resources monitoring networks, including groundwater resources networks.

5. ASSESSMENT OF PROTECTION MEASURES

5.1. Groundwater governance

Some of the technical failings of the groundwater RDM (GRDM) process to be touched on below must be seen within a bigger frame of groundwater governance in South Africa. Previously, neglected groundwater resources in South Africa benefited greatly by being incorporated into the excellent IWRM framework legislation created through its NWA, 1998. However, it soon became apparent that groundwater also requires a unique governance approach, because of its ubiquitous nature and relative ease of local access, with widely distributed and generally dispersed abstraction points and many stakeholders, who are involved in its development, use, as well as misuse. A recent review of groundwater governance defines it as (Villholdt *et al.*, 2018): 'Groundwater governance is the framework encompassing the processes, the interactions, and institutions, in which actors (i.e. government, private sector, civil society, academia etc.) participate and decide on management of groundwater within and across multiple geographic (i.e. sub-national, national, transboundary, and global) and institutional/sectoral levels, as applicable.'

Groundwater governance in South Africa has been assessed as weak to non-existent (Knüppe, 2011; Pietersen *et al.*, 2012; Seward, 2015). It is in particular the local level institutions that are still missing in South Africa. A generally recognized factor that must drive sustainable groundwater utilization is the participation of local water users and other stakeholders. Despite the good intent of the NWA, 1998, this critical requirement is still completely missing for groundwater resources. Groundwater's previous 'private water' nature still plays a major role in its lagging far behind the institutional development for surface water resources. No aquifer forums or CMA forums exist. The national will to overcome these problems and establish participative management for groundwater has so far been lacking (NGS, 2017).

Following participation in the foundational global project 'Groundwater Governance – A Global Framework for Action (2011–2014)' (FAO, 2016) to improve governance worldwide, South Africa adopted the 'Strategic Framework for Groundwater Governance' (Wijnen *et al.*, 2012) emerging from this initiative for its National Groundwater Strategy (NGS, 2017). Beside the Policy and Strategic level provided through national government, it includes a strong focus on the local level: organizations and institutions that control actual outcomes on the ground and respond (in varying degrees) to the rules and incentives from strategic-level governance. This level includes the individual groundwater users, local collective management institutions and relevant public agencies (Wijnen *et al.*, 2012; NGS, 2017). This is in line with global review findings of a need for co-management, i.e. a joint exercise of decision-making by a diversity of actors that go beyond conventional management by national government and its associates (Molle & Closas, 2019).

In order for local governance to improve, there needs to be a shift from the perception that groundwater governance can be 'fixed' by a once-off intervention, to the understanding that it is an ongoing and organic process. The requirements and commitment needed to realize good groundwater governance are daunting. There is a strong case for only attempting to improve local governance when and where there is a very strong need to do so, and essentially treating the remainder of the country's groundwater as a *de facto* private good. This is in line with the international understanding that moves to co-management of groundwater are usually triggered by dialogue over a real shared problem, like pollution or declining water levels getting out of hand in certain aquifers (Molle & Closas, 2019).

5.2. State of groundwater resources

The integrated and user-focused monitoring of water resources, as foreseen in the 5-year monitoring plan, has not yet taken off, largely because integration was to take place at the catchment level, whereas the CMAs that were to lead this process are only just starting to be established. A good development is the publication of an annual report on the State of Water Resources, based on the various monitoring programmes (DWA, 2012b). Some observed trends are described in the 2013/2014 State of Water Resources Report:

- In KwaZulu-Natal Province, a gradual declining trend in groundwater levels is observed (as a result of extensive plantation of Eucalyptus mainly in the coastal regions).
- In Limpopo Province, groundwater levels are well above historical levels as a result of good recharge in 2013; however, local deviations from the general trend are present in some places due to over-abstraction and/or a combination of factors.
- Groundwater in the important Karst aquifers in South Africa is under pressure from over-abstraction, indicated through a significant drop in water levels and spring discharges.
- Increasing nitrate levels are observed in three of the nine provinces and may be as a result of human activities, such as agriculture, industry and domestic effluents.
- Some of the southern cape coastal areas have consistently shown high salinity levels, which could be attributed to seawater intrusion and in other cases to agricultural activities.

In general, local impacts, like mining and industrial activities, are not visible in the national scale monitoring networks. Similarly, responses to any RDM actions cannot be observed yet. Only regions, which are already monitoring on a more local scale, have started to actively address regulation and protection needs. The Western Cape quarterly monitoring report (February 2015) provides examples:

- Over-abstraction in parts of the Sandveld and Klein Karoo with only localized impact has led to recommendations for monitoring committees to collect data and find source management solutions.
- Over-exploitation of the Vanrhynsdorp aquifer has led to the national Directorate Geohydrology providing support with monitoring and advice with management. No further groundwater-use licences are to be issued in the stressed parts of this aquifer.
- Groundwater levels in the primary aquifers of the Berg WMA near Langebaan are declining. Among improved management measures, the verification of groundwater use and the termination of any illegal groundwater use are recommended. Comprehensive Reserve determination, classification and development of a management plan are recommended to ensure that the aquifer is optimally used, taking into account the societal and ecosystem needs.
- The expansion of monitoring networks into new areas, where groundwater development is expanding (e.g. Kalbaskraal and in the Berg WMA) and where Reserve studies indicate aquifers, may be stressed (e.g. Gouritz WMA). Expansion into the Karoo, with high dependence on its sedimentary rock groundwater resources, is essential, in preparation for a more informed consideration of possible shale gas development.

5.3. Scientific methodology

The main finding has been that the whole RDM processes, i.e. the Reserve, Classification and RQOs, are completely defined and executed with a surface water environment focus. The specific water service role of groundwater resources and its management needs (including resource information requirements) are not yet addressed. Groundwater resources are just seen as a contributor to surface water systems, and all the protection focus are on these and not on the groundwater resource itself.

Before GRDM was systematically implemented as part of catchment-wide RDM implementation since 2012, most of the groundwater Reserve determinations have been undertaken separately, as part of licence applications and not as part of the ecological Reserve determination. Most such Reserve determinations, especially at Rapid and Intermediate levels, have just remained numerical values, produced at considerable expense, but without any practical consequences.

RQOs, which provide the opportunity to address the protection of important groundwater sources, have to date only been addressed via an 'Ecological Reserve' determination, assessed by an estimate of groundwater's contribution to river base flow. The BHN Reserve, which is to protect groundwater sources for community water supply, has to date only been expressed as a water requirement (a very small volume), which can only be controlled if relevant RQOs are set. This has not happened yet, and thus the BHN Reserve determinations have had no practical outcome for groundwater source protection. This must be seen together with the fact that groundwater source protection zoning, originally seen as the highest priority protection measure for domestic supply sources, has to date not been implemented anywhere.

The scientific methodology itself clearly lacks a much greater hydrogeological understanding of the aquifer than the present volumetric approach, assuming a uniform groundwater bucket over the whole quaternary catchment or another unit into which the catchment is divided. Experience has shown that specific protection objectives can only be achieved through specifications more detailed than average volumetric restrictions, over a whole resource unit, i.e. restrictions regarding where the abstraction can take place (distance from river, wetland or other boreholes) as well as setting minimum water level gradients.

A more integrated understanding of aquifers as hydrological systems in terms of recharge/discharge and ecosystem linkages, in both space and time, is crucial for such an approach. This would require a new investment into aquifer information and groundwater monitoring. In the drier parts of the country where there is no baseflow in rivers, no ecological Reserve based on groundwater can be determined, hence the Reserve cannot be utilized as a groundwater management tool. Moreover, the Reserve cannot be used to protect terrestrial ecosystems dependent on groundwater, as it only applies to aquatic ecosystems.

Simpler, spatially-based approaches (as an alternative to the recharge balance approach) are available to enable practical protection, which have not been applied to date. A radius of influence methodology was shown to be scientifically practical to provide plausible results and to be permissible under the country's water law (Seward *et al.*, 2015). The RDM process takes into account inputs by stakeholders. However, the case studies showed that participation has been very limited to date. This shortcoming relates to the overall groundwater governance failures.

5.4. Implementation of protection measures

Water-use licensing has at this stage proved to be the best way to provide practical water-use licence conditions including abstraction thresholds, abstraction and water level monitoring, compulsory membership of monitoring committees/WUAs, once established. None of such conditions have so far come through the RDM process.

Licensing of activities that can impact water resources, e.g. effluent disposal, appears to be the most important protection tool for groundwater. Vital source-directed control action has come about through legislation other than the NWA. The National Environmental Management Act, 1998 (NEMA) has been a crucial instrument for preventing or minimizing various forms of high impact on groundwater, e.g. from waste disposal sites, coal mining and petrol filling stations (Adams *et al.*, 2015).

At this stage, compulsory licensing of water use in terms of the Act has not yet been implemented, even in groundwater-stressed areas. This measure is very important, because groundwater was only declared public water with the coming of the 1998 Act and is thus still widely under-registered or non-registered. Also, the groundwater-use registration process did not yet achieve adequate information on the national water-use database. To achieve information on which sustainable management can be undertaken will be a long-term undertaking. It took hydrogeologists from a DWS regional office over a year to unofficially verify the use from widely distributed boreholes in one local municipality area (van Rhynsdorp). The verification of groundwater use as well as licence compliance monitoring should be taken on without delay. This information is at this stage seriously missing for the water resource planning and further licensing processes. In the implementation, priority should be given to the most stressed and most vulnerable aquifers.

Country-wide implementation of the intentions of the NWA, 1998 will depend on the existence of effective regional and local institutions and a strong regulatory framework. At this stage, there are still many problems with the establishment of these institutions, in particular, CMAs and WUAs. Much has to do with political processes to overcome inequities of the past. Because of this lack of regional/local institutions, there is large pressure on DWS regional offices, which have to play the role of proto-CMAs, which are already stretched in terms of groundwater specialist capacity.

5.5. Available geohydrological data and information

The implementation of RDM in South Africa is constrained by the available geohydrological data and information. Table 6 provides a summary of the present situation.

Table 6. | Available information systems/groundwater datasets in South Africa.

Information system	Held by	Data type
NGA	DHSWS	Borehole point data from 260,000 sites
HYDSTRA	DHSWS	Groundwater-level monitoring data
WMS	DHSWS	Groundwater quality monitoring data
WARMS	DHSWS	Groundwater-use information
GRIP	DHSWS (only in some regional offices	Borehole infrastructure information
ArcGIS Geodata	DHSWS	Spatial data, largely based on a 1:500,000 Hydrogeological Map series covering the country and produced from the above data sources
Private sector	Various companies	Datasets from a large number of groundwater-related projects

Data and information have become much more readily available since the Phase 1 Groundwater Resource Assessment (GRA 1) in 2003. However, a large amount of data held by the private sector, and more recently also by local government, is not yet available for general use.

In an outline of a future improved Groundwater Resource Assessment (GRA 3), the authors recommend a greater focus on representing and analysing groundwater data as part of IWRM and for increasing the quantity and availability of groundwater data in South Africa. Ensuring the submission of data by the private sector to public databases is a vital issue that can be carried out relatively easily and cheaply by requiring drilling contractors by regulation to routinely supply details of boreholes drilled to DWA in line with common practice in many other countries. Specific recommendations were also made to improve the monitoring of groundwater systems, both in terms of spatial coverage and for improved estimation of aquifer properties (Witthueser *et al.*, 2009).

Key geohydrological parameters in any licence application, groundwater recharge and groundwater contribution to baseflow (as well as to other groundwater-dependent ecosystems) still have very high uncertainty (Dennis *et al.*, 2013). Abstraction information, which was non-existent in the past, has improved through the water-use registration process but still needs to be systematically monitored and made available on the WARMS information system. There is thus an element of 'adaptive management' inherent in all groundwater schemes. Management monitoring, stipulated in RQOs, should thus become a critical part of RDM and Reserve determination.

6. CONCLUSIONS

There have been dramatic changes for groundwater resource development and management since South Africa's transition to democracy in 1994 and landmark water-sector reforms. Groundwater became the main source of supply in the major community water supply drive in which approximately 27 million people in South Africa had gained access to improved water supply by 2013.

The strategic role of groundwater was also recognized in policy and strategy. With the promulgation of the NWA, Act 36 of 1998, groundwater lost its previous status of private water and became public water and a 'significant resource'. In terms of the IWRM vision of the Act, all the rules by which water resources were to be conserved, protected, managed and controlled in an integrated manner now also applied to groundwater.

The registration of all water uses in terms of the NWA, including groundwater, has for the first time provided a country-wide picture of groundwater use per economic sector. At the same time, national hydrological mapping and assessment programmes had provided readily available and understandable country-wide information about groundwater occurrence and development potential. This information, together with a much better understanding of the role of groundwater, has helped to establish groundwater in the national planning function in terms of improved strategy, plans and feasibility studies.

Progress with developing groundwater-specific regulation within the framework of the NWA has been lacking. This is largely because the unique characteristics of groundwater are not adequately addressed in the surface water-focused management instruments, which are provided for the protection of water resources. This has become particularly clear in the roll-out of the RDM process as the NWA's instrument for water resource protection.

Before the classification of water resources was systematically introduced in various catchments in 2012, the key RDM process was mainly concerned with Reserve determination in support of water-use licensing. Since then, a considerable investment in terms of finances and expertise (mainly consultants) has been made with the inclusion of groundwater into the RDM roll-out in catchments. In 2013/2014 alone, over a thousand GRDM assessments had been carried out.

A conclusion that can be drawn up to that point of RDM implementation is that groundwater resources *per se* are not yet protected by these extensive measures. The whole focus is on the ecological Reserve and its ecological specifications, which are at this stage only defined for surface water resources. Already in the resource classification, catchment units are described in ecological categories and RQOs are expressed as numerical values, with no attempt to provide objectives that can be measured and can thus be put as licence conditions to control groundwater resource use and impacts.

As for the BHN Reserve component (which is to protect groundwater sources for community water supply), the outcome has only been numerical, small volumes that need to be reserved, with no practical outcome for groundwater source protection. Thus, groundwater sources for domestic supply have received no regulated protection to date, despite having been accorded the highest protection status in terms of national policy.

GRDM methodology will need a completely fresh focus on the unique hydrogeological characteristics of groundwater systems, supported by appropriate resource information. Attention will also have to be paid to the inclusion of unique groundwater-dependent ecosystems into RDM. Such methodology revision will have to be reflected in a related groundwater resource information strategy with emphasis on exploration, assessment and monitoring.

The lack of appropriate regulation is reflected in the generally poor management of local groundwater by municipalities as part of their water services responsibility. The tendency is also to only turn to groundwater as a last resort. The problem is a lack of capacity in municipalities as well as a systemic lack of support and regulation, where necessary, from national government.

One of the critical success factors for groundwater resource protection will be groundwater user/stakeholder participation. At the heart of it will have to be a political will to establish good groundwater governance through the co-management of groundwater resources through appropriate forms of shared decision-making by a diversity of actors at both national and local levels and to invest into an ongoing and organic process in this regard.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 14 January 2021; accepted in revised form 3 March 2021. Available online 9 June 2021