The challenges and implications of assessing groundwater recharge: A case study on Northern Sandveld, Western Cape, South Africa

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Abstract

The Department of Water Affairs and Forestry (DWAF) is currently carrying out detailed hydrogeological studies within the northern Sandveld area, Western Cape, South Africa. In addition DWAF funded preliminary studies have also been carried out in the area assessing hydrological, ecological and botanical components. The area is receiving much attention due to its environmental uniqueness (part of the area is a RAMSAR site) and its significant groundwater resources, which are being utilised for agricultural purposes and municipal water supply. In certain areas this groundwater abstraction is impacting on the surface water flows, groundwater and associated ecosystems.

In understanding the systems and their inter-relationships within the area, it is necessary to carry out water balance calculations. In carrying out such calculations, the quantification of the "input" component and associated temporal and spatial variability is important to address. With special emphasis on groundwater recharge, the area may be receiving both direct groundwater recharge, (as a consequence of precipitation), and distant groundwater inflow, via the large faults that transect the area, which may be importing groundwater from the inland recharge areas (i.e. the Cederberg Mountains).

One of the aims of the detailed hydrogeological study that is being carried out in the area, is to quantify both direct groundwater recharge and groundwater inflow into the study catchments. This paper outlines the setting of the project and the methods used to quantify direct recharge of groundwater in the northern Sandveld. It must be noted that the groundwater studies are not complete and the results presented here are still preliminary. The groundwater recharge quantification has huge significance for the Resource Directed Measures that are also being carried out in the area, in line with the requirements of the South African National Water Act of 1998. The Resource Directed Measures are aimed at ensuring water resource use and development is balanced by protection measures thereby guaranteeing the sustainable use of the resource.

Introduction

In order to optimally manage a groundwater resource that is being utilised, it is highly beneficial to carry out water balance calculations. One of the components of the water balance equation is the rate of groundwater input that needs to be determined. This input can be subdivided into three main components, namely: direct (vertical) recharge; recharge from river flow; and lateral inflow. For the study being carried out it is particularly important that the inputs be accurately determined.

The study area is located in the northern Sandveld, Western Cape, South Africa (see Fig. 1). The main reason for the area being studied is that it is a low rainfall area where significant groundwater abstraction occurs for both municipal and agriculture purposes. In addition, sensitive and important ecosystems in the area are showing varying degrees of impact. The objective of these studies is to understand the environmental linkages with surface and groundwater, and impacts resulting from groundwater use so management measures can be designed and implemented to ensure ongoing sustainable development of the area.

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It is particularly important to define groundwater inputs and especially direct recharge as significant economic benefit is being derived from groundwater usage by the agricultural sector, whilst the highly dependent ecosystems within the area are also very groundwater dependent and showing signs of being stressed and significantly impacted. Thus a balance needs to be sought between resource utilisation and ecological protection. De Vries and Simmers (2002) state that the quantification of groundwater recharge is a prerequisite for efficient and sustainable groundwater resource management in arid regions. They also state that recharge is defined in the general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir.

This paper discusses the main challenges associated with determining vertical groundwater recharge in an arid to semi-arid environment.

Background information

There are many references in international literature that state that groundwater recharge is one of the most difficult components of the hydrologic budget to quantify (Stephens and Knowlton (1986); Jackson and Rushton (1987); Cook and Kilty (1992); and Stone et al. (2001)). There is an increased difficulty in dealing with arid regions because of the variability of recharge with respect to time and space that is characteristics of arid areas (Verma (1979); Yair and Lavee (1985) and Simmers (1988)).

Natural recharge to an aquifer in an arid region may occur by various mechanisms, such as infiltration from the beds of ephem-

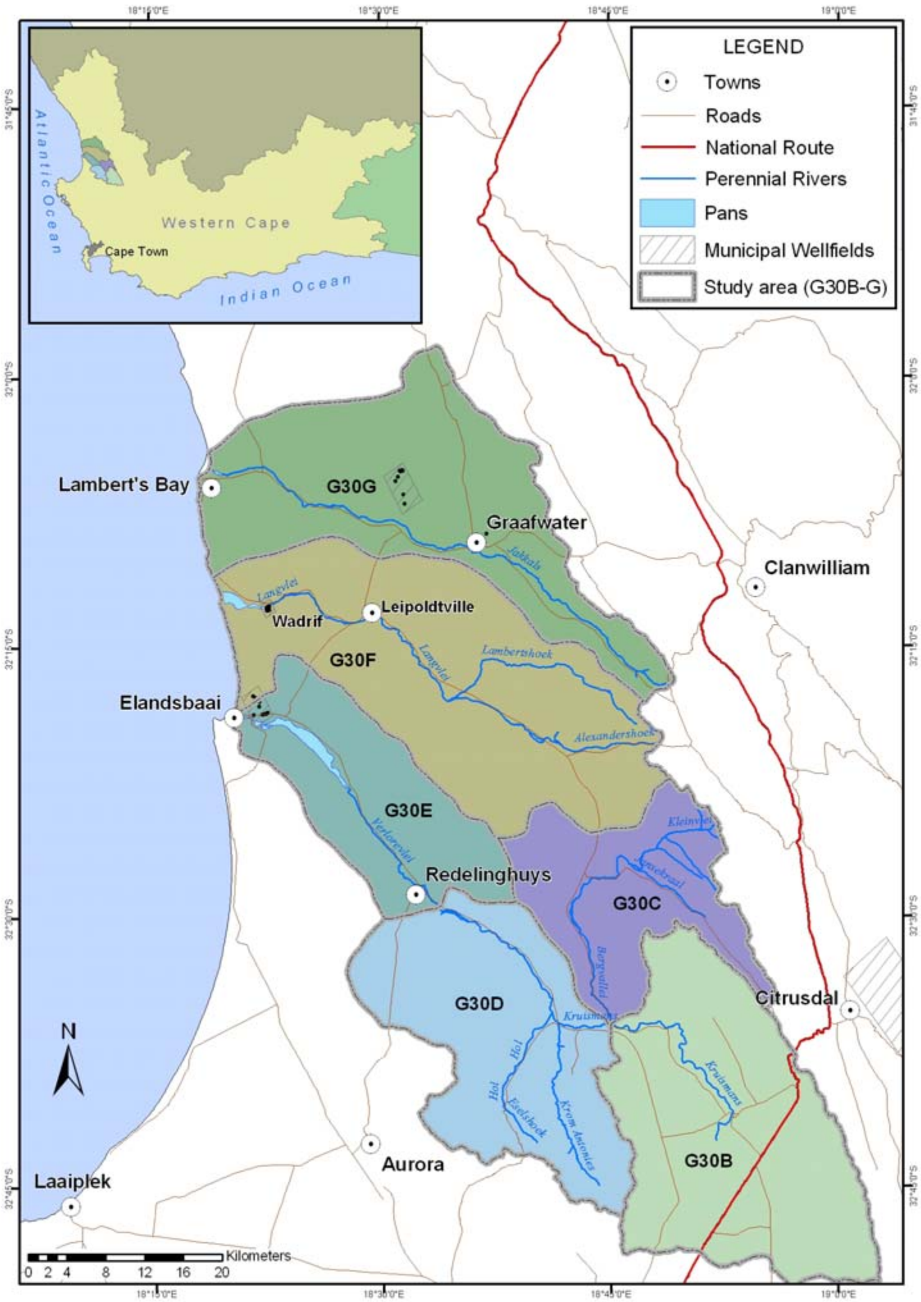

Figure 1
The study area, situated on the west coast of South Africa

eral rivers (Moench and Kisiel (1970); Besbes et al. (1978); Abdulrazzak (1983); Dillon and Liggett (1983); Lloyd (1986); Walters (1990); Sorman and Abdulrazzak (1993)), subsurface drainage from mountain areas through the alluvial material of valley beds (Khazaei, 1999) and the direct entrance of rainfall into the alluvial material of the lower plains (Dincer et al., 1974). In order to develop a successful recharge estimation approach for a region, the effects of all the mechanisms must be taken into account. To achieve this objective, Miles and Rushton (1983) and Simmers (1989) recommend a total catchment water balance approach. In this method all the factors affecting the recharge in the catchment, such as precipitation, evaporation, surface runoff, interflow, groundwater inflow and outflow, are incorporated (Senarath and Rushton, 1984).

With regard to groundwater recharge studies carried out on the South African west coast in the primary aquifers, a number of recharge values have been calculated. For the Atlantis area, Vandoolaeghe and Bertram (1982) used the water balance method to calculate a recharge rate of 26% of the rainfall (380mm/a). Bredenkamp and Vandoolaeghe (1982) calculated a recharge rate of 25% (rainfall of 380mm pa) also using a water balance method. They felt that a rate of 30 - 35% was not impossible. Bredenkamp (1982) modelled conditions at Atlantis and came up with a recharge rate of 21% of a total rainfall of 350mm pa.

Timmerman (1985) working between the Berg River and Elands Bay estimated a recharge rate of 15% in an area where the rainfall varies between 200 and 316mm pa. While investigating the Lower Berg River area Timmerman (1985) once again suggested 15% as the recharge rate (rainfall varies between 200 and 380 mm pa). In the Graafwater area (rainfall of 250mm pa) Timmerman (1986) assumed a "conservative" recharge rate of 8%. In the investigation at Strandfontein, Timmerman (1988) adopted a different approach - he stated that recharge would not occur on a yearly basis, but only sporadically. They suggested that recharge might only occur

At Elands Bay (rainfall of 196 mm/a) groundwater abstraction has been monitored for the last -2.5 years (late 1989 to 1992). During this period water levels have not dropped at all. Abstraction must therefore equal recharge. Calculations suggest a recharge rate of 12% per annum. This figure includes some horizontal inflow, although how much is conjecture (Jolly, 1992).

Gerber (1980) modelled the water balance on the Cape Flats aquifer (rainfall of between 600 and 750mm/a) and came up with a recharge figure of 40% for the dune area, although he did concede that this value did not take into account evapotranspiration of water that had already reached the groundwater level. Vandoolaeghe (1989) used a modelling exercise to calculate the exploitation potential of a hypothetical wellfield on the Cape Flats. During this exercise recharge was found to vary between 15 and 35% of rainfall.

Timmerman (1985), working on the Grootwater Aquifer at Yzerfontein (rainfall of 340mm/a) felt that 15% was the bottom limit for recharge to the aquifer. Baron (1990) working on the same area selected a more conservative figure of 10%.

Having presented all the above information it would appear that a vertical recharge figure of 8% is conservative for the primary aquifers of the west coast. Vegter (1995) indicated a value of 8% recharge for the Elands Bay area and 12% for the Lamberts Bay area.

However, there is literature that raises the possibility that the recharge percentage may be significantly less. Foster et al (1982) working on Ecca aquifers in the Kalahari (Botswana) calculated that during average rainfall years (450 mm/a) no groundwater recharge would occur in areas where the soil/ sand cover was deeper that 4 m. The rainfall would be stored in the sands and then evapotranspirated. Recharge would only occur in areas where the soil cover was thin or non-existent. Working in the same area Mazor (1982) however, refutes Foster et al (1982). Mazor (1982) maintains that water level measurements, and elevated tritium values prove that recharge does take place, although he ascertains that this is only in above-average rainfall years. He felt that preferential recharge zones exist within the sand cover, and recharge would occur, but with a time lag of up to four months, dependant on the sand thickness.

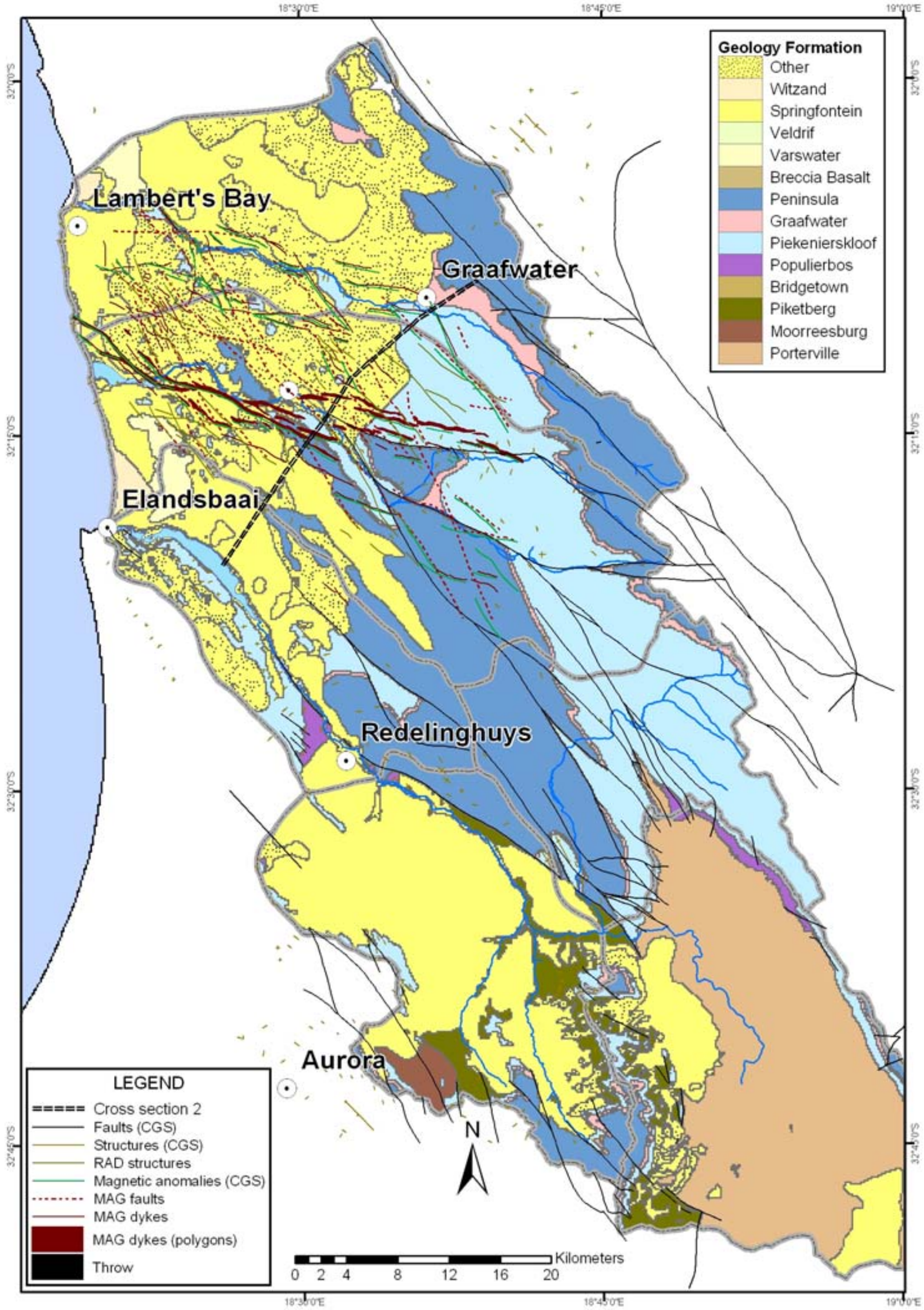

Figure 2
The main geological formations and structural features within the study area

Geological and hydrogeological setting of the study area

Geology

Basement rocks of the Malmesbury Group, Gariep Supergroup and Cape Supergroup underlie the Sandveld area. Rocks of the Malmesbury Group and Gariep Supergroup are primarily soft, easy weathering argillaceous rocks, whilst rocks of the Cape Supergroup form the Cedarberg mountain ranges on the eastern fringe of the Sandveld. Thick quartzose sandstones of the Table Mountain Group dominate the Cape Supergroup. Cenozoic deposits extensively cover the coastal plain.

The area has undergone a series of deformation events, resulting in the structural geology of the area having a NW-SE structural grain. The Sandveld is situated within the western branch of the Cape Fold Belt. Faults formed during the Mesozoic break-up of Gondwana have a similar orientation, but include a subsidiary WNW-ESE trend of fractures that were subsequently intruded by dolerite to form regional dykes. Most of the geophysical anomalies found during an airborne study may be explained in terms of known structural fabrics. However, this work revealed major, hitherto undiscovered faults and dykes that occur beneath the sand cover in several places (see Fig. 2).

Rifting of the Atlantic margin and subsequent drifting were followed by continuous erosion of the rock superstructure from about 120 Ma ago to the present. Several fluctuations of sea level during middle and late Cenozoic times produced the lowermost of the Cenozoic deposits in the Sandveld. Extensive Quaternary sand

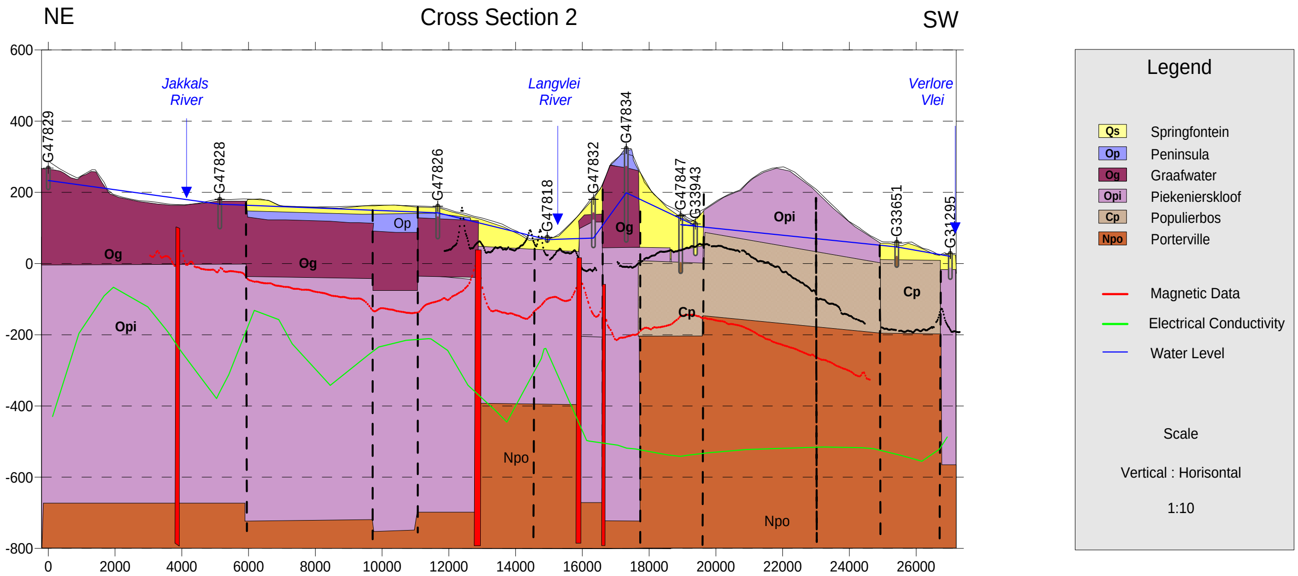

Figure 3

Hydrogeological cross-section, across the central portion of the study area (DWAF, 2004)[37]. Refer to figure 2 for the section line

deposits in turn cover these deposits.

Recently the Council of Geoscience reviewed the 1:250 000 geological mapping carried out in the area. Particular attention was given to geological structures and the production of geological cross sections (de Beer, 2003). Currently the Council for Geoscience is mapping the geology of the Sandveld area at a scale of 1:50 000.

Hydrogeology

The area comprises both unconsolidated primary and fractured-rock secondary aquifers. The primary aquifer is located on the western or coastal side of the study area. The aquifer comprises coarse grained and clean sand, and is typically high yielding. The aquifer thickness varies considerably and is controlled to some degree by palaeotopography. The groundwater table is typically shallow throughout the area and is also vulnerable to contamination. The primary aquifer is the main aquifer used for agricultural and domestic water supply purposes. Groundwater quality of the primary aquifer varies significantly. Salinity increases toward the coast, but is still used for agriculture purposes along the coastal zone. In general, groundwater levels mimic surface topography, but groundwater divides are not coincident with surface water divides (i.e. catchment boundaries). The general groundwater flow direction is westwards toward the coast.

The secondary aquifer is significant throughout the area. Structural features such as fault planes, weathered zones and bedding surfaces largely control groundwater flow in the aquifer. The secondary aquifer extends to the west beneath the primary aquifer. There is good connectivity between the primary and secondary aquifer. In general, the piezometric head of the secondary aquifer is higher than the water table in the secondary aquifer, suggesting discharge from the secondary aquifer into the primary aquifer. High borehole yields are obtained from well-sited boreholes and, in general, groundwater quality is good. The secondary aquifer is also used to supply groundwater for irrigation purposes.

There is seasonal interaction between surface water bodies and groundwater, although river flows during the hot, dry summer months become negligible. A number of springs are found throughout the area.

Conceptual flow model

The higher lying mountainous regions, occurring in the inland (eastern) portion of the study area, are the main groundwater recharge zones for the area. The high hydraulic head within the recharge zone then drives this recharge water through the bedrock toward the coast. Within the bedrock there is block faulting and fracturing. Groundwater flow in the bedrock preferentially occurs along some of these faults, however there is also flow within the fractured rock matrix. A cross-section trending perpendicular to the main structural trend of the area (northwest/southeast) is shown in Fig. 3 and the block-faulted nature of the area is apparent (DWAF, 2004). Faults depths, widths and degree of weathering are highly variable, and associated flow rates are thus also variable. The bedrock groundwater is of variable quality. The groundwater occurring within the primary aquifer is mainly derived from the underlying faults. Very little groundwater in the primary aquifer is derived from direct rainfall, due to the low rainfall amounts, high soil temperatures, high clay content and low soil moisture contents. In addition, piezometric levels within the secondary aquifer are shallower than water table levels in the primary aquifer and the isotopic composition of water within the primary aquifer is similar to that of inland rainfall.

Groundwater recharge results

A number of methods have been formulated for estimating groundwater recharge, such as direct measurement, Darcian approaches, tracer techniques, isotope dating, chloride mass-balance equations, analysis of baseflow hydrographs and spring discharges, water-table fluctuations, numerical modelling, water budgeting, etc. Information about these methods is given in Gee and Hillel (1988); Simmers (1988, 1997); Sharma (1989); Lerner et al. (1990); Allison et al (1994); Stephens (1994, 1996); Bredenkamp et al. (1995); Lerner (1997); De Vries and Simmers (2002); and Scanlon et al. (2002). Examples of relatively low-cost investigations at regional scales are provided by Adar et al. (1988); Gieske and De Vries (1990); Athavale et al. (1992); Edmunds and Gaye (1994); Kennett-Smith et al. (1994); Leaney and Herczeg (1995);

Sukhija et al., (1996); Birkley et al. (1998); and Rangarajan and Athavale (2000). Choosing an appropriate technique for a particular site is not straightforward (Scanlon et al. (2002)), and depends on several factors, including field constraints and availability of field data. However, techniques based on groundwater levels (water-table fluctuations) are among the most widely applied methods for estimating recharge rates (Healy and Cook (2002)). These methods are based on the premise that rises in groundwater levels in unconfined aquifers are due to recharge water arriving at the water table (Scanlon et al. (2002)).

Chloride mass-balance method

From the work of DWAF (2004) three main zones are delineated based on the chloride mass balance method. The upper catchment receives about 500 mm rainfall of which 130 mm is predicted to reach groundwater (28%). The recharge zone at the foot of the mountains is expected to receive between 250 and 300 mm rainfall, with about 15 mm reaching groundwater (5%). The rest of the catchment receives about 200 mm rainfall of which not more than 2 mm replenishes groundwater (1%). Groundwater level contour characteristics were used to confirm and refine the areas of groundwater recharge. The low recharge values obtained in the coastal area were also supported by anecdotal and empirical observations made by farmers active in the area (DWAF, (2004)).

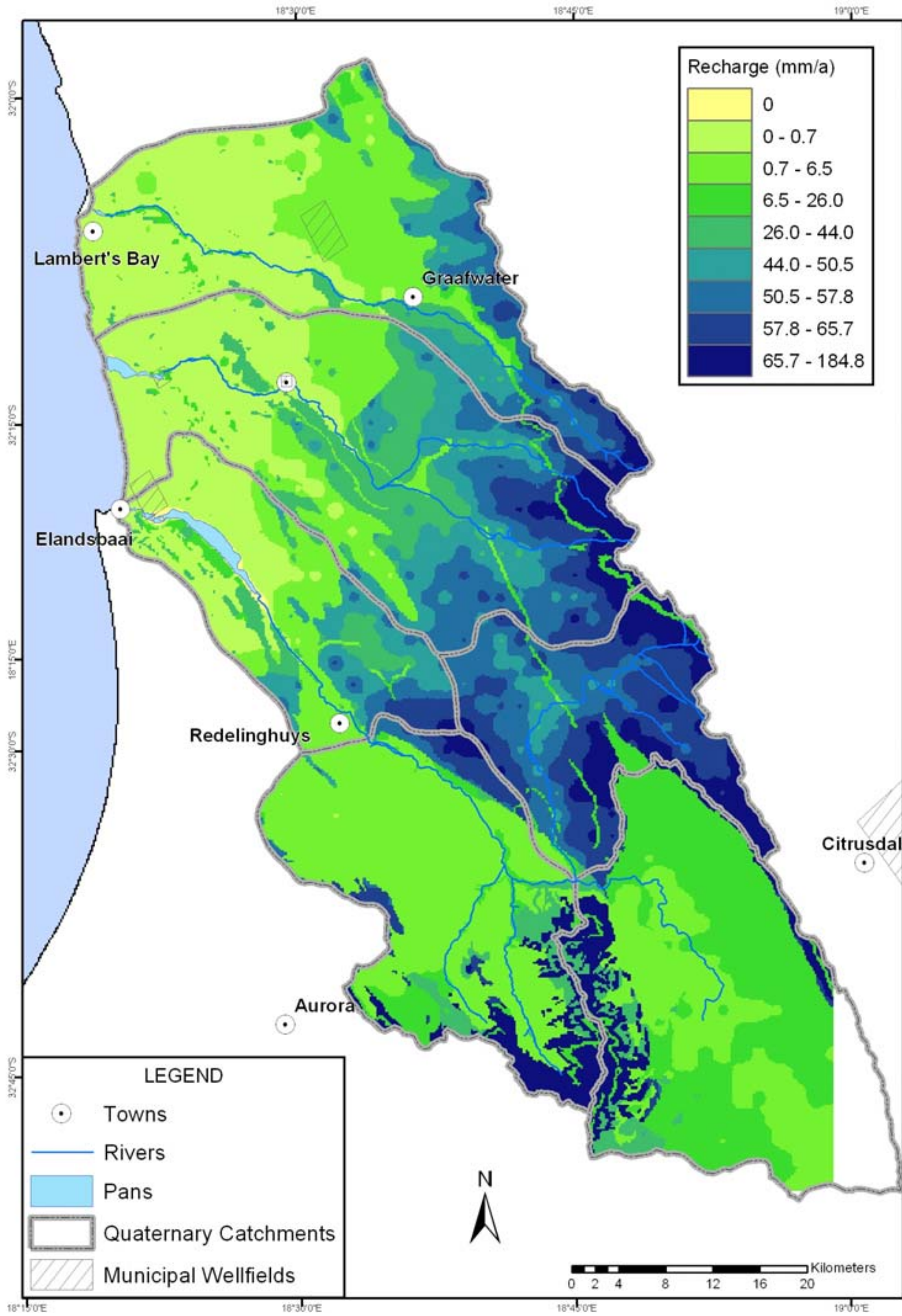

Figure 4
Groundwater recharge distribution across the study area

GIS modelling

In order to address the significant spatial variability of groundwater recharge occurring throughout the area, a GIS based approach was used to determine groundwater recharge distribution. Many factors were considered and an approach similar to that outlined in Conrad et al. (2003) considered. After discussions and testing it was decided to simplify the approach and only two factors were taken into account, namely: lithology and rainfall distribution. Based on available literature recharge percentages were assigned to the different lithological units and these percentages applied to the mean annual rainfall grid in the area. The results from the spatial modelling are shown in Fig. 4. The values and distribution obtained are similar to the modelling results obtained by Umvoto-SRK (2000).

Recharge assessments – point data

A focused effort is currently being made on the collection of time series data of groundwater levels and rainfall. In due course a significant database will be available of groundwater and rainfall time series data. However, currently time series data is mainly available for the municipal supply wellfields within the area. An

TABLE 1
Point recharge estimates based on boreholes with water level time series data and compared to the GIS modelled results

	Cl method		SVF		CRD		EARTH		GIS	
	%	mm/a	%	mm/a	%	mm/a	%	mm/a	%	mm/a
Graafwater wellfield	1.2	2.9	1.7	4.3	1.8	4.6	3.4	8.5	0.4	1.0
Wadrif wellfield	1.0	1.5	1.5	2.3	1.4	2.1	0.9	1.4	~0.3	0.45
Elands Bay wellfield	0.9	1.8	2.0	4.3	1.8	3.8	0.5	1.1	0.3	0.65
G33946	3.3	8.3	0.3	0.8	2.3	5.7	1.2	3.0	0.2	0.5

analysis of this data was carried out using a number of methods, including the chloride method, the Saturated Volume Fluctuation (SVF) Method, the Cumulative Rainfall Departure (CRD) Method and the Extended model for Aquifer Recharge and soil moisture Transport through the unsaturated Hardrock (EARTH) method. The point assessment results carried out on the boreholes with time series data are indicated in Table 1.

Discussion

Prior to the detailed hydrogeological studies being carried out in the Sandveld, recharge values for the primary aquifer within the study area were estimated to be conservatively 8%. As a consequence of the studies this value is considered to be high and direct recharge percentages in the region of 0.2 to 3.4 % are considered to be more realistic. The results presented in this paper are preliminary and will be reassessed once longer period water level time series data becomes available. In addition, isotopic sampling of groundwater has occurred and the results, once obtained, will also be analysed. Additional recharge methods including base flow and spring discharge techniques will also be followed up. The direct recharge is only one of the components required for quantifying groundwater inflow into the study catchments and in parallel with the recharge assessments other assessments are being carried out to determine deep seated inflow and the interaction between surface water and groundwater. The accurate quantification of groundwater inflow is very important, particularly in the light of the requirements of the South African Water Act of 1998. The Water Act states that the total volume of the resource must be quantified and basic human needs and aquatic ecosystem requirements (called a Reserve) set aside from this total volume, thereafter water can be allocated to other users such as municipalities, agricultural irrigators and industry (this study area has no international resource allocation obligations). Thus quantification of the total resource, including the Reserve and legal allocations, as well as illegal usage, is necessary to ensure the sustainable utilisation of our scare water resources in South Africa.

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