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Integration goes underground: A review of groundwater research in support of sustainable development in South Africa

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INTRODUCTION

The groundwater group of the CSIR has led groundwater research in South Africa in three critical areas during the past three decades: nitrates in groundwater; groundwater for ecosystems; and artificial storage and recovery of groundwater.

NITRATE IN GROUNDWATER

South Africa is a water-scarce country and it is believed that current levels of consumptive use may be close to sustainable limits. It is estimated that groundwater supplies 15% of bulk water supply, around 10% of agriculture and over 50% of rural communities supplies (DWAF, 2004). Many remote and small communities use untreated groundwater. High nitrates in drinking water tend to be more common in groundwater supplies than in surface water supplies (Kempster, 2005). South Africa has some of the highest natural nitrate levels in the world (>500 mg/L N-NO3).

In South Africa, high nitrate levels in groundwater are the single most important reason for groundwater sources to be declared unfit for drinking, i.e. nitrate N exceeding 10 mg/L (Marais, 1999). In 1993, Tredoux reported that hydrochemical results held by the Department of Water Affairs and Forestry (DWAF) showed that 27% of groundwater abstraction points (approximately 5 000) in South Africa yield groundwater with greater than 10 mg/L NO3-N. These are shown in **Figure 1**.

High levels of nitrate in drinking water may cause methaemoglobinaemia or Blue Baby syndrome (WHO, 1993) and death of livestock. In the future the risk is expected to dramatically increase as a result of efforts to contain HIV (Colvin and Genthe, 1999). The South African Department of Health advises HIV positive mothers to bottle-feed infants to reduce the risk of mother to child transmission of the HIV virus via breast milk, if the water is safe to use. This reduces the risk of infant mortality as a result of Aids, but may expose infants to other risks from contaminated drinking water.

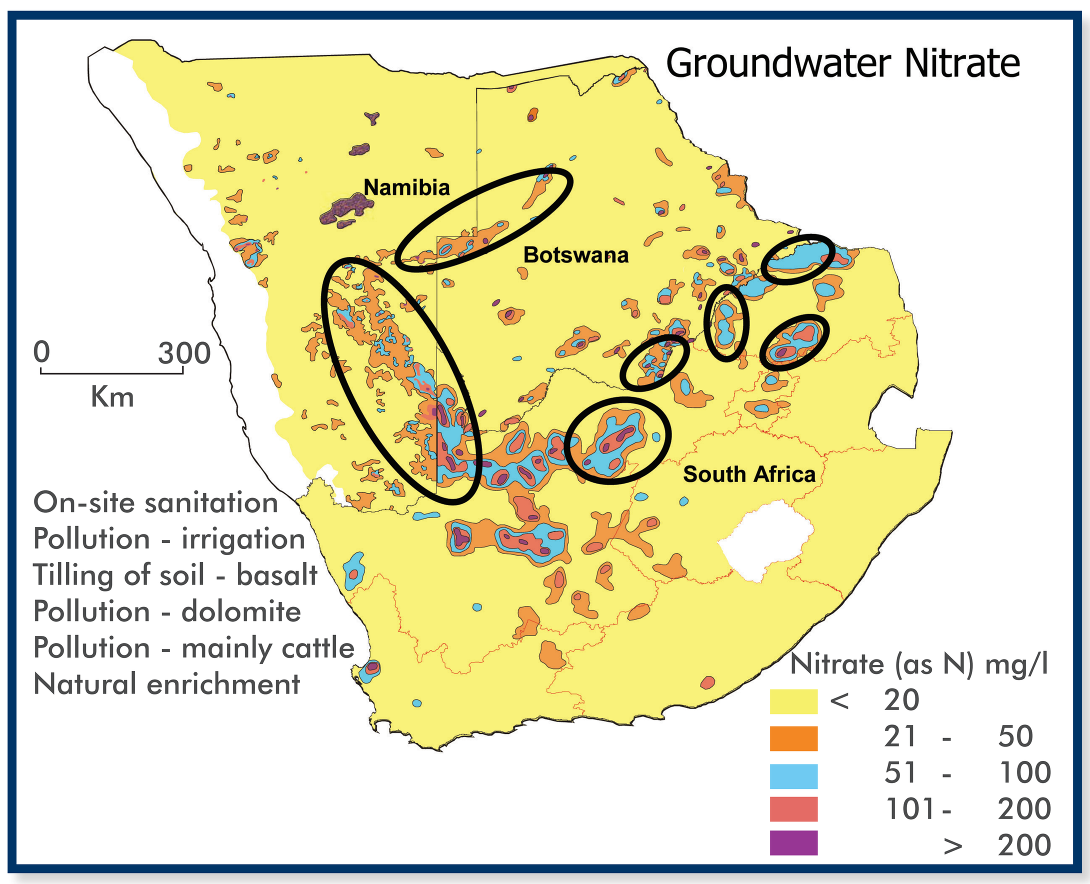

Figure 1: Location of areas of high nitrate in groundwater in the Kalahari basin and different causes of high nitrate

The distribution of nitrate in groundwater has been studied in Botswana, Namibia and South Africa. **Figure 1** shows a simplified map (Tredoux *et al.*, 2001) of areas where groundwater nitrate N exceeds 20 mg/L, i.e. twice the recommended limit of 10 mg/L set by the World Health Organization. Tredoux and Talma (2006) used the difference between ratios of nitrogen isotopes in specific environments to discern the sources of high nitrate in environments they studied. Conclusions based on their studies with regard to sources or potential sources of nitrogen pollution include the following:

1. In unconfined aquifers, nitrate concentrations can be highly variable over short periods as they are directly affected by recharge process (rainfall, infiltration etc.) as well as nitrate polluting activity.
2. Feedlots and dairy farming areas have a large potential for nitrate pollution if waste materials are not managed sufficiently. Such activities should be restricted to areas of aquifers that have impermeable layers to protect the groundwater resources.
3. Inappropriate on-site sanitation at rural villages and towns frequently leads to groundwater pollution by nitrate and the abandoning of well fields.
4. Low soil organic contents in the interior of South Africa limits the occurrence of natural denitrification, hence the persistence of nitrate in semi arid and arid savannah environments in southern Africa.

Current research is underway within the CSIR for various applications of denitrification technologies using slowly degradable carbon sources for denitrification. The CSIR is building capacity in this area and testing the application of this technology to enable the safe use of groundwater in rural areas currently affected by high nitrate levels.

AQUIFER DEPENDENT ECOSYSTEMS

If we are to use groundwater sustainably in the future we need to understand how ecosystems rely on natural flows of groundwater to springs, rivers and wetlands. Aquifer dependent ecosystems are often important in sustaining surrounding ecosystems: the oasis effect. **Figure 2** shows the riparian ecosystem on the Limpopo that remains green in the dry season, fed by groundwater in the alluvium. The groundwater group has looked at the wide array of groundwater-linked ecosystems in southern Africa and developed guidelines for their identification and protection within catchment management (Colvin *et al.*, 2007; Colvin and Saayman, 2006).

Figure 2: The Limpopo riparian aquifer dependent ecosystems uses water stored in the alluvial sediments long after the rains and surface flows have abated

Aquifer dependent ecosystems (ADEs) require groundwater from aquifers for all or part of their life-cycle to maintain a habitat with a water budget, or water quality, that contrasts with the surrounding ecosystems (Colvin *et al.*, 2007). ADEs occur through-out the landscape at various ecosystem scales. Examples of known South African ADEs include: in-aquifer ecosystems in the dolomites (North West province); springs and seeps in the TMG sandstone (Western Cape); terrestrial keystone species such as *Acacia erioloba* in the Kalahari; lakes and punctuated estuaries on the shallow sand aquifers of the east coast in KwaZulu-Natal; riparian zones in the seasonal alluvial systems of the Limpopo; seeps on the Karoo dolerite sills.

The identification of ADEs is often difficult and proving links between ADEs and aquifers often requires detailed, multidisciplinary observation and assessment. At a coarse national scale we can identify areas with a high probability of supporting terrestrial and aquatic ADEs, as shown in **Figure 3**. Probable vegetation classes have been identified from the National Biodiversity Initiative classification by botanists familiar with the different hydrological habitat and rooting habit of the different vegetation types (Colvin *et al.*, 2007).

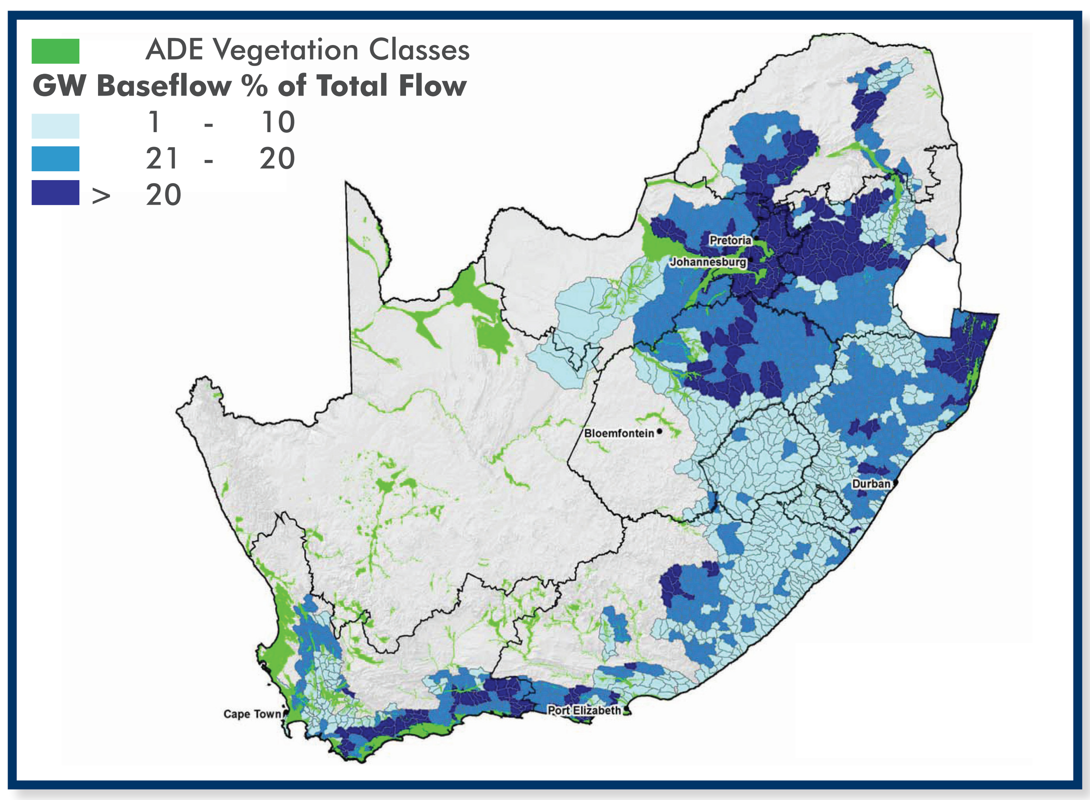

Figure 3: National scale indication of terrestrial ADEs (based on National Biodiversity Institute, NBI vegetation classes) and aquatic ADEs (based on GRAII calculated groundwater-fed base-flow as a percentage of total flows in quaternary catchments in South Africa)

The CSIR assisted DWAF in developing a policy to enable the protection of ADEs and sustainable management of groundwater. The policy proposes a new Aquifer Health Programme linked to the successful River Health Programme and Working for Wetlands. Initial focus areas will include monitoring and improving our knowledge of aquifer dependency and sensitivity to change; identifying ADEs at a catchment scale; informing desktop reserve determinations and resource quality objectives linked to groundwater licensing.

USING AQUIFERS AS STORAGE DAMS

In South Africa the rate of potential evaporation is high at between 1 500 mm along the cooler south coast and 3 000 mm in the dry interior. South Africa has a low mean annual rainfall of about 490 mm compared with a world average of about 860 and only 9% of this is converted to river run-off (Midgley *et al.* 1994). The risk of water losses and contamination in surface water storage dams is significant. Aquifers are often thought of as nature's dams – over 98% of terrestrial freshwater is stored underground.

Unused aquifer storage capacity can for the most part be developed at a significantly lower cost than surface storage facilities, and without the environmental problems frequently associated with surface storage. The overall costs of artificial recharge operations are often less than half the capital cost of conventional water supply alternatives. Artificial recharge schemes may be considered in areas where there are surplus surface water resources at certain times of the year and available unsaturated storage with sufficient permeability for injection and recovery. Opportunities for artificial recharge should also be considered in areas where evaporative losses from open water bodies are excessively high.

During the 1960s Windhoek experienced an acute shortage of water and the CSIR was directly involved in the development of the water reclamation system at Windhoek, which came into operation towards the end of 1968. In the 1970s, the CSIR and Israel collaborated closely on this topic and pilot scale artificial groundwater recharge of treated wastewater in the Cape Flats (Cape Town), towards the end of the 1970s, took place in parallel to the Dan Region Project of water recycling at Tel Aviv. The studies in the Cape Flats paved the way for the Atlantis artificial recharge project that started in 1980.

Research into nitrates in groundwater; groundwater for ecosystems; and artificial storage and recovery of groundwater.

Figure 4: A recharge basin at Atlantis well field, Western Cape, where artificial recharge is being implemented by the City of Cape Town, supported by the CSIR

The participation of the CSIR in the EU Project, 'Reclaim Water', centres on the Atlantis water resource management scheme. Artificial recharge of secondary treated domestic wastewater with urban stormwater runoff has been practised for more than 25 years. The Atlantis scheme faces several water quality management challenges, ranging from the control of saline water encroachment to industrial pollution threats and biofouling of production boreholes. On average, approximately 7 500 m^3 of water is recharged per day up-gradient of the well field while some 4000 m^3/d higher salinity industrial wastewater is treated and discharged into basins down gradient of the well field close to the ocean without further use for recharge. Hydrochemical monitoring of the various water sources has protected the overall quality of the system. Current research is looking at microbial contaminants and organic compounds and the risk that the potable water poses to immune-compromised individuals.

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