HOW MUCH GROUNDWATER DOES SOUTH AFRICA HAVE?

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ABSTRACT

This is a question that, until recently, hydrogeologists could not answer, much to the frustration of water engineers and planners, not to mention hydrogeologists themselves. In 1998, the so-called 'Harvest Potential' (HP) map of South Africa was produced using information from a national hydrogeological mapping project completed in 1995, where it was estimated that 19 000 Mm^3 of groundwater could be abstracted on an annual basis. In 2001, the HP map was revised to take into the highly variable permeability within and between the various aquifer systems and the available groundwater resources was down-scaled to only 10 000 Mm^3/a.

In late 2003, the Department of Water Affairs and Forestry (DWAF) initiated the Groundwater Phase 2 Project, which is aimed at the quantification of the groundwater resources of South Africa on a national scale. The project has been carried out by a consortium of consultants with SRK Consulting as project leaders in close collaboration with key DWAF personnel and was completed in June 2005. Algorithms have been developed for the estimation of aquifer storage, recharge, baseflow and the groundwater reserve. The quantities derived for the key aspects of recharge, aquifer storage and extractable groundwater are 30 520, 235 500 and 19 000 Mm^3/a, respectively.

1. INTRODUCTION

South Africa is a relatively dry and drought prone country. The rainfall is generally low and erratic with a mean annual precipitation in the order of 500mm compared to the world average of 860mm. Some 21% of South Africa receives less than 200 mm/a. The country has limited water resources and is ranked globally amongst the twenty most water-scarce countries. The distribution of these resources has, to a large degree, dictated the establishment of settlements, routes of migration and man's mode of living. The historic importance of the water resources can be gauged by the hundreds of town and farm names relating to water, i.e. Bloemfontein, De Aar

In terms of South Africa's overall water consumption, groundwater contributes only some 15% of the total volume consumed (DWAF, 2002). This percentage belies the fact that over 300 towns and 65% of the population are entirely dependant upon this resource for their water supply. Lack of reliable hydrogeological information has been identified as one of the reasons why groundwater has generally not been developed to its full potential. It is estimated that some 12 million people are still without an adequate supply of water to meet their basic needs.

Over 80% of South Africa is underlain by relatively low-yielding, shallow, weathered and/or fractured-rock aquifer systems. By contrast, appreciable quantities of groundwater can be abstracted at relatively high-rates from dolomitic and quartzitic aquifer systems located in the northern and southern parts of the country, respectively, as well as from a number of primary aquifers situated along the coastline (Figure 1).

This paper mainly highlights and summarizes the results of the Department of Water Affairs and Forestry's Groundwater Resources Assessment Phase 2 (GRA2) project which aimed at quantifying the recharge, storage and sustainable yield of the aquifer systems in South Africa.

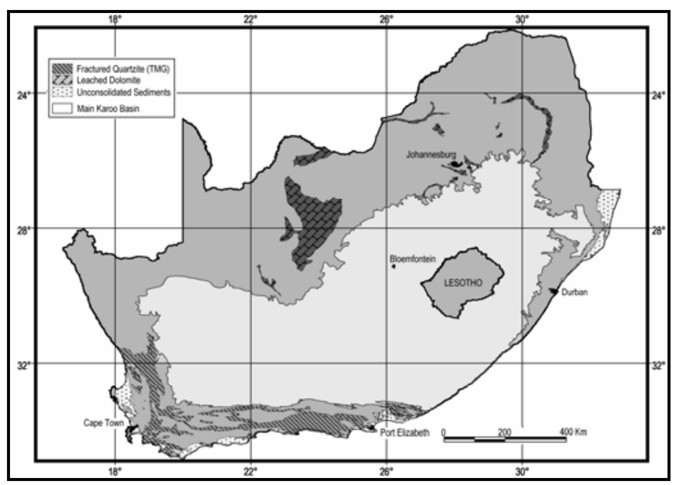

Figure 1: Distribution of significant secondary and primary aquifer systems in South Africa

2. PREVIOUS WORK

The question as to the total amount of groundwater available for development in South Africa could not, until recently, be answered by hydrogeologists, much to the frustration of water resource engineers and planners, not to mention the hydrogeologists themselves. Whilst the 'Surface Water Resources of South Africa' publication is in its third edition, no similar such body of work is available for groundwater.

Early attempts at quantifying the groundwater resources of South Africa, e.g. Enslin (1970), Vegter (1980), were largely educated guesses. Estimates of the sustainable groundwater yield as derived by these pioneers of hydrogeology in the country were 2 500 and 5 400 Mm^3/a, respectively.

Concern about the lack of systematic country-wide groundwater data collection and interpretation led the Directorate of Geohydrology in Department of Water Affairs and Forestry (DWAF) to launch in mid 1990 a programme to compile a series of 21 hydrogeological maps of South Africa at a scale of 1:500 000, each of which has an accompanying explanatory booklet. This was basically an aquifer classification project and was completed in 2005 (Figure 2).

In 1995, Vegter however produced the first synoptic and visual representation of the groundwater resources of South Africa. The work was published in a set of seven maps and an explanation booklet. It provided a valuable indication of availability of groundwater on a regional scale. The series of maps depict borehole yield probabilities, depth to groundwater-level, groundwater quality / hydrochemical type, mean annual recharge and groundwater contributions to baseflow on a national scale. The main maps basically represent a statistical analysis of information stored in DWAF's National Groundwater Data Base.

This work was built-on by Baron, Seward and Seymour (1998) with production of the so-called 'Groundwater Harvest Potential' map of South Africa. Regional estimates of aquifer storage and recharge were used to provide a sustainable groundwater yield in $m^3/km^2/a$, which the authors defined as 'the maximum volume of groundwater that could be abstracted per annum without depleting the particular aquifer'. Their estimate was 19 000 Mm^3/a.

Haupt (2001) further refined the Harvest Potential map by recognizing that in many cases aquifer permeability would be the main factor limiting the utilisation of the so-called harvest potential. He applied a factor to the harvest potential based on country-wide borehole yield analyses and came up with an estimate of groundwater availability of 10 000 Mm^3/a.

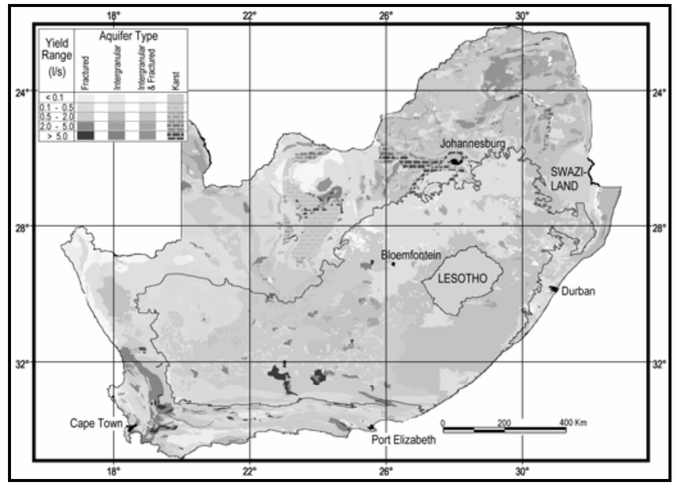

Figure 2: Composite of DWAF's 21 1/500,**000 scale a**quifer yield maps of South Africa

3. GROUNDWATER USE

To put the quantification of groundwater resources into perspective, a brief discussion on its use in South Africa is given. Groundwater is widely but variably used across the whole of the country. A more detailed breakdown of the sectoral use of groundwater in the major surface water catchments is provided by Hughes et all (2004) and is reproduced in Figure 3. This study the most up to date estimate of total groundwater use in South Africa, deriving a figure of 1 770 Mm^3/a. Sixty four percent of all groundwater abstracted is used for irrigation.

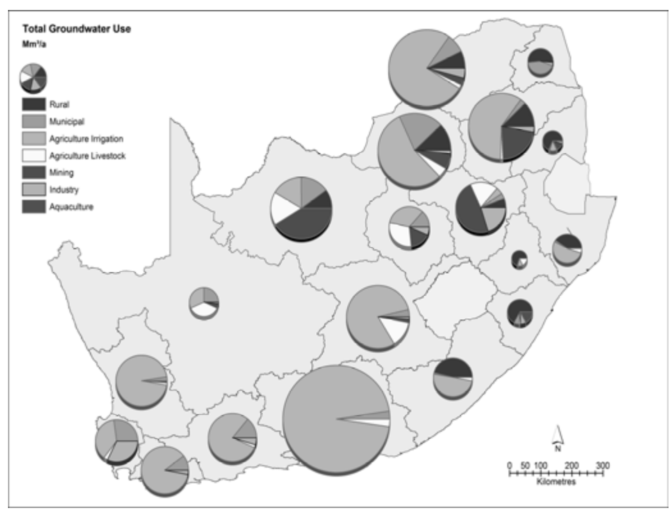

Figure 3: Groundwater use per Water Management Area

4. QUANTIFICATION OF GROUNDWATER RESOURCES

Whilst the 'Surface Water Resources of South Africa' publication is currently undergoing its fourth revision, no similar such body of work is available for groundwater.

In late 2003, the Department of Water Affairs and Forestry initiated the so-called Phase 2 Groundwater Resources Assessment (GRA2) project, the main aim of which is to quantify South Africa's groundwater resources. The project also required that GIS-based algorithms be developed that would enable DWAF to easily update the groundwater resource potential estimates in the years ahead as new and more detailed geohydrological information became available. A raster or grid based GIS model was developed and all inputs and outputs were produced at a cell size of 1x1km.

The following key outputs from the project will be discussed (1) aquifer storage, (2) recharge and (3) yield.

4.1 Aquifer Storativity

GIS layers were developed for various levels within a conceptual aquifer system (Figure 4). These aquifer levels are grouped into two broad zones; namely (i) 'static' storage zone, which is the volume of groundwater available in the permeable portion of the aquifer below the zone of natural water level fluctuation (level 2), and (ii) 'dynamic' storage zone, which is the volume of groundwater available in the zone of natural water level fluctuation. The levels are listed below:

Static storage:
- Level 1 - base of the aquifer
- Level 2 - base of the natural dynamic groundwater elevation

Dynamic storage:
- Level 2 - base of the natural dynamic groundwater elevation
- Level 3 - current groundwater elevation
- Level 4 - average groundwater elevation
- Level 5 - top of the aquifer

A sixth level, a management waterlevel restriction, was introduced to take into account any possible environmental, legal or other constraints placed on the volumes of water that may safely be abstracted from an aquifer system, e.g. restrictions to ensure that DWAF's 'Reserve' requirements are met, restrictions on maximum waterlevel drawdown in dolomitic aquifers due to the hazard of sinkhole formation or avoiding intrusion of saline water.

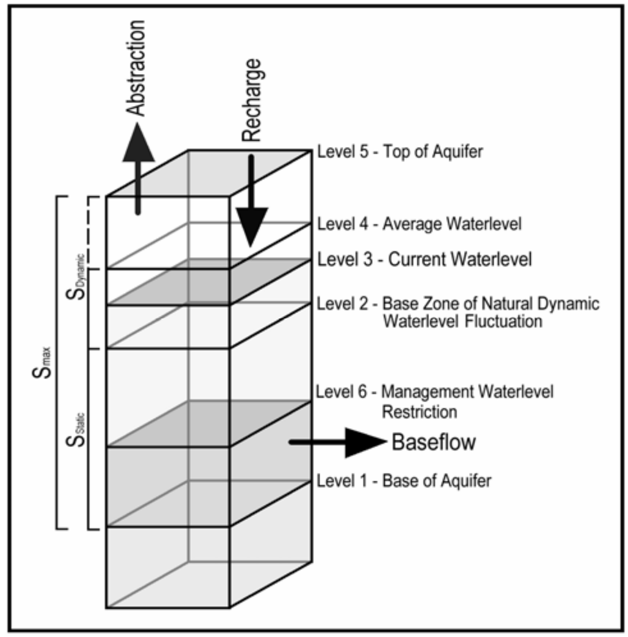

Figure 4: Six Levels in Aquifer System used to assess volumes of Groundwater held in Storage

The volume of water stored between any two aquifer levels or zones is estimated as the volume of aquifer material reduced by an appropriate storage-coefficient or specific yield. The GIS model makes use of a number of these potential storage volumes (levels) together with parameters such as rainfall recharge and baseflow to determine the annual volumes of groundwater available for use on a sustainable basis.

The approach involved defining the thickness and storativity of two aquifer zones, (i) the upper 'weathered-jointed' or WZ and (ii) the underlying 'fractured' zone or FZ. It is estimated that 79% of this water is stored in the WZ which is on average only 33m thick, as opposed to an average FZ thickness of 121m – providing a mean aquifer thickness of 154m. The mean storativity of the WZ and FZ is estimated at 2.62×10^{-3} and 1.52×10^{-4}, respectively. The distribution of storage is shown in Figure 5 which indicates that some 235 500 Mm^3 of groundwater may be stored in aquifer systems in South Africa.

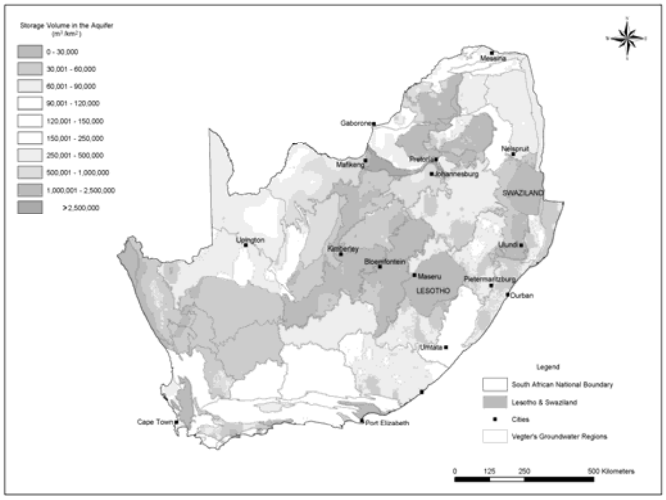

Figure 5: Estimated total volume (m^3/km^2) of groundwater stored in South African Aquifers

4.2 Aquifer Recharge

The annual groundwater recharge from rainfall was estimated using the chloride-mass-balance and a GIS based modelling approach using various empirical rainfall versus recharge relationships. This was followed by cross calibration of results with field measurements and detailed catchment studies. A mean annual recharge volume of 30 520 Mm^3 was thus calculated.

4.3 Groundwater Resource Yield Estimates

The methodology developed to estimate the sustainable yield of the groundwater resources during the GRA2 project employs a basic water-balance approach, where the change in storage in a system is equal to all inputs to, less all outputs from the system.

Over long periods of time and where the groundwater system is in its natural state (i.e. without any abstraction), the natural inputs will be in balance with the natural outputs, such that the change in storage will be zero. This means that the groundwater component of the hydrological system is in a quassi steady-state, which implies that the averaged values of the variables have not changed over the time period over which the averaging took place. However, if groundwater is abstracted from the system, this balance is disturbed and the system is no longer in steady-state and water levels will decline in response to withdrawals from groundwater storage. A new steady-state will be established, in theory, if abstraction does not exceed recharge. If abstraction exceeds recharge the system will remain in a dynamic (transient) or unsteady-state. Groundwater is now removed mainly from storage, as well as a proportion from river systems.

A GIS based raster-modelling approach was used to apply these basic water-balance equations to each cell in the study domain for both steady and unsteady-state conditions. The steady-state algorithms are applied to produce information relating the 'average' groundwater conditions using 'averaged' input datasets (i.e. mean annual recharge, average water level etc.) These averaged outputs will only require updating should more accurate input datasets be acquired or if the algorithm is enhanced. The transient-state algorithms need to be applied at regular time intervals, in this case yearly, to produce outputs about the current status of the groundwater resource, and will be required as input information generated during the previous time step (i.e. antecedent conditions such as aquifer storage and water levels). The algorithms are developed in a hierarchical system whereby the output from one lower-order algorithm is required as input into the next higher-level algorithm, where an additional refinement or management restriction is applied and so on.

4.3.1 Groundwater Resource Potential

The Groundwater Resource Potential (GRP) is defined as the maximum volume (m^3) of groundwater that can be abstracted per unit area per annum without causing any long-term 'mining' of the aquifer system (i.e. without continued long-term declining waterlevels). The GRP is based purely on physical inputs / outputs and aquifer storage. It is therefore not equivalent to the 'sustainable' or 'optimal' yield of the system, which normally takes into account factors such as intrusion of poor quality water, variable aquifer permeability, practical and cost issues relating to extracting the water etc.

Two basic algorithms have been developed to determine the GRP based on the (i) average or steady-state (AGRP) and (ii) dynamic or transient-state aquifer conditions.

The steady-state Groundwater Resource Potential dataset is similar to DWAF's Harvest Potential map in that they both provide estimates of the maximum volumes of groundwater that are potentially available for abstraction on a sustainable basis, and only take into consideration the volumes of water held in aquifer storage and the recharge from rainfall. The feasibility of abstracting this water is limited by many factors due mainly to the physical attributes of a particular aquifer system, economic and/or environmental considerations. One of the most important of these is the inability to establish a network of suitably spaced production boreholes to 'capture' all the available water in an aquifer system or on a more regional scale (Water Systems Management, 2001). The factors limiting the ability to develop such a network of production boreholes, include, *inter alia*, the low permeability or transmissivity of certain aquifer units, accessibility of terrain to drilling rigs, unknown aquifer boundary conditions.

The Average Groundwater Resource Potential or AGRP of aquifers in South Africa (Figure 6) is estimated under normal rainfall conditions at 49 249 Mm^3/a, which decreases to 41 553 Mm^3/a during a drought. These estimates are regarded as the maximum volumes that could be abstracted on a sustainable basis, if and only if, an adequate and even distribution of production boreholes could be developed over the entire catchment or aquifer system – which is impractical both physically and economically.

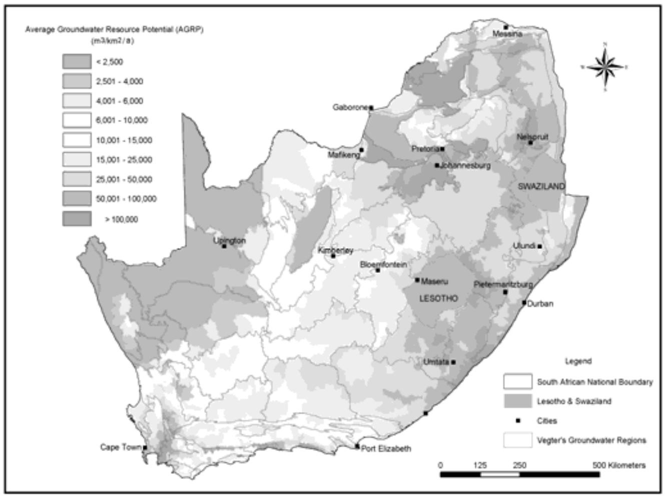

Figure 6: Average Groundwater Resource Potential for South Africa

4.3.2 Groundwater Exploitation Potential

In order to account for the pumping limitations discussed above, the GRA2 project made use of Haupt's (2001) concept of an 'Exploitability Factor' or EF and Vegter's (1995) national 'Borehole Prospects' coverage to generate a 1x1km EF grid for the country. Vegter stated that the prospects of obtaining a groundwater supply from a particular lithological unit may be judged by analysis of the yield distribution of an adequate number of randomly spaced boreholes drilled into this unit. He classified the lithostratigraphic units of the country into 16 water-bearing categories and analysed the yield information from 120 000 boreholes obtained from DWAF's NGDB. The Borehole Prospects coverage is therefore an indication of the extent to which various lithological units are able to act as aquifers.

The EF factor was applied to the AGRP grid to produce the so-called 'Average Groundwater Exploitation Potential' or AGEP coverage. The total AGEP of aquifers in South Africa is estimated at 19 073 Mm^3/a, which declines to 16 253 Mm^3/a during a drought. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis.

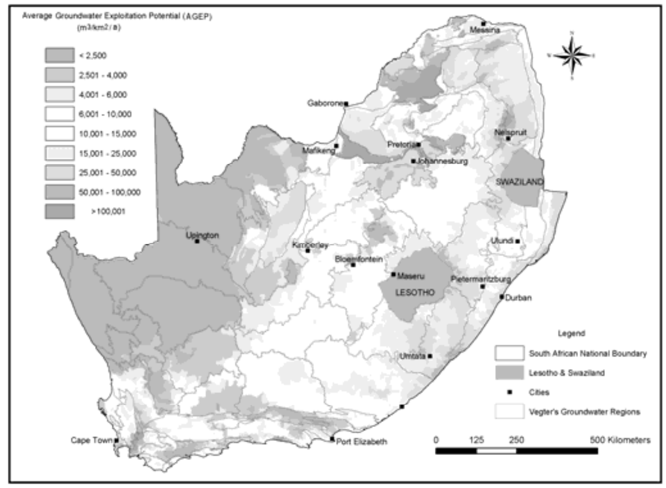

Figure 7: Average Groundwater Resource Potential for South Africa

Groundwater quality is one of the main factors restricting the development of available groundwater resources. Although there are numerous problems associated with groundwater quality, some of which are relatively easily remediated, high concentration of total dissolved solids, nitrates and fluoride are considered to be the most common and serious problems associated with water quality on a regional scale.

4.3.3 Potable Groundwater Exploitation Potential

The Potable Groundwater Exploitation Potential (PGEP) of aquifers in South Africa is estimated at 14 802 Mm^3/a, which declines to 12 626 Mm^3/a during a drought. Nationally, this represents almost a 30% reduction in the annual volumes of available groundwater for domestic supply due to water quality constraints.

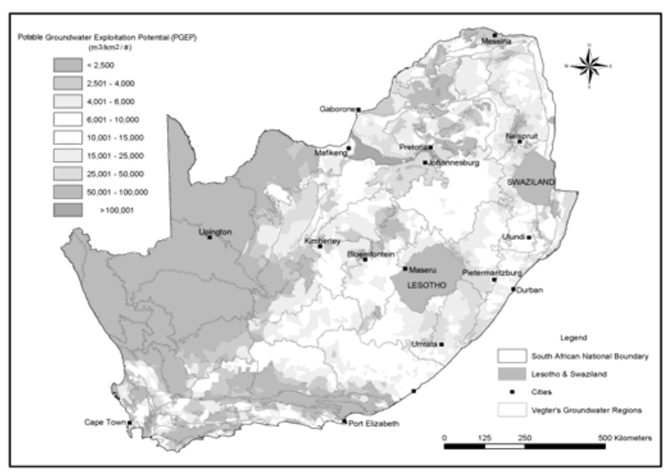

Figure 8: Potable Groundwater Exploitation Potential of South Africa

4.3.4 Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may ultimately be limited by anthropogenic, ecological and/or legislative considerations, which ultimately is a management decision that will reduce the total volume of groundwater available for development – referred in the GRA2 project as the Utilisable Groundwater Exploitation Potential (UGEP). This includes the important legislative restriction imposed on the volumes of groundwater available for utilisation by the requirements of the 'Groundwater Component' of the Reserve as stipulated in the South African National Water Act of 1998. Other aspects such as protection against the hazards of saline intrusion or sinkhole formation, conserving important groundwater dependant ecosystems, maintaining baseflow to rivers etc. can all be factored in using this approach.

The Utilisable Groundwater Exploitation Potential (UGEP) under normal rainfall conditions and under drought conditions is estimated at 10 353 and 7 536 Mm^3/a, respectively. The UGEP represents a management restriction on the volumes that may be abstracted based on the defined 'maximum allowable water level drawdown' and therefore it is always less than or equal the AGEP. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis.

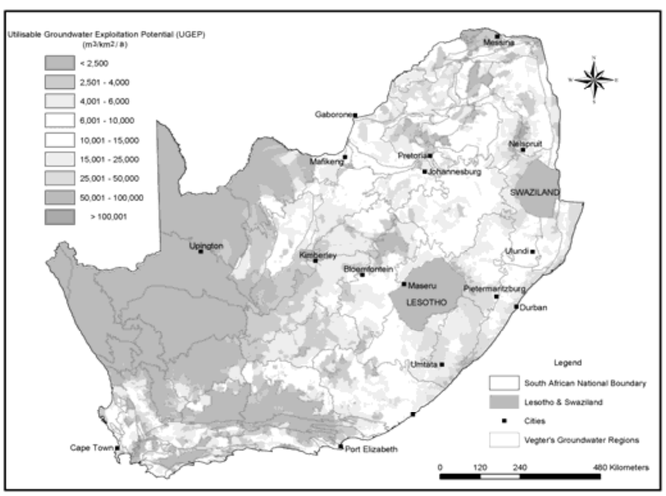

Figure 9: Utilisable Groundwater Exploitation Potential of South Africa

5. CONCLUDING REMARKS

Estimates of the available groundwater resource potential of South Africa range from a maximum of 47 727 Mm^3/a to as low as 7 536 Mm^3/a. For general water resource planning purposes, it is recommended that the so-called 'Average Groundwater Exploitation Potential' or AGEP be adopted where the total volume of groundwater available for abstraction under normal rainfall conditions is estimated at 19 073 Mm^3/a and which declines to 16 253 Mm^3/a during a drought. It is likely that, with an adequate and even distribution of production boreholes in accessible portions of most catchments or aquifer systems, these volumes of groundwater may be annually abstracted on a sustainable basis. Only approximately 6% by volume of the AGEP is currently being abstracted on an annual basis.

6. ACKNOWLEDGEMENTS

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