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Using sustainability indicators as a basis for classifying groundwater in South Africa

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Abstract Under the South African Constitution, everybody has a right to an environment not harmful to their health and wellbeing; to have an environment protected for the benefit of present and future generations; and to have access to sufficient food and water. The main responsibility of the Department of Water Affairs and Forestry (DWAF) is to ensure sufficient water of an acceptable quality is available to meet basic human needs, and to support economic and social development. South Africa is not a water-rich country and, as a result, water has to be managed and used wisely. Under new legislation, water management in South Africa is now based on three key principles, namely sustainability, equity and efficiency. The National Water Act (Act 36 of 1998) (NWA) requires water to be set aside for environmental and basic human needs before allocation for other uses. A key mechanism to achieve this is classification of water resources. A classification system for groundwater resources is currently being developed. While trying to integrate the groundwater classification system with those of other components of the hydrological system (rivers, wetlands and estuaries), indicators are being used to identify the point at which groundwater use is no longer sustainable. Potential indicators being considered include sinkhole formation, saline intrusion, decrease in river and spring flow, and vegetation die-off. Observation of any of these conditions requires the resource be classified as a D category or worse, thereby requiring management intervention to modify use to within sustainable limits.

Key words classification; groundwater; indicators; sustainability

INTRODUCTION

Under the South African Constitution, everybody has a right to an environment not harmful to their health and wellbeing; to have an environment protected for the benefit of present and future generations; and to have access to sufficient food and water. The main responsibility of the Department of Water Affairs and Forestry (DWAF) is to ensure sufficient water of an acceptable quality is available to meet basic human needs, and to support economic and social development. South Africa is not a water-rich country and, as a result, water has to be managed and used wisely. Under new legislation, water management in South Africa is now based on three key principles, namely sustainability, equity and efficiency. The National Water Act (Act 36 of 1998) (NWA) requires water to be set aside for environmental and basic human needs before allocation for other uses. A key mechanism to achieve this is classification of water resources. This paper describes the new legislation in general, and focuses on classification of groundwater using sustainability indicators. Attention is only given to quantity issues, as other provisions of the NWA address groundwater quality.

NATIONAL WATER ACT

Following democratization of South Africa in 1994, water legislation in the country was given a complete overhaul. This resulted in promulgation of the National Water Act (Act 36 of 1998). The NWA required a number of changes to be made to the management of water resources in South Africa. This was particularly true in the case of groundwater, which shifted from being a private resource to a public resource. The NWA, which provides a legal framework for the effective and sustainable management of South Africa's water resources, is founded on principles of sustainability, equity and efficiency (DWAF, 2004). The National Government, acting through the Minister of Water Affairs and Forestry, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable, equitable and efficient manner, for the benefit of all persons and in accordance with its constitutional mandate. To do this, the Department of Water Affairs and Forestry must consult widely with all interested and affected parties, and consider relevant environmental and socio-economic factors.

The Act recognizes two basic rights to water, namely the Reserve and Schedule One Use. The Reserve comprises two parts, namely the ecological component and the element relating to basic human needs. It is the responsibility of the Minister of Water Affairs and Forestry to ensure sufficient water from a resource is available to meet basic human needs and the needs of the ecological reserve before allocating water to meet other obligations and water users. Schedule One of the Act entitles a person to use water in or from a water resource for purposes such as reasonable domestic use, domestic gardening, animal watering and fire fighting without having to register that use or apply for a license.

The Reserve is one of five legal decision-making tools provided by the NWA to attain a balance between protecting and using water resources. Other tools are Classification of Water Resources, Resource Quality Objectives (RQOs), Source-directed Controls (pollution prevention and remediation) and mechanisms to manage emergency incidents. The two latter tools—not addressed further in this paper—aim to control and manage impacts that result (or could result) from the use of a water resource and adjacent areas in terms of pollution (disposal of effluents) and over-use of water resources (abstraction of water). Classification, the Reserve and Resource Quality Objectives target the protection of the health of a water resource, and are collectively described as resource-directed measures (RDM). These address the quantity and quality of water in a water resource, the animals that live in that resource, and vegetation in and around the resource. It is now generally recognized that the Reserve in itself provides little protection to groundwater resources, except in instances where groundwater supports or sustains basic human needs or aquatic ecosystems. However, collective use of Classification, the Reserve and RQOs provides a powerful mechanism to protect groundwater resources.

CLASSIFICATION

The NWA requires the Minister to develop and use a classification system to determine the class of all or part of the water resources considered to be significant. The class of a resource forms the basis for setting the Reserve and RQOs. Provision is made in the Act for preliminary determinations of the class of a water resource before the formal classification system is established. This allows methods and tools to be developed simultaneously with implementation of the Act.

The class of a resource is to be set by water resource managers, technical specialists and stakeholders in a catchment. In addition to water-related technical issues, consideration is also given to other elements such as social and economic factors during the catchment visioning, and public participation processes. This paper only considers technical considerations for classifying groundwater resources, as it is expected the process of classifying resources through stakeholder participation will be based on considerations such as economics, politics and social aspects.

In developing methods and tools for implementing the NWA, experience gained from setting instream flow requirements (IFR) formed the basis of the resource classification system (Tharme, 1996; Tharme & King, 1998). Reference conditions and the present state of a resource are assessed, and using a simple set of rules, the water resource class is set in terms of natural, good, fair and poor. This is terminology readily understood by non-hydrological specialists (Fig. 1).

In considering appropriate classification procedures, the NWA prescribed that limits of sustainability would mark the difference between what would be considered acceptable use and unacceptable use. Defining the point at which a resource is no longer used in a sustainable manner is generally difficult. The level of sustainability probably fluctuates over time, and impacts from over-use could manifest themselves only some time after the impact was caused. Further, the change from sustainable use to over-use is gradual, and not necessarily marked by some distinct change. Notwithstanding these problems, it was decided that those resources considered as being used at or about the limits of sustainability should be assigned a “D” category. Those resources categorized as being either an “A”, “B” or “C” are considered as being used sustainably, while those categorized as either “E” or “F” are over-utilised, and some corrective management action is required.

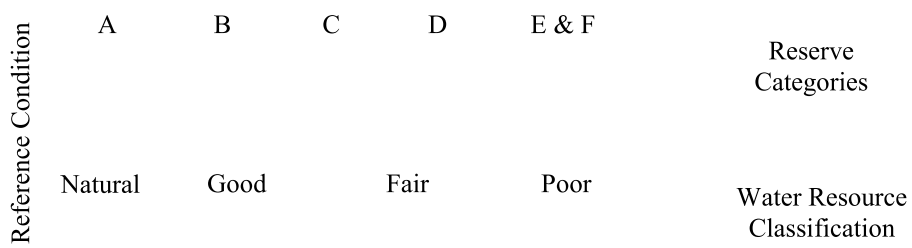

Fig. 1 Categories used in defining the class of a water resource.

SUSTAINABILITY

Sustainability is one of the guiding principles of the NWA, and the Act takes account of water needs of both present and future generations. The concept of sustainability is well recognized, but not particularly well defined and generally difficult to quantify. DWAF have interpreted that for something to be sustainable, it must help create economic growth; it must benefit all relevant parties equally (social equity); and it must not harm the environment (ecological integrity) (DWAF, 2004). Their slogan "Some, for all, forever" neatly encapsulates these principles.

In spite of being a guiding principle, sustainable water use is not defined in the NWA. By definition, sustainable water use implies ongoing use of water over an extended period of time. In setting levels of use, consideration needs to be given to current water needs and to those of future generations, as well as social, economic and environmental factors and the benefits of use. South Africa is unique, as water must be made available to citizens disadvantaged under the previous political dispensation, who did not have access to water. The National Environmental Management Act (Act 107 of 1998) (NEMA) defines sustainable development as "the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations".

The concept of a safe or sustained yield for aquifers has been widely used when assessing groundwater resources, both locally and internationally. Safe yield and sustainability are conceptually similar, and share the characteristic of being difficult to quantify. Bouwer (1978) defined safe yield as the "rate at which groundwater can be withdrawn without producing undesirable effects". He noted safe yield is equal to average rate of replenishment or recharge, but accepts this concept has been stretched beyond its hydrological meaning. More recently, the concept of safe yield and sustainability has been debated in the literature (Bredehoeft, 1997; Alley & Leake, 2004; Jacobs & Holway, 2004), with much of the argument requiring that we move away from regional water balance approaches, and focus more on local issues such as groundwater levels when considering sustainability.

Understanding the role of groundwater in sustaining the environment is still in its infancy. Promulgation of the NWA and its recognition of a unitary hydrological cycle have resulted in closer working relationships between surface water hydrologists and geohydrologists (Parsons, 2003); more detailed consideration of the groundwater contribution to baseflow (Hughes, 2004; Sami *et al.*, 2005); and consideration of ecosystems dependent on groundwater (Hatton & Evans, 1998; Brown *et al.*, 2003; Colvin *et al.*, 2003). As a result, the sustainable volume of groundwater available for abstraction has to be considered in a wider context than recharge and rates of abstraction.

SUSTAINABILITY INDICATORS FOR GROUNDWATER

Sustainability indicators are widely used to describe and measure the sustainable management of natural resources. Mannis (2004) noted the word for indicator in Arabic is "pointer". Indicators are statistics directed specifically towards policy concerns and pointed towards successful outcomes and conclusions of policy. They need to be understandable, in that they are clear, simple and unambiguous; conceptually well founded; limited in number; and dependent on data readily available or available at reasonable cost. Colvin *et al.* (2004) expanded on the need for indicators to be developed, understood and accepted by the community as the NWA requires the public be consulted regarding the use and management of water resources in South Africa.

In general, indicators are highly aggregated and dependent on the availability of good quality data and information. Examples of powerful and recognizable indicators include Gross Domestic Product (GDP), the Consumer Price Index (CPI), the adult literacy rate and the infant mortality rate.

Indicators specifically relating to groundwater are described by Fairweather & Napier (1998), Montaigne (2002) and others, and include depth to groundwater; various groundwater quality parameters; people, stock and crops supported by groundwater; and net amount discharged or abstracted. Godfrey *et al.* (2002) proposed core indicators for groundwater in South Africa that include intensity of use of groundwater; total groundwater used per sector; people dependent on groundwater resources; groundwater salinity; groundwater nutrients; and groundwater microbiology. Use of these proposed indicators will be hampered by a lack of data, spatial changes due to the heterogeneous nature of fractured rock aquifers prevalent in South Africa, and an inability to set sustainable thresholds.

Little reliable information exists regarding groundwater use in South Africa. Recent national estimates range between 1100 Mm^3 $year^{-1}$ and 3500 Mm^3 $year^{-1}$ (Hughes *et al.*, 2005; Rosewarne, 2005). Far more effort is required to reliably ascertain groundwater use in the country and monitor expected increase in its use. While reliable data are available at a local scale in particular instances, any nationwide indicator based on groundwater use must be treated with caution.

Approximately 98% of South Africa's aquifers are fractured and weathered in nature. This results in highly variable characteristics over a short distance. Groundwater quality can vary by an order of magnitude in less than a kilometer while hydraulic properties may vary by a few orders of magnitude across a dyke, fault or other geological structure. With this variation, it is difficult to develop indicators to reflect, for example, water quality across a groundwater resource.

Because depth to groundwater is easy to measure and monitor in a borehole, it may appear an obvious groundwater indicator—at least at a conceptual level. However, its use as an indicator is undermined by an inability to quantify limits of acceptable change. Depth to groundwater reflects a balance between inputs (subsurface inflows and recharge) and outputs (subsurface outflows and abstraction). If inputs are greater than outputs, groundwater levels rise until a new balance or equilibrium is reached. Conversely, when groundwater abstraction is initiated or increased, groundwater levels drop over a period of time until the level reflects the new balance. However, a lowering of the water level does not necessarily reflect unsustainable groundwater use, but rather a shift toward a new balance. An inability to determine an acceptable degree of groundwater level change before abstraction induces undesirable effects, and limits groundwater levels being used as meaningful indicators of sustainable use.

Good quality hydrological and environmental data monitored over a period of time are required before parameters such as groundwater levels, chemistry and abstraction can become useful indicators of sustainable groundwater use. To overcome current problems associated with a lack of good groundwater data sets, consideration is being given to using indicators that demonstrate when sustainable levels have been exceeded. These include sinkhole formation or subsidence, saline intrusion, reduction in baseflow or spring flow, vegetation die-off and emergence of groundwater supply problems or conflicts. While these indicators fail to provide early warning of impending problems, they do allow for a better appreciation of threshold levels—knowledge that could be used to good effect elsewhere.

STRESS INDEX

Notwithstanding earlier observations about the inaccuracy of information pertaining to groundwater use in South Africa, a Stress Index was adopted to guide the technical classification of groundwater resources in the country. The index is determined by dividing groundwater use in a particular resource unit by the estimated recharge to that unit. The present status category of the unit is then defined on the basis of the stress index (Table 1). The groupings used for classification were developed in consultation with experienced geohydrologists across South Africa. Opinions varied regarding the level at which to differentiate between sustainable and unsustainable groundwater use, but there was a degree of consensus that a level of 0.65 could initially be used. It was noted that the Water Systems Analysis Group at the University of New Hampshire (USA) developed a water stress index where they related population density to water availability (Montaigne, 2002). Highly water-stressed populations were defined as those that use more than 40% of the available renewable water.

Application of the Stress Index has suggested that the groupings used are at an appropriate and reasonable level. While some practitioners were uncomfortable about using the index because of the low level of accuracy in quantifying both groundwater use and recharge, the coarse and simple approach used allows for reasonable categorization of that resource. The index matches the characteristics of sustainability indicators described above, and allows the public to comprehend the resource classification and subsequent allocation mandated under the NWA. It was found useful to try to use other indicators to support the categorization determined from the Stress Index (Table 1).

It was earlier noted that impacts resulting from groundwater abstraction in South Africa have not been scientifically documented. It is crucial that this be addressed. The number of instances where groundwater is being used unsustainably appears to be limited in the context of the volume of groundwater used in the country. If

Table 1 Guide for determining the present status category of a groundwater unit using the Stress Index.

Present status category	Description	Stress index (abstraction / recharge)
A	Unstressed or low levels of stress	<0.05
B		0.05–0.20
C	Moderate levels of stress	0.20–0.40
D		0.40–0.65
E	Stressed	0.65–0.95
F	Critically stressed	>0.95

groundwater abstraction is having significant impacts that are not being detected, current allocation of groundwater may be too generous. Similarly, if impacts are not occurring, or only occurring in specific geohydrological settings, then current allocation may be favouring protection of groundwater resource to the detriment of promoting sustainable use. It is expected research into impacts resulting from groundwater abstraction in South Africa will contribute to an improvement in the understanding of the role of groundwater in the environment.

CASE STUDIES

Sinkhole formation and subsidence

Dolomitic aquifers cover about 3.3% of the area of South Africa but account for about 30% of the groundwater potential of the country (Kok & Simonis, 1989). In addition to abstraction for municipal supply and irrigation, large volumes of groundwater are abstracted from dolomitic aquifers to dewater mines. Sinkholes can form as a result of large-scale abstraction, sometimes with catastrophic and fatal consequences. Brink (1979) described increased occurrence of sinkholes on the Far West Rand in the mid-1960s as a direct result of mine dewatering, one of which claimed the lives of 29 people. Other examples include sinkholes forming in the vicinity of Pretoria and Bapsfontein. Increased and ongoing occurrence of sinkholes clearly points to unsustainable abstraction, with many of the reported problems of groundwater use in South Africa being associated with this geohydrological setting. While it is difficult to predict where and when sinkholes will form, once formed they are readily visible and hence can easily be used to indicate when sustainable limits of groundwater abstraction have been exceeded.

While subsidence of primary aquifers as a result large-scale groundwater abstraction is well documented (Venice, Mexico City, San Joaquin Valley), no such occurrences are known in South Africa. Unconsolidated primary aquifers only account for 1% of the area of South Africa and 2% of the groundwater potential of the country (Kok & Simonis, 1989). As a result, subsidence is unlikely to be a useful indicator in areas away from the east coast primary aquifer system and localized primary aquifers such as those found at Atlantis, Saldanha and Port Nolloth.

Saline intrusion

Saline intrusion is generally only applicable in coastal areas, but can also occur when two aquifers with different water qualities are juxtaposed. Because saline intrusion can readily be detected by taste and/or simple electrical conductivity field measurement, the ingress of saline water into an aquifer is a useful indicator of when sustainable limits have been exceeded. Examples of this exist at Robben Island (Parsons, 1998), Bushmans River Mouth (Reynders, 1984) and Struisbaai (Weaver *et al.*, 1999). In some cases, saline intrusion is the result of abstracting at too high a rate rather than exceeding the sustainable yield of the system. Saline intrusion is usually a localized issue and can be redressed through good aquifer management.

Reduction in baseflow and spring flow

Groundwater contribution to baseflow and springs is conceptually well understood, but difficult to quantify. Recognition by the NWA of a unitary hydrological cycle has forced a better appreciation of surface–groundwater interaction (Parsons, 2003) and much research is being undertaken to quantify and predict the contribution of groundwater to surface water bodies (Cleaver *et al*., 2003; Hughes, 2004; Sami *et al*., 2005). Because of the widespread gauging of rivers in South Africa, reduction in baseflow could be a potential indicator of unsustainable groundwater use. However, complex land use changes and building of impoundments usually mask the less noteworthy effects of groundwater abstraction. Two lengthy legal disputes relating to possible impacts to river flow as a result of groundwater abstraction illustrate this (Vermaaks River, Hex River), as both were settled out of court.

Large parts of South Africa are semiarid and the rivers ephemeral in character. While groundwater may not sustain baseflow in these environments (Fig. 2), discharge through seasonal springs is an only source of water for many rural and impoverished South Africans. Similarly, groundwater discharging into riparian zones and wetlands sustain ecosystems until the next period of rain. While few springs are monitored, visual observations and/or remote sensing suggests regular mapping of springs could be a useful indicator of unsustainable groundwater use. Lessons learnt by Cleaver *et al.* (2003)—that not all springs are groundwater fed—need to be heeded.

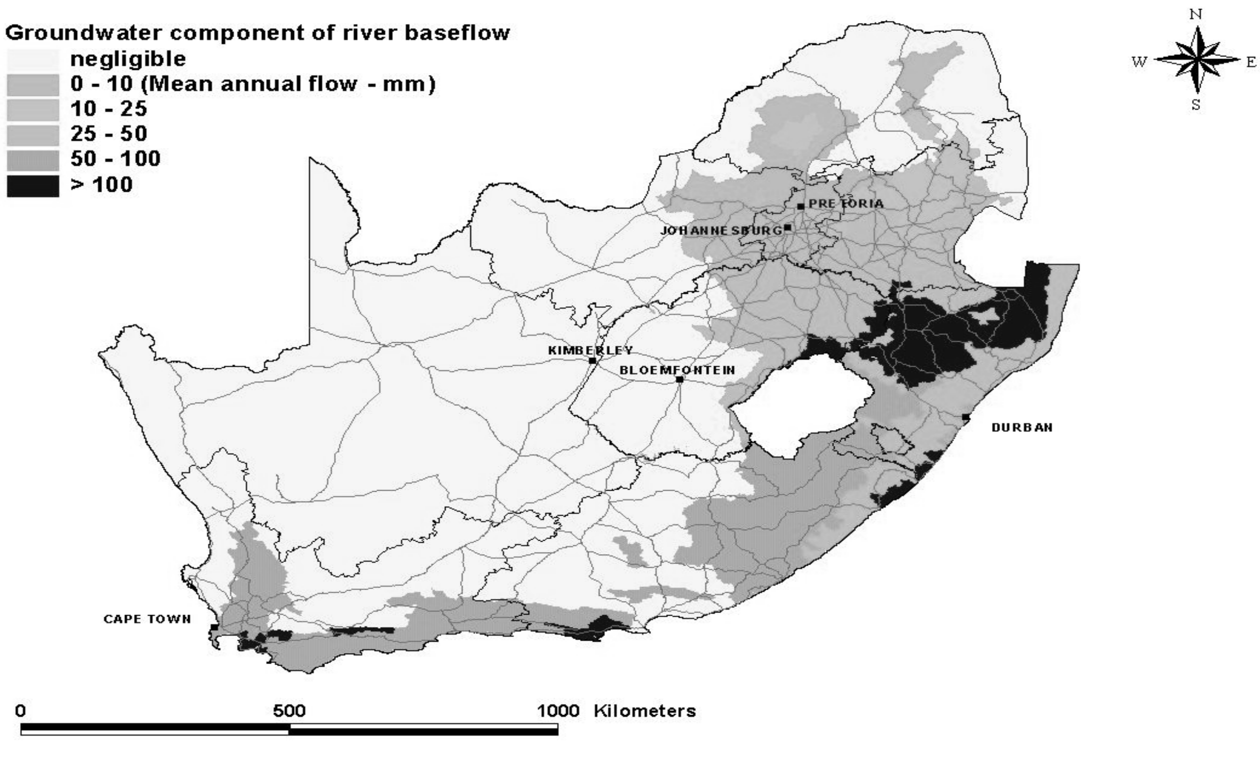

Fig. 2 Estimation of groundwater contribution to river flow by Vegter (1995).

Vegetation die-off

In spite of a lack of evidence that groundwater abstraction has had any significant impact on vegetation in South Africa, this issue remains a concern amongst the environmentally aware sectors of our community. Remote sensing and ground truthing could be used to monitor vegetation changes, thereby making them ideal indicators. Because much vegetation is not groundwater dependent or facultative in nature, few instances exist where it is suspected that groundwater abstraction has impacted vegetation. Scott & le Maitre (1998) reported a few anecdotal accounts of groundwater abstraction impacting on vegetation, but none were supported by measured and monitored data.

Establishment of a wellfield directly adjacent to the Wadrif wetland resulted in declining groundwater levels and a gradual drying of the wetland (Conrad & Munch, 2004). An electrical short at one of the pump stations resulted in a fire that ignited the drying peat layers in the subsurface and decimated the wetland and associated ecosystems. The fire burnt for almost two years and resulted in a 1–2 m lowering of ground levels. The Stress Index of the area was set at 1.22, resulting in an F or poor categorization. While illustrative, this case study is exceptional and few instances of vegetation die-off are expected. As a result, this indicator will probably not be particularly useful in identifying unsustainable groundwater use.

Emergence of groundwater-related problems

The emergence of groundwater-related problems could be used as an indicator of unsustainable groundwater use. Known examples include widespread reduction of borehole yields (Dendron, Tosca), steadily declining groundwater levels (Uitenhage) and increased levels of conflict between property owners (Hex River Valley, Koo Valley). The Stress Index of the De Doorns area in the Hex River Valley was set at 0.82, i.e. stressed with an E categorization. The high Stress Index was supported by observed lowering of groundwater levels and borehole yields during the hot, dry summer months. This leads to increased levels of tension and conflict in the Valley. However, the system appears to fully recovered by the end of the winter rain season.

While indirect, reduction in borehole yield (as result of a significant fall in groundwater levels) is usually apparent to groundwater users. Falling groundwater levels can be disastrous to those communities who tap their water from wells or shallow boreholes. Where such problems occur, management intervention is required. The NWA makes provision for compulsory licensing, during which all water authorisation is withdrawn, the resource re-assessed and water re-allocated in an equitable way that promotes sustainable use.

CONCLUSIONS

Promulgation of new water legislation in South Africa requires that water resources be used and managed in a sustainable manner. Classification is a key part of this process and a Stress Index has been adopted to facilitate classification based on technical considerations only. While the index is simple in nature and based on data known to have a low accuracy, it provides guidance regarding appropriate resource classification. This is particularly true when supported by other indicators. Absence of good groundwater data sets restricts the type of sustainable indicators that can be used. Indicators that demonstrate when sustainable limits have been exceeded have proved useful, but these lack any warning capabilities. However, they could prove adequate until such time that more data intensive indicators can be used.

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