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Strategy and Guideline Development for National Groundwater Planning Requirements

Review of GRA1, GRA2 and International Assessment Methodologies

AUGUST 2009

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Note on the Department of Water Affairs (DWA)

The Department of Water Affairs (DWA) was until recently known as the Department of Water Affairs and Forestry (DWAF). The Department of Water Affairs is part of the Ministry of Water and Environmental Affairs, under a single Minister. The acronyms “DWA” and “DWAF” both appear in this report, the latter mainly as references to past work done when the Department was known as the Department of Water Affairs and Forestry.

National Groundwater Strategy:

Review of GRA1, GRA2 and international assessment methodologies

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EXECUTIVE SUMARY

South Africa is a relatively dry and water stressed country. Groundwater, important today in sectors ranging from irrigation to basic domestic water supplies, promises to make proportionately greater contributions to the nation's water supplies in future as surface water availability reaches its limits. No comprehensive estimates existed of groundwater availability at a national scale prior to the publication of a series of national groundwater maps in 1995, intended to support better planning and management of groundwater. These were followed by the Groundwater Resources Assessment phase 1 (GRA1) process coordinated by the Department of Water Affairs and Forestry (DWAF, now DWA), which by 2003 had made available a set of 21 hydrogeological maps at a scale of 1:500 000 which together cover the entire country. The production of accompanying booklets is underway.

The national maps and the GRA1 process did not however make estimates of the total volumes of groundwater which could be used annually in South Africa, taking various constraining factors such as recharge and water quality into account. The Groundwater Resources Assessment phase 2 (GRA2) process, which began in 2003, aimed to resolve this and other issues by concentrating on the quantification of the resource, the production of a "planning potential" map, the quantification of recharge and groundwater/surface water interaction, the classification of aquifers, and the quantification of groundwater use for the whole country. Both GRA1 and GRA2 relied mostly on data held by DWA in its databases – much of which was gathered over decades of government sponsored drilling programmes. Relatively little private data is available.

The Groundwater Resources Assessment phase 3 (GRA3) process started in 2008, and is aimed at building on the previous GRA processes. A central concern of GRA3 is the limited data currently available for groundwater resource assessment in South Africa. Also important is the adoption of more sophisticated methods for groundwater management at a local scale, taking into account all users of the resource (including the environment).

All three groundwater resource assessment methodologies are hampered to some extent by the relative lack of groundwater data in South Africa. As a result, some of the algorithms used in GRA2 are questionable. One outcome of this is that the GRA2 data (or depictions of the GRA2 data such as maps) are not yet freely available, for fear that these will be misunderstood by users unfamiliar with the uncertainties in many areas.

Approaches and methodologies for the depiction, assessment and management of groundwater in three "case study" countries (the United Kingdom, Australia, and California in the United States) have been reviewed in this document in order to inform the current South African policy debate. They were chosen on the basis of available data, and are also countries where serious efforts are being made to understand groundwater resources at present. Whilst these approaches naturally differ in terms of responsible authorities, *institutions and legal requirements, they share a growing recognition that the numerical quantification and depiction of groundwater resources ("hydrodynamic methods") at a local scale is an important management tool in these countries. This in turn relies heavily on large amounts of good quality groundwater data, and a major challenge for GRA3 in South Africa will be to improve groundwater data collection and accuracy. There is a growing recognition (and parallel incorporation into policy and law) in all three case study countries that groundwater cannot be managed in isolation from other parts of the water cycle – and this is in accordance with basic integrated water resources management (IWRM) principles. Administrative and legal processes (for example California) do not always lend themselves naturally to integrated water resources management and in this field South Africa, with our National Water Act, has a head start.*

Recommendations arising from this review include:

- *Groundwater resource assessments, predictions of groundwater availability and groundwater management rely heavily on sufficient good quality groundwater data. Efforts to improve data collection and storage need to be made. In particular, data that is generated by the private sector should be captured where possible. A relatively easy way of greatly improving groundwater data collection would be to register drillers and collect the data they generate. Improvement of centrally held data quality and addressing the compatibility of regional groundwater databases are also important.*
- *The international examples show that there is no single accepted way of assessing and managing groundwater, apart from the fact that all rely on good data. A fixation on a single "cure-all" methodology in South Africa is therefore not appropriate. Whilst better assessments are always possible, it needs to be accepted that uncertainties will always exist, and that these should not stand in the way of groundwater development.*
- *A strong and capable groundwater capacity within the Department of Water Affairs at all levels is vital to many of the strategies for increasing groundwater use in South Africa. Efforts to improve this capacity should be supported.*

National Groundwater Strategy:

Review of GRA1, GRA2 and international assessment methodologies

1. INTRODUCTION

Groundwater makes up the bulk of all fresh, liquid water on earth, and although it is still sometimes overlooked by planners it is now usually recognised as a vital strategic resource. There is a continuous need for improvements in the accuracy of groundwater resource assessments, both in terms of groundwater quantity and quality. Improved assessments are needed for planning purposes, environmental protection, legal compliance and risk management, amongst other reasons. More attention to groundwater assessment should be seen against a background of increasing demand for water, escalating awareness of pollution, and growing concerns over variations in precipitation due to climate change.

Examining available groundwater data can give a good picture of regional groundwater availability and quality, and a good average idea of borehole characteristics. Since aquifers often vary in their hydraulic properties over short distances, however, local scale groundwater prediction or assessment is more complicated – at these scales the variability in local aquifer properties can make regional “average” assessments meaningless. The time scale is important too – an assessment conducted on the basis of one year’s data may not be representative of a longer term average. The challenge therefore is to make the best use of regional groundwater properties data to predict and assess local groundwater resources, whilst at the same time being aware of the limitations of the data. Issues of scale become more and more important as a smaller area is selected for assessment. As the United States Geological Survey’s Circular 1323 of 2008 on groundwater availability in the United States puts it: “On a national scale, we know quite a bit about the Nation’s ground-water resource; how¬ever, much of the information is generalized and has limitations when attempts are made to plan for the future” (Reilly et al, 2008:7).

At a local scale it may be necessary to examine the groundwater dataset in more depth statistically (spread around mean, standard deviation) and also to take more account of the record length, density and reliability of data in the local area. The type of aquifer (degree of heterogeneity, typical extent of seasonal or local water table fluctuations, recharge characteristics, etc) also needs to be taken into account. However, the use of existing regional estimates in local groundwater investigations only goes so far, and in most cases it will be necessary to conduct field work and perhaps drilling to establish local aquifer properties with the required degree of confidence. Local groundwater investigations may be aimed at establishing a reliable water supply for a town, at tackling a groundwater pollution plume, or improving environmental flows, for example. All of these situations call for a high degree of confidence in the outcomes of the work – usually much higher than can be obtained by using regional estimates based on limited local data only.

Assessments of world groundwater resource availability vary: Raymond Nace of the United States Geological Survey (USGS) estimated the total volume of fresh groundwater in storage as 7 million km3, based on the assumption of 5 % porosity to a depth of 1000 m (Price, 1996). Estimates of the total however range as high as 60 million km3 (Price, 1996). Groundwater is also the world's most extracted raw material, with withdrawal rates in the region of 600 to 700 km3 per year (IAH, 2003). Unlike many other raw materials however much groundwater under natural conditions is constantly being replenished. The economic value of groundwater is too great to be gauged solely in terms of volumes used, because its use corresponds to high economic and social use value (and it is often the only viable source of water for large communities in some areas). It is thought to provide about half of the world's drinking water on average, although this varies widely by country (IAH, 2003). In rural areas, dependence on groundwater is often much higher.

The world groundwater map

The UNESCO-supported WHYMAP programme produced (amongst other outputs) a world hydrogeological map at a scale of 1:15 000 000 (Puri and Aureli, 2005). The map divides the world into three fundamental aquifer types by colour (blue for major ground water basins, brown for local and shallow aquifers, and green for more complex areas). In addition, three intensities of each colour in the green and blue areas classify recharge into high, medium and low areas, to give a rough indication of sustainability. A later "transboundary" edition of the world map showed proposed transboundary groundwater systems as circles superimposed on the map. Being a world map, it lacks the detail for anything but a broad or strategic assessment of national groundwater resources. It is also a useful tool for marketing or publicizing groundwater, and for contributing to international discussions on water resources. Further information can be found at http://www.whymap.org/.

Figure 1.1: Box describing the UNESCO world groundwater map

South Africa’s groundwater resources are increasingly recognised as being of great importance to the environment, to basic human needs, and to sustainable national development. This follows many decades in which groundwater was relegated to an essentially “local” resource, regarded in law as the property of the landowner, and accorded far less attention that surface water. This is despite the total renewable volumes of groundwater in South Africa being of equivalent magnitude to our surface water resources. Groundwater also has many acknowledged advantages over surface water, such as its resistance to hydrological droughts, its generally good natural quality and the fact that it can usually be found close to where it is needed.

Previous estimates show that “available groundwater resource potential” in South Africa for a typical year ranges from about 7.5 km3/a to as much as 47.7 km3/a, taking various factors such as the Reserve, transmissivity and water quality into account (Rosewarne et al, 2006). The GRA 3 project aims to improve on these estimates, but also to ensure that the implications of these estimates – i.e. that the high quantities of groundwater available and the potential uses qualify it as a national asset of key strategic and developmental importance – are more widely accepted.

2. DESCRIPTION AND REVIEW OF GRA1 METHODOLOGY

2.1 BACKGROUND TO GRA1

At a workshop in November 1989 convened by the Water Research Commission (WRC) in Pretoria a primary goal of hydrogeological research in South Africa was defined as “The identification and characterisation of South Africa’s groundwater resources in terms of their occurrence, quality and development potential” (Vegter, 2001). A later workshop confirmed the need for a national hydrogeological mapping programme. In 1995 the Groundwater Resources of South Africa (consisting of a report and accompanying set of groundwater maps) was published by the WRC (Vegter, 1995). The maps were based on a statistical analysis of data from approximately 120 000 boreholes held by the Department of Water Affairs and Forestry. The seven national scale maps on two A0 sheets were a first attempt at a visual representation of South Africa’s groundwater resources, and are as follows:

- Borehole prospects
- Saturated interstices
- Depth of groundwater level
- Mean annual groundwater recharge
- Groundwater component of river flow
- Groundwater quality
- Hydrochemical types

The information contained in this map set was later used to compile a Groundwater Harvest Potential map of the Republic of South Africa (Baron et al, 1998), which estimated the total sustainable volume of groundwater that could be extracted annually in South Africa for different areas. Regional estimates of storage and recharge were used to calculate this sustainable yield (Woodford et al, 2006). The total Harvest Potential for the country amounted to an estimated 19 km3/a (Rosewarne et al, 2006). Despite certain shortcomings (Vegter, 2001) this map represented by far the most comprehensive effort to date to answer the question “how much groundwater can be sustainably used in South Africa?”, which hydrogeologists were (and are) frequently asked by surface water experts and by planners.

South Africa's Groundwater Regions

Beginning before the development of the national maps described above, and continuing to the present day, a long-term project recognising the subdivision of the country into a series of "Groundwater Regions" has been underway (Vegter, 2001). These regions are based on the occurrence of groundwater (mainly type of porosity – i.e. primary or secondary) as well as on lithostratigraphical, physiographical and climatic considerations (Vegter, 2001). Groundwater in a region is not necessarily part of the same hydraulic or hydrological unit. It is intended that each region will ultimately have a separate groundwater report and map or maps, explaining and depicting groundwater occurrence and conditions in the region in detail. A number of groundwater issues including methods for geophysical exploration, recharge, hydrochemistry and the siting of boreholes are included in the reports. A total of 64 Groundwater Regions have been defined, and to date four of the reports have been completed (Vegter, 2006). The completed reports are available from the Water Research Commission (WRC). The Groundwater Regions work is continuing as resources and skills allow, with at least one further region currently in the pipeline. No date for the final completion of all the regions has been set.

Figure 2.1: Box describing Vegter's Groundwater Regions

At the same time as the national scale maps described above were being compiled, an initiative by the Department of Water Affairs (DWA) through its then Directorate: Geohydrology to develop a series of twenty-one hydrogeological maps together covering South Africa at a scale of 1:500 000 got underway. By the year 2000 eight of these maps had been produced (Vegter, 2001), and the series was completed in 2003. It is also intended that each map will be accompanied by an explanatory brochure, and to date nine of the brochures have been finished. The legends of the 1:500 000 Hydrogeological Map Series (sometimes called the "general maps") are based on the international legend for hydrogeological maps developed by UNESCO (1983) in order to assist with uniformity and to present the hydrogeological information in a way that is widely understood internationally. However, some modifications to the UNESCO system were considered necessary, including the classification of fissured and fractured groundwater occurrence in a more detailed manner since these aquifers underlie most of South Africa (King, 2002). The groundwater classification on the Hydrogeological Map Series includes four classes of aquifer overlying a simplified geological background represented by a letter as follows:

1. Intergranular (type a)
2. Fractured (type b)
3. Karstic (type c)
4. Fractured and Intergranular (type d)

The land area is furthermore divided into five productivity or “borehole yield” classes, ranging from 0-0.1 L/s to >5 L/s, and numbered from 1 (lowest yield class) to 5 (highest yield class). Thus an alphanumeric code is assigned to any area providing information on both the mode of occurrence and the yield class.

The Hydrogeological Map Series includes schematic cross sections showing typical groundwater occurrence, as well as a series of four inset maps as follows:

- Distribution of borehole data (1:2 000 000 scale)
- Elevation above sea level (1:2 000 000 scale)
- Mean annual precipitation (1:2 000 000 scale)
- Groundwater quality (1:1 500 000 scale)

Both the national scale maps developed by Vegter (1995) and the Hydrogeological Map Series developed by DWA relied on statistical examinations of data held in the DWA National Groundwater Database (NGDB) and, to a lesser extent, data obtained from other sources. From the earliest days of water well drilling in South Africa, a number of government departments and government sponsored organizations (such as the Council for Geoscience and its predecessor the Geological Survey of South Africa) have been involved in siting and drilling water boreholes. Drilling was offered on a subsidised basis to farmers and other groundwater users. Information from these activities has formed the bulk of the data held in the NGDB, whilst information from private drillers and contractors is comparatively scarce. The data assessment and production of the Hydrogeological Map Series has come to be known as Groundwater Resource Assessment phase 1 (GRA1) (Rosewarne et al, 2006).

2.2 REVIEW COMMENTS ON GRA1

The GRA1 work was groundbreaking in that it led to the production of the first full set of regional hydrogeological maps (Hydrogeological Map Series) of South Africa. The main intention of GRA1, and the Hydrogeological Map Series, was to provide an overview of the hydrogeological conditions in a given map area for planners (Meyer, 1999). Maps were also aimed at the scientist and the “interested layman”. The GRA1 work, together with the national maps and “groundwater regions” of Vegter (1995 and 2001) has undoubtedly led to a higher awareness of the importance and potential of groundwater in South Africa. As the former Director of Geohydrology at DWA Mr Eberhard Braune states in the foreword to the Oudtshoorn 3320 Explanatory Booklet “These General Maps represent a synthesis of the most up-to-date data and geohydrologist’s knowledge. These maps are also very useful in identifying areas where additional data need to be collected and further investigations need to be conducted” (Meyer, 1999). At present work on Vegter’s “groundwater regions” continues in parallel with the production of the Hydrogeological Map Series and explanatory booklets. Both systems have advantages – the accessibility and completeness of the General Maps contrasts with the local detail inherent in the groundwater regions. As far as is known, no attempt has been made to produce a series of maps incorporating information from both systems – no doubt partly because the groundwater regions series is not yet complete.

3. DESCRIPTION AND REVIEW OF THE NATIONAL GROUNDWATER DATABASES AND INFORMATION SYSTEMS

The following section discusses databases which can be accessed for groundwater data and/or information in South Africa. The databases are maintained by the Department of Water Affairs and Forestry, and are used to provide information to a variety of users (planners, developers, farmers, researchers and others) as well as in the Department's internal planning, regulatory, information-dispensing and licensing procedures. The databases are often unable to provide a complete picture of boreholes and groundwater conditions on a local scale, and are usually not adequate on their own for local planning and water allocation. This is because they either do not contain complete records of all groundwater sources, or the records are not up to date. Detailed planning at a local scale would normally require additional data collection such as a hydrocensus or further drilling.

3.1 NATIONAL GROUNDWATER DATABASE (NGDB)

The NGDB data set is probably the most comprehensive borehole data set in South Africa and incorporates an estimated 225 000 boreholes. However, the quality of the data is variable. A common problem is the lack of complete borehole records (e.g. borehole locations not accurately recorded). Borehole pumping test or aquifer information is rarely available and data quality auditing is done in the office (i.e. boreholes are seldom verified in the field). Earlier records held in the NGDB have estimated locations based on the cadastral farm name on which the borehole is found – this can lead to inaccuracies in position of several kilometres. Modern pumping rates are rarely available. Records date from the early part of the last century to the present day; some records are many decades long, others consist of a single point and date. Many boreholes have lengthy sets of monitoring data, recording water levels taken by DWA personnel annually or more frequently.

It is of concern that there appears to have been a decline in borehole data capture in the last ten years or so in some areas - for example in the Tshwane dolomites near Pretoria (WGC, 2008). Monitoring boreholes in that area which have fallen into disuse or been destroyed by development are hardly ever replaced. Much of the data, particularly the monitoring data, is derived from boreholes either drilled or owned by DWA. Records from private boreholes are less common. The information from the NGDB is freely available on application to DWA in Pretoria, who maintain the database. **Figure 3.1** shows the annual growth in records acquired by the NGDB since 1985. The rise in acquisitions between 1992 and 1996 reflect the efforts made during the production of the Hydrogeological Map Series (GRA1)

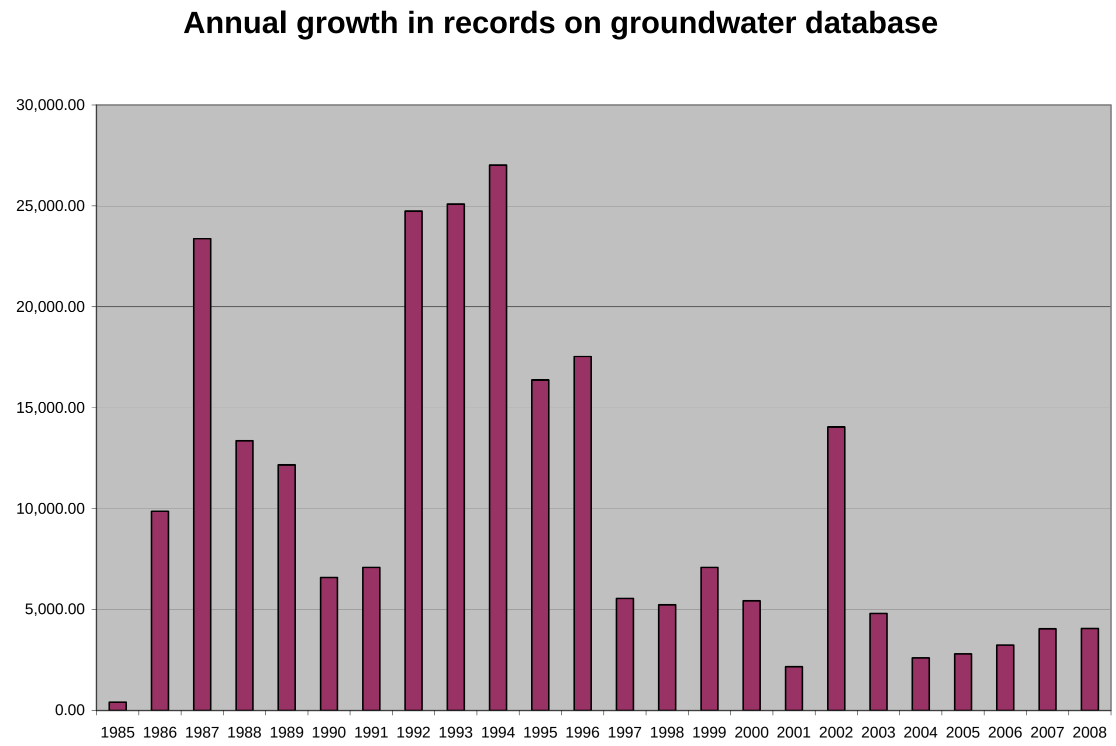


Figure 3.1: **Annual growth in NGDB and NGA records, 1985 – 2008**

3.2 NATIONAL GROUNDWATER ARCHIVE (NGA)

The NGDB is not internet-based and will be replaced with the online National Groundwater Archive (NGA), which will be operational in 2009. The NGA will allow access via the internet and also allow consultants and others to upload borehole information directly, thus augmenting the database. At present no compulsory registration of boreholes on the database is envisaged, as far as is known.

3.3 REGIONAL GEOSITE NUMBERING SYSTEMS

The numbering systems for geosites (borehole, spring, well, etc) are different for all nine South African provinces. For example, the Limpopo region’s numbering system is based on the water services areas representing the administrative level on which DWA’s Regional Offices implement water services, and the numbers are called H-Numbers. The H-numbering system was adopted in the early 1990’s and is related to a combination of geographical and political boundaries.

3.4 WATER MANAGEMENT SYSTEM (WMS)

The water quality database holds the most accurate point-source information. The WMS does not contain any borehole or aquifer information, but the quality of the chemical analyses results is excellent. It is not linked to the NGDB or other hydrogeological databases, but operates as a "stand alone" chemistry database. The WMS database resides at the Institute for Water Quality Studies (IWQS) within the Department of Water Affairs and Forestry.

3.5 WARMS DATABASE

DWA also maintains the Water Authorisation and Use (WARMS) database, which gathers together information provided by licence holders on groundwater use. Municipalities also collect groundwater use information, and some of this is submitted to DWA for incorporation into WARMS.

Table 3-1: Development of the NGDB (Bertram, pers. comm.)

DATE	DESCRIPTION	NOTES
1985	NGDB operational, first records captured by University of Free State for test purposes	At the end of 1985 the NGDB officially handed over to DWA.
1986 - 1989	Approximately 200 000 borehole records available at DWA, an early aim was to capture these records. Location data poor, so not adequate for large-scale analysis.	The 200 000 records originated from the government's drillers, representing a concerted effort to capture available data over many years.
1989 - 1991	Serious decline in growth during these years can be attributed to loss of focus on data capture and emphasis on human development.	Focus on human development may have ultimately worked against data holdings.
1992 - 1996	Focus in these years changed to supply the data necessary for Vegter's Groundwater Resources of RSA map (Vegter, 1995)	Management focus changed to identify and train dedicated coding and capturing personnel. Main focus still on the 200 000 in-house records.
1997 - 2001	Following completion of the Vegter map, focus on data capture lost	
2001	GRIP in Limpopo underway, this data captured onto AquaBase and loaded into NGDB	Some of this data was captured from about 200 reports given to the DWA national office by the NW Region.
2002 - 2007	Data capturing devolved to regions. Lack of data capturing staff in regions hampered progress	GRIP in E Cape data contributed to recent NGDB growth. GRIP in KZN launched in 2007 but data captured in AquaBase.

4. DESCRIPTION AND REVIEW OF THE GRIP PROJECT

4.1 GRIP RATIONALE

The Groundwater Resource Information Project (GRIP) was first introduced in the Limpopo Region to collect all groundwater related data, verify this in the field, and present it to planners and engineers in a format that is sensible and easy to incorporate in planning studies (Botha, 2005). Groundwater Resource Information Projects (GRIPs) have also recently been introduced in the Eastern Cape and in Kwazulu-Natal. The overall aim of the GRIP is a properly developed and implemented groundwater information system to generate information and/or knowledge necessary for integration of groundwater into the holistic management of our water resources.

4.2 GRIP SPECIFIC AIMS

- To deliver borehole information and hydrological/geological information to all institutions involved in water supply and management to enable real-time decision-making for planning, operational and management purposes.
- To support the full implementation of regional- and national groundwater databases. The data can be manipulated to develop a series of planning maps, develop site-specific water supply business plans and to assist planning engineers with groundwater development and management programmes.
- Effective dissemination of information through the development of a database accessible through the World Wide Web.
- To support future specialist groundwater studies addressing key priorities.

4.3 GRIP OUTCOMES

- The development and maintenance of a regional groundwater database.
- The development of groundwater potential and protection maps with supporting documentation.
- The development of maps and documentation in support of future resource development.
- The establishment of a Groundwater Service Centre with supporting information.

Groundwater is a strategic resource with respect to rural water supply but may be perceived as an unsustainable resource only suitable for hand-pump installations, emergency water supply or for rural use in small communities (DWAF 2004). The latter perception arose due to a perceived lack of reliable and available or accessible information. This negative perception is related to the following:

- A lack of reliable borehole information or point-source data. The capturing of borehole data is currently not a legal requirement in South Africa and data from the large number of boreholes drilled every year is not captured.
- Difficulty in accessing groundwater data. The data needs to be captured in a manner that serves the needs of both the National Water Act (NWA) and the Water Services Act (WSA) and should be useable (relevant to) and accessible to all relevant stakeholders. Therefore, when developing a Water Service Development Plan (WSDP) for a district municipality where groundwater plays a strategic role, the information needs to be available to the water management authority in a format that is useful. Data needs to reflect water services needs such as infrastructure information, accurate spatial distribution, sustainable yields and management requirements.
- The data also needs to satisfy the needs of the National Water Resource Strategy (NWRS) and future Catchment Management Strategies (CMS's), reflecting on recommended yields, strike depths, future development yields, etc. of the available resources and future management thereof.
- The Groundwater Resource Information Project (GRIP) is an example of an information management tool devised to capture and present borehole point data and generate information/knowledge for use by water service authorities or CMAs, local and national government and others. When completed GRIP will provide water service authorities and CMAs with verified borehole or point data information and enable IWRM institutions to protect, use, develop, conserve, manage and control groundwater resources though a process that meets basic human needs, allows equitable access, facilitates social and economic development, protects aquatic and associated ecosystems, reduces and prevents pollution and degradation, and meets international obligations. Most importantly it should enable DWA to monitor and regulate groundwater abstraction and use.

4.4 GRIP REVIEW

It is the intention of the DWA that the GRIP data eventually be incorporated into the National Groundwater Archive. At present this process is hampered by a lack of resources. Most specialists agree that a GRIP (or something very similar) is a desirable thing to have in every province in South Africa. There is far less agreement on where funds and human resources are to come from to make this a reality. The GRIP project in the Eastern Cape has been badly hampered by lack of resources, and this calls into question whether it is realistic to expect GRIP to proceed in its current format across the country. GRIP is also administered by the regional DWA offices, which are themselves currently in a state of flux (transition to Catchment Management Agencies) and which lack a clear mandate for medium to long-term data collection. For a national GRIP to succeed, more support will need to be given to the programme. Implementation is the main challenge GRIP faces, together with the planning and resources that this implies. An advantage of the GRIP projects is that they bridge the gap between the national and regional scale.

5. DESCRIPTION AND REVIEW OF GRA2 METHODOLOGY

5.1 INTRODUCTION TO GRA2

The GRA1 process was groundbreaking in many ways – for example in providing the first ever set of hydrogeological maps based on commonly accepted international standards, and which are in continual use today. However, GRA1 did not quantify the groundwater resource in South Africa in terms of how much water can be realistically abstracted every year, given such constraints as recharge, quality, transmissivity and the potential impact on surface water flows and on the environment. The Groundwater Resources Assessment project phase 2 (GRA2) began in 2003 and was aimed in part at addressing these issues. The GRA2 project consisted of five main tasks, summarized as follows (Rosewarne et al, 2006):

1. Quantification (basically aquifer storage)
2. Planning Potential Map (updated harvest potential map)
3. Recharge and Groundwater/Surface Water Interaction
4. Aquifer Classification
5. Groundwater Use

The description of the GRA2 assessment methodology is given in a series of DWA reports, which are structured following the five main topics listed above. For each topic a literature review, a description of the methodology applied for GRA2 and a final report summarising the main findings is given.

The following critical review of the applied methodologies is accordingly structured into the five topics. It must be emphasized that the review does not entail any verification or review of the derived data on e.g. groundwater recharge itself. Each review topic consists of a summary of key outputs and a description of the methodology used to arrive at the outputs (including critical review comments).

5.1.1 Key outputs

- Country-wide 1 km x 1 km grid showing average groundwater storage.
- Country-wide 1 km x 1 km grid showing current groundwater storage based on previous year’s input data (especially recharge and abstraction).

5.1.2 Methodology

The quantification of the national groundwater resources is based on a water balance approach, i.e. what flows in must flow out (including abstractions) or cause a change in storage:

$$\left(Q_{in}+\Delta Q_{in}\right)-\left(Q_{out}-\Delta Q_{out}\right)+Q_{ab}=\Delta V$$

5.2 GROUNDWATER QUANTIFICATION

Groundwater storage is calculated on a 1 km x 1 km grid as the sum of water volumes stored in the weathered and fractured zones of South African aquifers (product of specific yield Sy respectively specific storage Ss, saturated thicknesses and surface area) and aggregated to a quaternary catchment scale.

The storage is subdivided into a static storage zone SStatic (volume of groundwater available in the permeable portion of the aquifer below the zone of natural dynamic water level fluctuation) and a dynamic storage zone SDynamic (volume of groundwater available in the zone of natural dynamic water level fluctuation). The static and dynamic storage zones are related to five "physical" aquifer levels defined in separate GIS layers as follows (**Figure 5.1**):

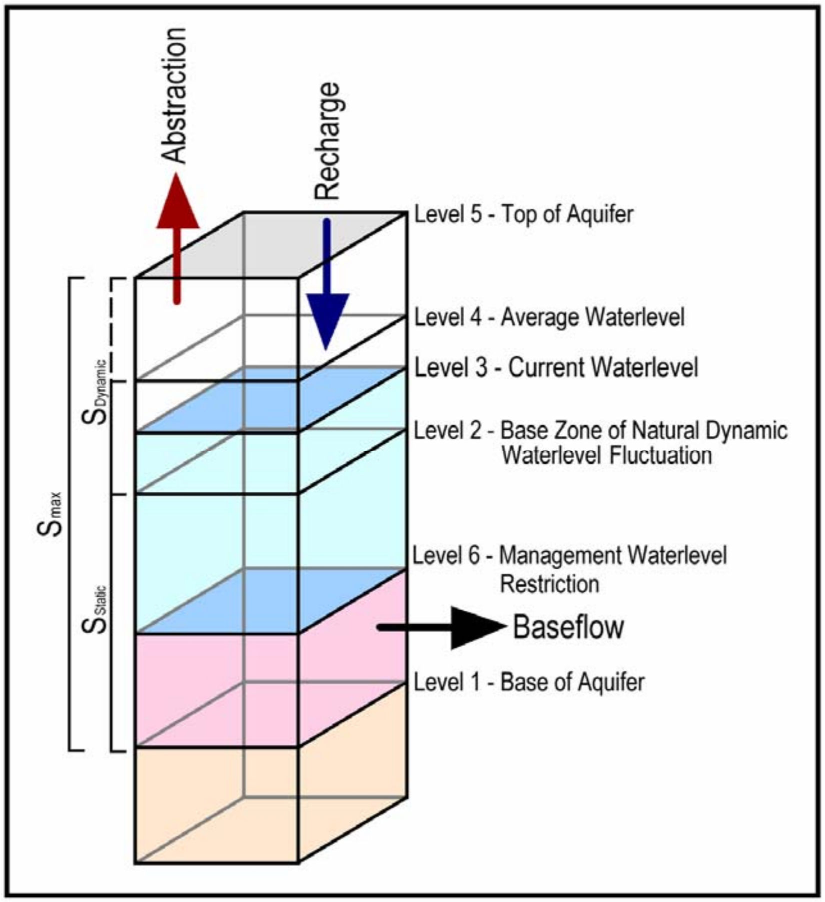


Figure 5.1: Aquifer levels used to assess stored volumes of groundwater

5.2.1 Critical review of input parameters

The base of the aquifer (**Level 1**) is in this context defined as the depth of readily available and exploitable groundwater, determined as the depth where the water strike frequency (density) graphs approach a maximum (depth of weathered zone, absent for TMG) or zero (depth of fractured zone). The water strike frequency plots are essentially a modification of Seymour's (1996) approach, using an extended database of 152 569 NGDB records for Vegter's 64 groundwater regions. If too few data is available for a specific region, depths of geologically similar, adjacent regions are used. Following the initial determination based on water strike frequencies, the thickness of the weathered zone is corrected for the topographical setting, i.e. reduced by e.g. 5 % for slope angles of 5°.

While the approach obviously makes best use of available data, it is generally a subjective approach and fits of strike density graphs for some regions appear arbitrary or based on other (unsubstantiated) information. Furthermore the often insufficient number of deeper water strike data causes a statistical bias in the density curves. A correction of deeper water strikes densities as a function of the borehole depth distribution (to avoid diminishing maxima in weathered zone) appears necessary. Additional shortcomings of the approach include the unrealistic assumption of a completely (up to base of weathered zone) saturated fractured zone and the assumption of homogeneous regions. Vegter's groundwater regions are geologically heterogeneous and single derived parameters of strike densities, which are in the following assigned to quaternary catchments; result in crude approximations of aquifer depth. Subsequently the determined average depth to the base of the weathered zone for Vegter's 64 groundwater regions is a very deep 56 m below ground level. The average base of the fractured zone on the other hand is a rather shallow 116 m below ground level. For selected regions the fractured zone is extremely thin (thickness below 20 m, e.g. regions 12, 20, 24, and 38) and in 4 regions (regions 51, 54, 55 and 63) the weathered zone is apparently deeper than the fractured zone, indicating clearly conceptual errors.

The base zone of natural dynamic water level fluctuations (**Level 2**) is defined in the methodology report (not defined in the final report) as the lower depth range of the maximum of strike-density curves for Vegter's (2001) 64 groundwater regions (and included quaternary catchments). As stated above for level 1, the determination is subjective, sometimes arbitrary and assumes homogeneous regions. Additionally, topographic effects (recharge – discharge areas) on water level fluctuations are neglected and instead a geologically determined parameter (water strikes in boreholes determined over a period of decades!) is used to define the base of water level fluctuations. This approach neglects systematic fluctuations of water levels due to drought cycles.

The current groundwater elevation (**Level 3**), primarily used to estimate available groundwater storage for the following year, is calculated from recent NGDB elevation values. Using water levels measured at different times, the approach neglects seasonal water level fluctuations. Furthermore the spatial distribution of boreholes captured in the NGDB is not uniform, and a bias may exist towards boreholes potentially influenced by abstractions. However, correcting regional water levels for abstractions based on (for example) the WARMS database is virtually impossible.

The determination of the average groundwater elevation (**Level 4**) is not given in the final report, but apparently defined in the methodology report as the centre of Vegter's (1995) groundwater level interval map. It therefore represents average water levels under the climatic conditions and abstractions up to the 1990's, without consideration of more recent conditions. As before the heterogeneity of the regions is neglected and a secondary sub-division of water levels into quaternary catchments used.

The top of the aquifer (**Level 5**) is also not defined in the final report, but given in the methodology review as the minimum elevation of the 1 km x 1 km grid used for the resource assessment. While the top of the weathered aquifer is related to the surface elevation, it does not coincide exactly with it due to the occurrence of soil horizons, calcrete or ferricrete layers, etc. Furthermore the accuracy of the surface elevation depends on the digital terrain model (DTM) resolution. In this case the DTM from the 90 m x 90 m Shuttle Radar Topography Mission was used.

Level 6 is used in the calculations to represent management water level restrictions based on environmental, legal or other constraints placed on the volumes of water that may safely be abstracted. While it is incorporated into the model, it is not used in the regional determination of available groundwater resources.

Additional important **data requirements** for the methodology include the specific yield and storage coefficient of the weathered and fractured zones respectively. Both parameters are not readily available on a regional scale and an exponential decrease (within reasonable limits) of the parameter with depth is assumed. The decrease function is altered for each region to arrive at reasonable values at required depths, e.g. zero at the base of the fractured zone. The derived average yield for Vegter's 64 regions is around a relatively low 8E-03 and the average specific storativity is approximately 3E-04.

The applied methodology is essentially a continuation of the GRA I methodology with a larger NGDB database available. A major shortcoming is that the aquifer information is inferred from non-randomly distributed data (e.g. the NGDB boreholes are typically sited on anomalies around population centres, **Figure 5.2**), and it is assumed that the data is representative of each groundwater region.

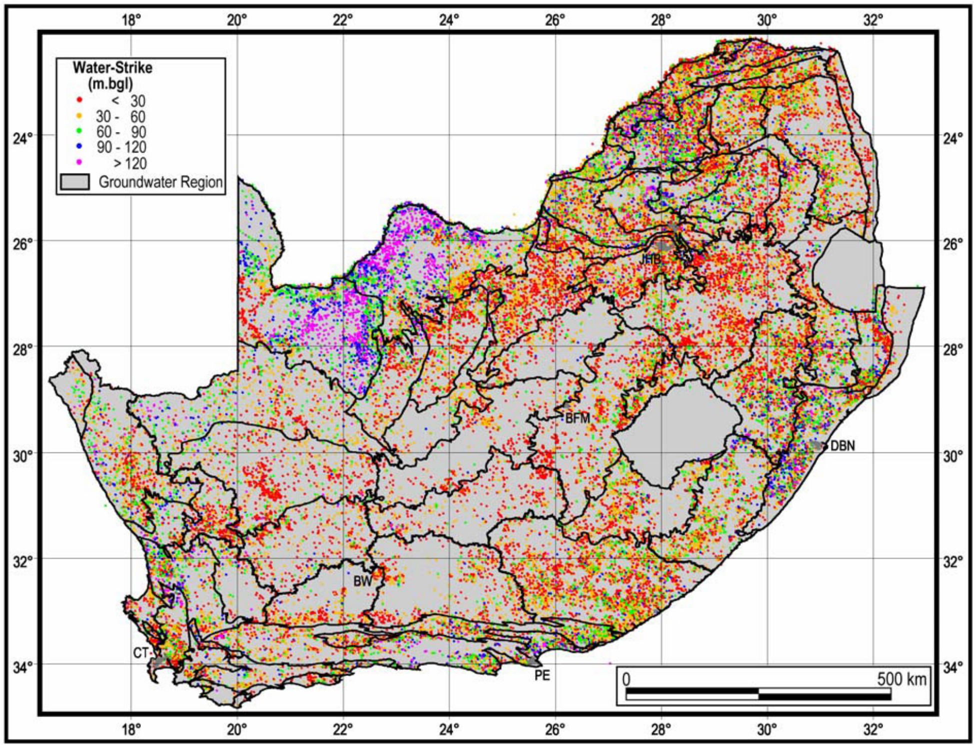


Figure 5.2: **Example of a mean water strike map showing spatial distribution of the NGDB data**

5.3 GROUNDWATER RECHARGE

5.3.1 Key outputs

- Country-wide 1 km x 1 km grid showing GIS based recharge estimates aggregated to quaternary catchment scale.
- Annual and mean annual recharge values per quaternary catchment.
- Recharge threshold values (RTV = monthly rainfall below which no direct groundwater recharge occurs) per quaternary catchment. Note that this neglects preferred recharge.
- National recharge volume estimated at 30.52 km3/a or 5.2 % of mean annual precipitation (Vegter (1995) estimated 33.82 km3/a or 5.8 % of MAP)

5.3.2 Methodology

National recharge values are calculated on a quaternary catchment scale using a chloride mass balance (CMB) approach, i.e. the ratio of chloride content in rain and groundwater respectively. In order to apply the CMB method despite limited spatial coverage of chloride measurements in precipitation, theoretical linear relations between mean annual precipitation (MAP) and chloride content, elevation and chloride content as well as distance to coast and chloride content (only for coastal regions) were derived for coastal and inland regions. The relations were used to derive grids of chloride content in precipitation, before these were averaged for coastal and inland regions and combined to a national grid, which was subsequently smoothed. It is obvious that the various mathematical operations limit an assessment of the reliability of derived data, but the initial poor to almost absent correlations between chloride content in precipitation and MAP or elevation (r^2 only around 27 %) for the inland station question the applied approach. The apparently better correlation between the final smoothed calculated dataset and observed values (Fig. 6.7, r^2= 79 %) is a direct result of the predominance of coastal chloride values with high concentration ranges. The inland values show a completely different (linear) relation in comparison to coastal values, and calculated correlation coefficients are therefore not representative. The general underestimation by the model of chloride contents in inland precipitation should theoretically result in an overly pessimistic estimation of inland recharge figures.

Chloride contents in groundwater were interpolated (kriging) for a 1 km x 1 km grid based on 28 465 measurement locations extracted from the NGDB (a harmonic average was used for stations with time series data, or if multiple stations fell into one grid cell). Interpolated values were overwritten with measured values for the cells containing such.

In view of cyclic variations of chloride content or even linear trends for impacted stations the calculation of harmonic averages for stations with time series data is generally questionable. Furthermore the data should have been classified into annual data sets and subsequently used to estimate annual recharge values. Such an approach would have enabled the identification of potential cyclical effects and trends, which currently average each other out. Excluding pre-1980 data from the dataset furthermore results in a potential time difference of up to 26 years for determined chloride values, a time span during which land use changes and climate changes could have occurred and impacted on chloride concentrations. Another major shortcoming of the method refers to the applicability of the CMB method itself, which originally uses the chloride content in soil water and/or the groundwater surface, while the NGDB data represent mostly pumped samples to achieve a sample representative of the aquifer and not necessarily the unsaturated zone.

The two datasets (grids) are subsequently used to estimate “raw” recharge percentages based on their ratio, neglecting dry deposition of chloride (especially in coastal regions and an important contribution to the salt load). The derived grid is again smoothed before it is ”calibrated” (using multiple linear regression) against known recharge values by introducing rating (influencing) factors accounting for the depth to water table, soil drainage rate, rainfall seasonality, geology, land cover, topography as represented by slope and the coefficient of variation of annual precipitation. While the correlation coefficient (r^2) between calculated recharge values and point values from literature improves from 20 % for the "raw" estimates to around 45 % for the "calibrated" estimates, it must still be considered as a very poor (or even non-existent) correlation. After a final smoothing of the recharge grid it is used to determine the recharge values per quaternary catchment as well as for the country. The derived national recharge figure of 52.7 km^3/a (equal to an average recharge of 9 % of MAP) appears rather high.

The smoothed "GIS calibrated" recharge grid values are again "calibrated" (using linear regression) against recharge values determined in the GRA2 GW/SW interaction project (reducing the national recharge estimate to 27.2396 km^3/a), before the recharge values of 413 quaternary catchments are "adjusted" to match minimum baseflow values (per quaternary catchment) as determined by the GRA2 GW/SW interaction project. The final "adjusted", "calibrated", "GIS-calibrated and smoothed" recharge grid estimates the national recharge volume as 30.5187 km^3/a, or 5.2 % of MAP. Correlation (r^2) between the final estimated recharge values and point values from literature improves to a still disappointing 56 %. It is obvious that the various smoothing and calibration or adjustment procedures do not help to improve the reliability or scientific defensibility of CMB recharge figures, and a further discussion is deemed unnecessary. The recharge figures should essentially be recalculated with more chloride data, or different methods (e.g. the Cumulative Rainfall Departure method or the Water Table Fluctuation method). It is furthermore interesting to note that the correlation between the "final estimates" and Vegter's recharge estimates show a clearly non-linear relation between the two with a calculated correlation coefficient (for a linear relation) of 67 % with the "adjusted, calibrated, GIS-calibrated and smoothed" recharge estimates appearing to limit recharge values to threshold values like 100 mm (see **Figure 6.28** in final report).

The groundwater recharge project team furthermore estimated precipitation threshold values (PTV) for recharge to occur per quaternary catchment. The PTV was determined for each quaternary catchment by calculating the cumulative distribution of estimated monthly recharge values based on monthly rainfall data for the period 01/2000 to 08/2004. A 98 % non-exceedence criterion (assuming a normal distribution) for recharge was used to set the PTV at the corresponding precipitation value. The short time series of rainfall data considered obviously questions the application of statistics based on large data sets and influenced by cyclic climate variations. Beyond this short-coming the setting of PTV at a percentage of mean monthly precipitation is an over-simplification of the underlying processes, as noted by the authors themselves, and renders determined values questionable and difficult to defend. Accordingly within the GRA2 project itself the PTV was contradicted by the surface-groundwater interaction group, which set it at 200 mm.

5.4 GROUNDWATER SURFACE WATER INTERACTIONS

5.4.1 Key output

- Quantification of stream flow depletion by groundwater abstractions.

5.4.2 Methodology

The project team used two alternative methods to estimate the soil moisture content:

1. Hydrograph separation (Herold method) to determine groundwater baseflow (defined as baseflow from a regional aquifer), interflow (defined as baseflow from perched aquifers) and storm runoff on a monthly basis (data base: WR90, observed flow data / stochastic hydrograph). “Back calculated” sub-surface storage is then used to estimate recharge.
2. The catchment soil moisture time series S determined by WRSM 2000 is directly used to calculate a time series for recharge. If the “aquifer capacity” (defined as the product of aquifer thickness and storativity) is reached, any excess recharge contributes to interflow. Groundwater storage is depleted by evapotranspiration and groundwater outflow (function of gradient) and abstractions (also reduces baseflow).

The “reverse engineering” of subsurface storage and recharge from hydrograph/baseflow separation, which is then used to assess impacts of groundwater abstractions on baseflow is obviously highly problematic for impacted and regulated catchments. The hydrograph separation is considered as a subjective method, with the hydrograph being influenced by stream regulations (e.g. dams or weirs), direct abstractions, induced recharge or diversion of water from a river as well as discharges or return flows into a river. In other words, baseflow in a regulated and impacted catchment might only originate to a minor degree from groundwater, as assumed in the separation method.

Recharge is in either case calculated as a fraction of the maximum recharge at maximum soil moisture content. The fraction is determined by the weighted ratio of the difference between actual soil moisture content and the soil moisture below which there is no recharge and the difference between maximum soil moisture storage and the soil moisture content below which there is no recharge.

The potential recharge from the soil moisture contributes to actual aquifer recharge until the “aquifer capacity” is reached, when the “excess recharge” begins to contribute to interflow. Since groundwater abstractions reduce aquifer storage and prolong or prevent the time needed to reach the “aquifer capacity”, it increases recharge and reduces interflow. For catchments without groundwater abstraction interflow is calculated as the difference between baseflow obtained from the hydrograph separation and calculated groundwater baseflow. Further losses may occur by evapotranspiration demand by zones of shallow groundwater, which is calculated as the product of mean annual evaporation, monthly distribution and Acocks veld type crop factor minus precipitation (all data from WR90). Evapotranspiration from this shallow groundwater occurs as long as the demand exceeds precipitation and decreases with decreasing groundwater storage. It reaches zero once the groundwater storage drops below the stream level (static water level), i.e. it does not allow the vegetation to induce recharge from the river. Additional losses from aquifer storage arise as a result of regional groundwater flow, which is calculated using gradients derived from the aquifer storage (of quaternary catchments) and Darcy's law.

Following the consideration of these losses groundwater baseflow is then calculated as a non-linear function of the head difference between groundwater and surface. Fitting parameters allow the modeled rate of groundwater baseflow to be limited or prevented.

Generally groundwater abstraction depletes groundwater storage and groundwater baseflow as a function of the aquifer diffusivity (ratio of transmissivity and storativity), the distance from the river, and time.

Groundwater baseflow and transmission losses due to prevailing head gradients in the aquifer are calculated using what appears to be the Rushton & Tomlinson (1979) nonlinear relationship, while Glover's (1974) method (based on Theis's (1941) solution) is apparently used to quantify effects of groundwater abstractions on stream flow. In the latter method the authors omit the complementary error function of the original solution by introducing two new fit parameters, both without any physical meaning. Beyond this deficiency the quantification suffers from the same conceptual shortcomings as the original solution by Glover/Theis, i.e. the assumptions of fully penetrating wells and rivers and a perfect hydraulic connection between the river and the aquifer.

5.5 GROUNDWATER USE

5.5.1 Key outputs

- National sectoral (municipal, rural, agriculture/irrigation, agriculture/livestock, industry and mining sectors) and total groundwater use maps (low confidence estimates).
- Comparison of current and previous groundwater use estimates and observations drawn from validation of datasets and sources.

5.5.2 Methodology

While the project team outlines the Principle Method to achieve mid-term groundwater use estimates of a medium to high confidence, due to scarcity of groundwater use measurements a simplified method (**Figure 5.3**) is necessary to achieve groundwater use estimates of a low confidence. Different available data sources are used to estimate sectoral groundwater use before they are summed up to give the total national groundwater use figure of 1.88623 km^3/a.

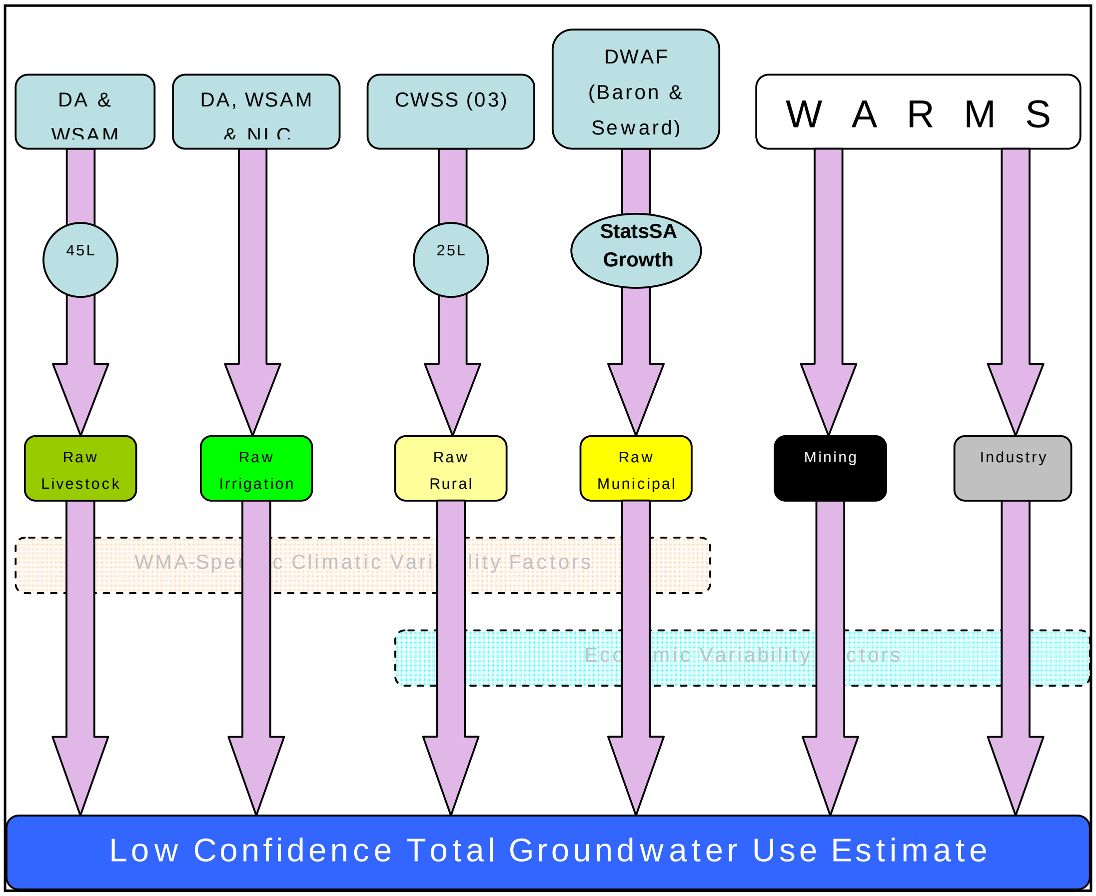


Figure 5.3: **Schematic representation of applied current method**

It is interesting to note that the WARMS database is only used to estimate groundwater use by the mining and industrial sectors.

5.5.3 Agriculture / Irrigation Groundwater Use

The determination of groundwater use for irrigation per quaternary catchment follows essentially the Baron and Seward (2001) method. The spatial distribution of irrigation throughout a catchment is based on the irrigated land cover classes from the National Land Cover dataset (NLC 1998). Total irrigation requirements per catchment are derived from the WSAM (2001) and divided according to the area given in the NLC. The percentage groundwater dependence of irrigation is finally derived from the DA Development Survey, which relates to the Broad Homogenous Agricultural Areas (BHLG), and irrigation requirements are again assigned according to the size of the sub-areas. Finally the sub-areas are aggregated to a quaternary scale. It can be assumed that the applied method generally gives a relatively accurate estimate of the spatial distribution of groundwater use for irrigation within a catchment, but the authors themselves question the reliability of the groundwater reliance information given in the BHLG.

5.5.4 Agriculture / Livestock groundwater Use

As above the method of Baron and Seward (2001) is followed. Livestock units watering requirements per catchment were obtained from the WSAM, multiplied by 45 L per stock unit per day and finally multiplied by percentage groundwater dependence from the BHLG.

Groundwater use by aquaculture as extracted from the WARMS database is included in the final groundwater use map.

5.5.5 Mining Groundwater Use

Groundwater use by the mining sector is extracted from the WARMS database, where mine lease holders have to register their groundwater use as part of their EMPR. Not all mines registered in WARMS are reported as active mines to the Council for Geoscience and vice versa, questioning the accuracy of both databases.

5.5.6 Industrial Groundwater Use

Industrial groundwater use is extracted from the WARMS database and aggregated on a quaternary catchment scale. The authors state that double accounting with Municipal groundwater use is likely and that several regions appear to lag behind with registration (Eastern Cape and KwaZuluNatal), questioning the confidence of derived groundwater usage data.

5.5.7 Rural Communities Groundwater Use

Rural groundwater usage was aggregated from the updated Water Services communities' data; the database of service delivery to rural areas (includes the 2003 population and water source information). Since the percentage of water supply by groundwater was unknown for a large number of villages in the latter database, the percentage of groundwater reliance for the specific Water Management Area (WMA) was assigned to these villages. If surface and groundwater are conjunctively used for water supply to a village, a reasonable estimate of 50 % groundwater reliance was used. Multiplying the percentage reliance on groundwater by the population of the village gives the estimated number of people using groundwater per village. Aggregation of the village information to quaternary catchment level and multiplication by 25 L daily requirement and 365 days per year yields the annual figures. The authors note that the assumption of 25 L per person per day appear to be an overestimate and that seasonal variations in groundwater dependence could not be quantified. It is obvious that the applied method relies on a number of questionable (e.g. population census and percentage groundwater reliance) and outdated (2003) data, but represents a reasonable low confidence estimate based on available data.

5.5.8 Municipal Groundwater Use

The municipal groundwater use determination is based on scaling the town groundwater use data of Baron and Seward (2001) using a projection of population for June 2004. While the town groundwater use data (per person) rely only on limited data from the Eastern Cape regional DWA office and are therefore regionally biased, the projection of the 2004 population relies on 1996 and 2001 Statistics SA census data and assumed growth factors (taking into account declining fertility, increasing mortality and migration).

The large number of underlying assumptions and projections in the method renders it questionable and of low confidence, but in the absence of a complete WARMS database (with regard to municipal groundwater use) or other accurate data it provides at least a crude figure.

5.5.9 Comparison of current and previous groundwater use estimates

The comparison of these current estimates with previous national, regional (GRIP) and local studies highlights the low confidence groundwater use figures derived using the current method (as stated by the authors themselves). Major deviations between current estimates and validated studies are related to agricultural and rural groundwater use, though similar large deviations can be expected if validated municipal groundwater use data become available.

5.6 GROUNDWATER RESOURCE CLASSIFICATIO

5.6.1 Key output

- National classification of (ground-)water resources

5.6.2 Methodology

The classification evaluates the contributions of different surface and groundwater resources within a catchment to the downstream water resources along with the ecological condition of the resources to rate the ecological health of and to develop a sustainability baseline configuration for a catchment.

The management class (MC) of a resource is determined by a six-step process as outlined in **Figure 5.4.** Each MC is associated with a set of economic, social, hydrological and ecological characteristics that relate to the ecological integrity of the resource respectively its capacity to deliver Ecosystem Goods and Service Attributes (EGSAs), and subsequently to the degree of acceptable impacts.

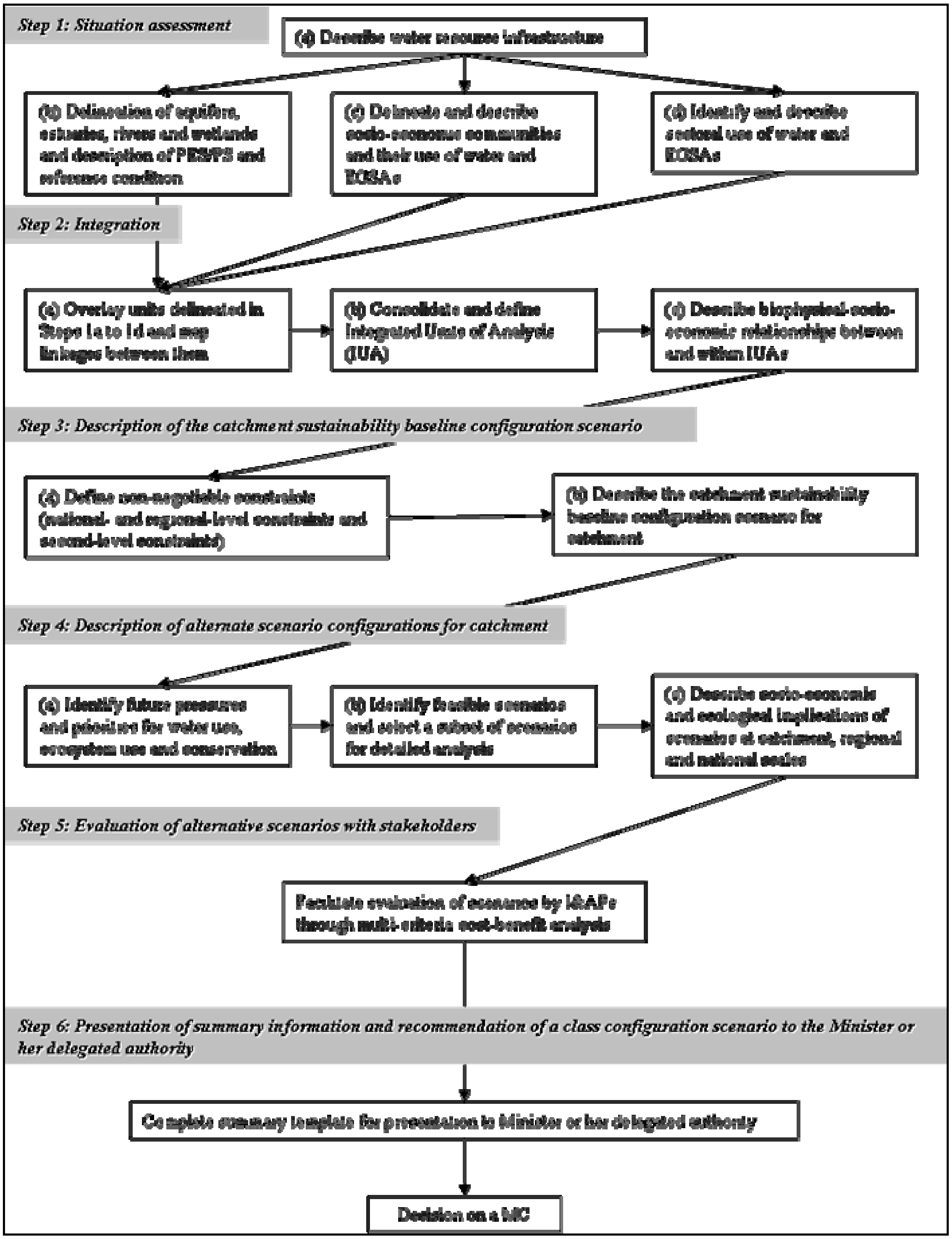


Figure 5.4: **Outline of national water resource classification process**

5.6.3 Situation assessment

The situation assessment includes the description of the water resource infrastructure in a catchment (well fields, boreholes etc.), the delineation of groundwater resource units including probable aquifer dependent ecosystems (ADEs, with linked EGSAs) and a hydro-geomorphological classification of surface-groundwater interactions according to Xu et al (2003).

Aquifer vulnerability with regard to contamination and over-exploitation are assessed using the DRASTIC method (with an unrealistic derivation of hydraulic conductivities of aquifers and impacts of the vadose zone from geological data on a 1:1 million scale) and a simplified score system based on aquifer recharge, storage (both based on GRA2 assessments discussed above) and coefficient of variation of precipitation.

The present status category of the groundwater resource units is then spatially characterised using 3 categories, which assess quantity impacts (abstractive use as a percent of recharge), natural groundwater quality (using, unfortunately, DWA water quality guidelines instead of the legally binding SANS 241) and impacts on groundwater water quality (using the product of the contaminant hazard rating from the National Land Cover data and the DRASTIC vulnerability index). It appears that the proposed groundwater resource assessment is of a similar detailed scale as a comprehensive Reserve determination, with resultant time and financial commitments. It is furthermore not clear why the authors propose a hydro-geomorphic classification of surface groundwater interaction in contradiction to the method proposed for GRA II above.

Due to data scarcity (see discussion of the groundwater use assessment above) the delineation and description of socio-economic communities and their sectoral use of water and EGSAs will be one of the most challenging tasks in the national water resource classification process and will need future alignment to the methodology currently developed by Statistics SA. In its current form it appears only applicable in a research environment or on a very limited spatial scale.

5.6.4 Integration

The integration of the different information layers is essentially an overlay of the information gathered during the situation assessment, but unfortunately only new maps of surface groundwater interaction (as percent of baseflow and with a new categorisation) are given. In the absence of available required detailed data, the integration step appears mostly theoretical, especially with regard to “integrated units of analysis”.

5.6.5 Description of the catchment sustainability baseline configuration scenario

The catchment sustainability baseline configuration scenario gives the maximum extent to which a catchment's water resources can be used for water supply or waste removal by referring it to a health class D under consideration of the groundwater Reserve non-allocable water or water allocated for strategic use of water supply schemes. The latter constraints are supposed to be also given in a separate definition of non-negotiable constraints. In other words; the description of the catchment sustainability baseline essentially entails a very ambitious reserve determination (above desktop level) for the entire country. For surface but also groundwater resources and aquifer dependent ecosystems the assessment should also consider the downstream dependence on upstream conditions in river systems or aquifers (e.g. passive saltwater intrusion), which would require even more detailed and site specific studies on a national scale. The proposed "permitted changes in groundwater levels from present status level accounting for selected national scale sustainability constraints" assigns a water level change of zero to large parts of the country (especially around population centres like Gauteng or Cape Town), i.e. eliminates any future groundwater use if strictly followed.

5.6.6 Description of alternate scenario configurations for catchment

The description of alternate scenarios for the catchment entails the consideration of future pressures and priorities for water and ecosystem use as well as an evaluation of the scenarios (which is not further specified). However, the socio-economic and ecological impacts of the scenarios should be evaluated with different models, with the yield model being the only model specified by the authors. Furthermore generic rules associated with the proposed management classes are presented but are of no further assistance for a specific case.

While the consideration of alternate scenarios is, for example, best practice within the EIA process, further standardised guidelines with regard to the evaluation of the scenarios should be given. In the current form the proposed evaluation is too generic and vague for general application.

5.6.7 Evaluation of alternative scenarios

The evaluation of alternative scenarios with stakeholders and presentation of summary information and recommendation of a class configuration scenario to the Minister are the final steps of the resource classification. These follow essentially legal requirements and require no further discussion.

5.6.8 General remarks

The proposed national classification of (ground-) water resources is in most parts scientifically defendable and laudable, but might be too ambitious if the data availability is considered. The classification follows in major parts a comprehensive to intermediate groundwater Reserve determination with the additional consideration of downstream water resources and aquifer dependent ecosystems, and hence proposes a very resource intensive assessment methodology which also has to incorporate different spatial levels.

Deviations from surface-groundwater assessment methods proposed in a separate GRA2 report, as well as the established GRDM methodology, lack integration of methods and this needs to be rectified.

5.7 GROUNDWATER PLANNING POTENTIAL

5.7.1 Key output

- Planning potential maps of Groundwater Quantification, Recharge and Surface Water Interactions, Aquifer Classification and Groundwater Use

5.7.2 Methodology

The planning potential maps for South Africa consolidate essentially the data output of the 4 project reports above into national estimates of the maximum volume of groundwater that can be abstracted per quaternary catchment on a sustainable basis without depleting the aquifer system. The proposed methodology to determine the groundwater harvest potential is a revision of the method by Baron et al. (1998), which considered groundwater storage, recharge and recharge frequency. The revised methodology applies a simple steady-state (with or without abstractions) water balance approach. Transient algorithms are provided to determine the current status of a water resource based on input data from the previous year, though the simplicity of the algorithms does not allow for the transfer of water between neighboring 1 km x 1 km grid cells and renders the methodology rather inadequate.

The steady-state and transient algorithms are used to derive not only the harvest potential, but a series of different water volumes potentially stored in South African aquifers under varying planning constraints.

5.7.3 Groundwater resource potential

The groundwater resource potential (GRP) is the maximum volume (m3) of groundwater that can be abstracted without ‘mining’ the aquifer system. The average GRP for pristine aquifer conditions (no abstractions) is calculated based on the mean annual recharge, aquifer storage (**level 1 – level 4** in **Figure 5.1**), a drought index as given by Seymour and Seward (1997) and the mean annual contribution of groundwater to river baseflow. An average dry season GRP is calculated based on Schultze’s (1997) coefficient of variation of mean annual precipitation. Calculation of the current transient GRP follows the average GRP calculation, but considers additionally abstractions and current volumes of stored groundwater.

It is obvious that GRP determination is influenced by the shortcomings in the determination of recharge, aquifer storage and baseflow contribution discussed above. Considering potential error propagation, recharge and baseflow estimates appear to be the most sensitive and critical parameters.

5.7.4 Groundwater exploitation potential

The exploitation potential of an aquifer is the portion of the groundwater resource potential, which can be practically abstracted. The exploitation factor used for downscaling is simply derived from Vegter's (1995) exploitability – accessibility dataset (average probability of drilling a borehole with a yield > 1.0 and > 2.0 L/s) for fractured aquifers or set to 0.7 for all primary aquifers. While a single value for all primary aquifers appears unrealistic (e.g. alluvial versus weathered aquifers), Vegter (1995) assumed an adequate number of randomly spaced boreholes in the NGDB to derive the exploitation factor for fractured aquifers. However, NGDB boreholes target typically any form of discontinuity in an aquifer and cannot therefore be seen as randomly distributed. The assumption of randomness for systematically drilled boreholes should theoretically result in an overestimation of the groundwater exploitation potential.

The groundwater exploitation potential is further scaled down to a potable groundwater exploitation potential with a potability factor, which considers TDS, NO3, K, Na, SO4 and Ca concentrations with regard to DWA's domestic water quality guidelines (marginal quality as lowest acceptable class). The applied potability factor neglects very important micro-biological parameters (e.g. E. coli), important trace element concentrations (e.g. F), which can render groundwater in many rural areas unfit for human consumption. Also neglected are cyclic variations in water quality during droughts (despite being used for such calculations).

While the factor that is currently used is therefore too optimistic, the application thereof is generally questionable as it neglects potential water treatment – much groundwater rejected as being of poor quality could be used given suitable treatment. If a similar approach was used for surface water this would probably designate almost all currently used surface water resources as non potable.

Another subset of the groundwater exploitation potential is defined as the utilisable groundwater exploitation potential, which considers the ecological Reserve in the definition of aquifer storage (**level 6** in **Figure 5.1**). While the authors claim that the basic human need component of the reserve is considered in the annual abstractions (for transient calculations), their approach neglects a potentially large part of the reserve which has to be catered for despite the population being supplied already. Again, the utilisable groundwater exploitation potential will be an overestimate and does not help in planning. It should be scrapped and the Reserve (both components) incorporated into the groundwater resource potential.

5.8 SUMMARY COMMENT ON GRA2

In summary, GRA2 is an ambitious and commendable endeavour to quantify South Africa's groundwater resources. Due to a shortage of reliable groundwater data, and a very uneven distribution of data across the country, some of the methods used in the GRA2 process are questionable. GRA2 emphasises the urgent need for more data on South African groundwater, and better quality data.

Partly due to the lack of data on which the GRA2 process is based, and the consequent potential to misrepresent certain catchments, the GRA2 datasets are not presently freely available from DWA. It appears that the GRA2 data is also not routinely used by water resource planners, no doubt partly due to difficulties in obtaining the data as well as issues with accuracy and reliability.

GRA2 has lessons for any future Groundwater Resource Assessment process – mainly that some caution needs to be exercised when extrapolating from only a small amount of data. There is also a need for any outputs of a GRA process to be made widely available, so that planners may use them and so that other scientists may review the methodologies involved.

6. REVIEW OF SELECTED INTERNATIONAL METHODOLOGIES

Approaches for groundwater assessment and management differ world-wide, and depend to some extent on the legal and institutional mechanisms which underpin them. A variety of factors, not all of them “technical” or even directly related to groundwater (for instance legal history, national institutional structures, or disinclination towards groundwater use) all play a role. Three international examples have been selected to give an overview of how groundwater is assessed and managed elsewhere, and to draw conclusions relevant to South Africa. These examples are the United Kingdom, Australia and California. They were chosen on the basis of available data, and are also countries where significant efforts are being made to understand groundwater resources at present.

6.1 UNITED KINGDOM

6.1.1 Introduction

Groundwater makes up about a third of water for public supplies in England and Wales, about 11 % in Northern Ireland, and about 3 % in Scotland (Grey et al, 1995). This reflects the different aquifer potentials across the UK and variations in the availability of surface water resources. If non-consumptive uses (such as cooling) are taken into account, groundwater makes up about 15 % of water used. Although these figures show the importance of groundwater in the UK, they mask regional variations. For example, in the south-east of England, the most heavily populated part of the country, groundwater makes up most of the drinking water supply. Even in Scotland, where total groundwater use is low, there are around 30 000 private groundwater supplies, located particularly in rural areas where no other source may be available. Scottish groundwater is also used for public water supply and is economically important to industries such as breweries, agriculture and mineral water bottlers (SEPA, 2008).

The most important aquifers in the UK are the Cretaceous Chalk, the Permo-Triassic Sandstone, and the Jurassic Limestones. All of these aquifers show both fracture and intergranular groundwater flow, with the relative importance of each depending on the lithology and on the location. Borehole yields in all three aquifers can exceed 40 L/s.

6.1.2 Legal setting and institutions

Groundwater has been exploited in the United Kingdom for thousands of years, but laws specifically relating to national groundwater management date back to the 1945 Water Act, which defined national water policy and made some provisions for abstraction control and data collection (Grey et al, 1995). Further laws followed: the 1963 Water Resources Act recognised the unity of the hydrological cycle.

and the river basin as the basic management unit. The 1989 Water Act led to the formation of the National Rivers Authority (NRA) as an independent regulatory body with responsibility for water resources. The Water Resources Act of 1991 obliged the state to “monitor the extent of pollution in controlled waters”, which includes groundwater (Koreimann et al, 1996). The NRA was succeeded by the Environment Agency (EA), which is today the primary public body mandated to protect and improve the environment in England and Wales (Scotland and Northern Ireland have similar organizations). The EA has a head office, eight regional offices and twenty two area offices, and is responsible for the management of the UK’s groundwater resources through information, education and the enforcement of regulation (such as licences). The EA carries out its own groundwater research, and also commissions research from other organizations such as the British Geological Survey (BGS) and private consultants. Groundwater quality is protected legally both at a European Union level (Groundwater Directive 80/68/EEC) and by UK law (Groundwater Regulations 1998), although these are set to evolve as new EU legislation (especially the Water Framework Directive) comes into force in the next few years. Groundwater levels (or abstraction quantities) are controlled through a licensing system enforced by the Environment Agency. The EA relies on an extensive monitoring network of both groundwater and surface water resources (the two are considered to be part of the same resource), supported by a programme of research including conceptual and numerical modeling of major aquifers. Both quantity and quality of water are measured. The EA works with groundwater users in industry (such as water companies), farmers, private users and research organizations to refine groundwater policy at the local level.

6.1.3 Groundwater management resources – maps, databases and publications

Hydrogeology maps at a scale of 1:625 000 cover England, Wales and Scotland, and are intended for broad planning and conceptual purposes.

A series of more detailed regional hydrogeological maps at scales of around 1:125 000 exist for most major aquifer areas and some areas of lower groundwater potential (**Figure 6.1**). The information depicted on the regional maps varies from map to map, but typically includes potentiometric contours, annual rainfall, expected groundwater fluctuations, aquifer base levels, aquifer thicknesses, groundwater quality variations, locations of major abstractions and typical borehole hydrographs. The extent of saline water intrusion is shown on some of the maps. These maps give a reasonably good indication of expected borehole prospects, but for detailed local planning or for borehole siting and drilling further information is usually sought. Some of the information (e.g. the piezometric contours) is available as digital vector files for use in GIS systems, but the maps were compiled before the common use of GIS and are normally used as paper copies. They are available for sale from the BGS, the EA, and other outlets.

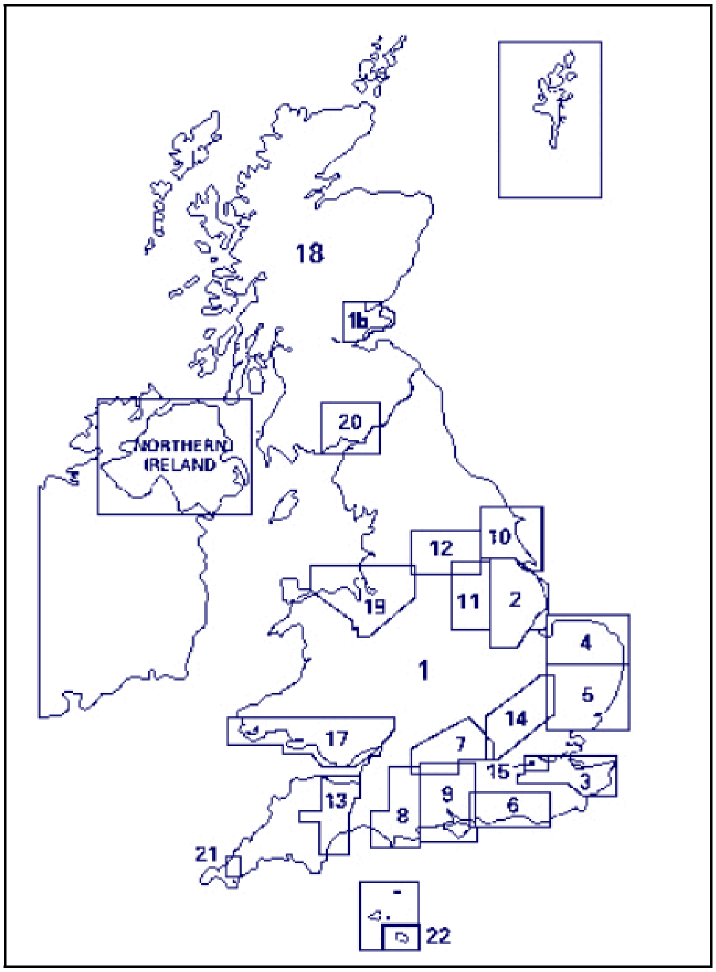


Figure 6.1: **Availability of UK regional hydrogeology maps**

A series of Groundwater Vulnerability maps covering the whole of England and Wales are published at a scale of 1:100 000, showing the vulnerability class of the underlying aquifers, based on type and yield of aquifer and the nature of the overlying material. The maps are based on the underlying aquifer classification, together with the soil leaching potential, depth to groundwater, presence of made ground and other factors. These are mainly used for planning purposes and for regulation, and further information is usually sought for local developments. The maps were prepared by the Soil Survey and Land Research Centre, and the British Geological Survey (BGS).

A large number of research reports and books are also available for British aquifers, including manuals on the properties of the major and minor aquifers produced by the BGS and series of reports on baseline groundwater quality for a number of aquifer regions produced by the BGS and the Environment Agency. The aquifer properties manuals show the geographic extent of each aquifer, summarize its hydraulic properties based on all available data, and provide information on groundwater quality.

The British Geological Survey (BGS) holds data on over 105 000 water wells and boreholes in its “WellMaster” database. By law, information on all boreholes in the UK should be passed to the BGS for their records, although in practice this does not always happen. In common with South Africa, the lack of information in some records is often a problem. Copies of most of these records, some dating back to the nineteenth century or earlier, can be obtained by anyone for a small fee. The information contained in each record varies, but as a minimum would give the exact location of the borehole and usually some indication of the lithology. Some records include detailed information on water level changes, water quality, and pumping test results. Any investigation at local scale of groundwater prospects would normally consult this database. The Environment Agency keeps a database of all licensed and domestic groundwater users, together with information on groundwater fluctuations and quality changes from a network of monitoring sites. This information is used by the Environment Agency in its planning and regulatory functions.

6.1.4 Assessment methodologies

Early estimates of groundwater volumes and sustainable use by the Environment Agency (EA) were based on recharge calculations, or on baseflow separation methods (Burgess, 2002). Both of these methods are problematic however, and today the EA considers that conceptual and numerical models of groundwater areas are necessary to manage groundwater, including the impact of abstractions on river flows and on dependent ecosystems. The EA is currently working on a programme aimed at deriving numerical models of all the major aquifer units in England and Wales, which will be used to support groundwater management decisions (Burgess, 2002). By 1998, 30 % of major aquifers were covered by numerical models, although not all of these models were updated or in use. Currently a good proportion of this modeling work is contracted out by the EA to the private sector, but in 2002 the EA’s long-term strategy was to bring more of the modeling work in-house as the work brings peripheral benefits to EA staff (Hulme et al, 2002). This groundwater modeling work is aligned with national and regional water resource strategy documents published and updated by the EA. The basis for the UK’s assessment methodology for groundwater therefore appears to be numerical models of aquifers, based on sufficient high-quality data.

Exploitation of groundwater for commercial purposes (including public supply) in the UK would normally be preceded by a hydrogeological study by the company concerned, which would inform their decisions and also support their licence application to the EA. Currently many aquifer units in England and Wales are considered to be over-exploited, and licences for large abstractions are not available. (An exception to this is the London Basin, where rising water levels in the Chalk aquifer are a concern). Abstractions for private domestic use, up to a maximum of 20 m3/day, are however exempt from licensing but the EA must still be notified and a record of the borehole provided to the BGS (similar to a General Authorisation in South Africa).

In an attempt to align and coordinate research into groundwater, including groundwater resource estimation and sustainability, the UK Groundwater Forum was established in 1994. The Forum has published a document which lays out issues and research needs in UK groundwater (Grey et al, 1995), and continues to act to draw together partners from the research and regulatory communities and from industry.

Groundwater assessment and management in the UK has grown from a situation in the 1970s where groundwater management has been described as “very poor” (Lloyd, 1994:39) to one in which a greater recognition of the role of groundwater in national water security, environmental health, flood prevention and other factors has led to greatly improved management based on increasingly accurate data and more sophisticated modeling techniques.

6.2 AUSTRALIA

6.2.1 Introduction

Australia is mainly arid to semi-arid, and has a land area of more than 7.6 M km2. About 80 % of the area (i.e. not population) of the Australian continent is mainly dependent on groundwater for consumptive use, and use of groundwater exceeds surface water in both Western Australia and the Northern Territory (Brodie, 2002). Concerns over security of water supply in Australia have been growing in recent years, particularly following the worst hydrological drought ever recorded (which began in 2005/6 and still hadn’t broken in some areas at the time of writing) and predictions of long-term climate change (Guardian, 2006). “Reform” of water policy and law is a strong theme in modern Australian policy and environmental direction, with an acknowledgement that certain modes of water use are not sustainable.

The most productive aquifers in Australia tend in general to be surface sedimentary aquifers, such as alluvium associated with rivers. For example, yields from irrigation wells in the Hunter River Valley in New South Wales can be up to 40 L/s (UNESCO, 2004). The Great Artesian Basin covers an area of about 1.7 M km2, and underlies parts of four states. It is up to 3 000 m thick, and artesian flows of more than 100 L/s have been recorded (UNESCO, 2004). It supplies more than 600 000 ML of groundwater per year for various uses, and is currently the subject of a 15-year plan to improve management (GABCC, 2000). The representation and assessment of groundwater resources over such a large and relatively sparsely populated area magnifies a number of problems which occur world-wide, such as the difficulty of collating a sufficient density of data for assessments to be meaningful. Australia is relatively far advanced in making groundwater data available digitally and freely (i.e. no charge) available.

6.2.2 Legal setting and institutions

6.2.2.1 National Level

At national level in Australia the Department of the Environment, Water, Heritage and the Arts and the Department of Climate Change have Divisions dealing with water, including groundwater. Policy is implemented at State or Territory level via the state level departments, which vary in name and mandate from state (or territory) to state. For example in New South Wales the Department of Water and Energy delivers the New South Wales Government's policy on water, whilst Queensland has a Department of Natural Resources and Water and an Environmental Protection Agency. Laws relating to water can be passed at both national and state/territory level.

A major "cross cutting" initiative at national level, known as the Australian Government National Water Commission, contributes to water (including groundwater) policy and assessment in all states or territories. The Commission is an independent statutory authority within the national Department of the Environment, Water, Heritage and Arts. The chair of the commission reports directly to the Minister. Following the 2005 National Water Commission Act, the National Water Commission began to compile a baseline picture of Australia's water management and resource issues, known as "Australian Water Resources 2005". This picture has been compiled with the help of the Water Resources Observation Network (WRON), a network comprising of several Australian institutions with expertise in the water sector including the CSIRO, the Bureau of Rural Sciences, the Australian Bureau of Statistics, and the National Land and Water Resources Audit (see below).

In 2007 the Australian National Water Commission through its Water Science Group began a programme (with a budget of A$ 82 million) to improve national knowledge and understanding of groundwater. The motivation behind the formation of the Commission included concerns over Australia's water resource management, a lack of data in some areas, and a skills shortage in the water sector. The groundwater programme's three main components are:

1. The National Groundwater Assessment Initiative – the main part of the Action Plan, the Initiative funds groundwater work and research into areas where it is needed, ranging from harmonisation of groundwater terms and standards to the management of risks to groundwater quality. Proposals are solicited from eligible organizations.
2. National Centre for Groundwater Research and Training – the Centre will train postgraduate scientists in areas of groundwater expertise.
3. Knowledge and Capacity Building component – this initiative will develop

groundwater guidelines and promote good practice to assist in groundwater sustainability.

The National Water Commission has just completed a study of the state of water planning in Australia, including an examination of case studies (Hamstead et al, 2008).

The Australian National Land and Water Resources Audit was established in 1997 following the National Heritage Trust Act, and has just concluded its operations. The audit was a collaborative programme between the Australia's government and states to provide data, information, and nationwide assessments of Australia's natural resources (NLWRA, 2008). An early recommendation of the Audit was the need for more strategic data collection to ensure data is accessible, collated and provided to the community and all levels of government as information. The Audit worked closely with other national government agencies such as the Office of Spatial Data Management, the Spatial Sciences Institute and the National Water Commission.

The Australian Bureau of Rural Sciences provides scientific advice to government on agriculture and related topics, and employs a multi-disciplinary team of scientists. Under their Integrated Water Sciences Program the Bureau carries out research into groundwater. The Bureau holds digital coverage of the 1:5 000 000 scale Hydrogeology of Australia map compiled by Jacobson and Lau (1987), and publishes reports on groundwater such as "An Overview of Tools for Assessing Groundwater-Surface water Connectivity". The Bureau is currently engaged with a project called Water 2010 (see below) which seeks to model national catchment water balances, a part of which is an assessment of groundwater recharge.

The CSIRO (Commonwealth Scientific and Industrial Research Organization) of Australia conducts research into a wide range of environmental problems (amongst other research areas). Its Hydrology Research Programme includes a Groundwater and Surface Water Hydrology Group, whose expertise includes the development of conceptual and numerical catchment models.

Headquartered in Canberra, Geoscience Australia (formerly the Australian Geological Survey Organisation) is Australia's national geological science organisation, producing geoscientific information and knowledge. Geoscience Australia also carries out research into groundwater resources via its Groundwater Group, part of the Geospatial and Earth Monitoring Division. Geoscience Australia works in partnership with state-level geological organisations, such as the Northern Territory Geological Survey or the Queensland Department of Mines and Energy.
The Australian Bureau of Meteorology (BoM) is headquartered in Canberra, and has state offices in each state capital. Its main focus is on climate, but it collaborates with

other organizations in water resource assessment. The BoM has a Water Resources Group, which is involved with a number of projects aimed at assessing Australia's water resources, including groundwater. These include the Australian National Land and Water Resources Audit and the National Water Initiative (both mentioned above). Data and information about these programmes can be downloaded from the BoM website at http://www.bom.gov.au/hydro/wr/

6.2.2.2 State Level

The day-to-day practicalities of groundwater management are generally carried out at state level or lower and state level institutions normally regulate groundwater abstractions – although the exact policy depends on the state or territory. For example, in New South Wales "Available Water Determinations" are made by the (state) Minister for Water under the Water Management Act (2000). These "determine the volume of water available for extraction for the various categories and subcategories of access licences in relation to those water sources covered by water sharing plans throughout the State" (NSW, 2008). In many parts of the state, new water licences are "embargoed" (no new ones available), and prospective water users must purchase existing licences. Furthermore, the state can (and does) seek to reduce some licence allocations when negative impacts occur – for example a new groundwater plan for the Lower Gwydir area of New South Wales required large cuts in entitlements, although final figures were only agreed after extensive consultation with (and campaigning by) affected parties (Hamstead et al, 2008). Licence allocations may be reviewed annually, in line with predictions for the "water year" ahead. At the level of individual boreholes, owners need to obtain consent from the New South Wales Department of Water and Energy to drill the borehole, but the requirement for a licence depends on what the water will be used for (e.g. domestic and stock use normally does not require a licence). The Department of Water and Energy operates a "Groundwater Drilling Unit" which carries out drilling tasks not normally tackled by ordinary drilling contractors (e.g. deep artesian boreholes, unstable formations, etc.). The Unit has several specialised drilling rigs, a pumping test rig and a geophysical logging truck. Drillers in Australia are required to be licensed, and must submit their drilling records to the appropriate authorities where they are kept as a database.

6.2.3 Maps and resources

The earliest published groundwater maps in Australia were outputs of the state geological surveys in the nineteenth century, but there is evidence that Aboriginal peoples used diagrams showing water sources in prehistoric times (Brodie, 2002). A major output of the National Land and Water Resources Audit was the Australian Natural Resources Atlas, which includes mapping with a hydrogeological basis such as the mapping and categorization of groundwater flow systems at a national scale, and estimates of relevant parameters such as soil hydraulic conductivity and soil water content. Digital data is available on-line from the Australian Natural Resources Data Library at http://adl.brs.gov.au/anrdl/php/, much of it free of charge. The Atlas is intended to be used by managers and community groups for planning and management purposes.

In addition to hydrogeological maps published at a small scale by Australian government agencies, other hydrogeological maps include those published by state groundwater agencies at a larger scale covering important state groundwater resources. These maps include:

- The 26 maps at 1:250 000-scale of the Murray Basin Hydrogeological Map Series
- The 1:5 000 000 scale map of the Hydrogeology of the Great Artesian Basin (Habermehl and Lau, 1997), which covers roughly a fifth of Australia (about 1.7 M km2)
- Specialised hydrogeological maps (e.g. groundwater vulnerability, salinity hazard/risk and groundwater dependent ecosystems) developed in the 1990s
- State-level mapping covering priority groundwater management areas

Most of these maps are available as digital GIS coverages, and much of this data is free to download from the websites of institutions such as the Bureau of Rural Sciences and the Australian Natural Resource Data Library. Efforts are being made to standardise digital hydrogeological data, and to fill data gaps. The aim is to allow the production of maps customised for area and for theme, based on a variety of "underlying" hydrogeological and other datasets in digital format.

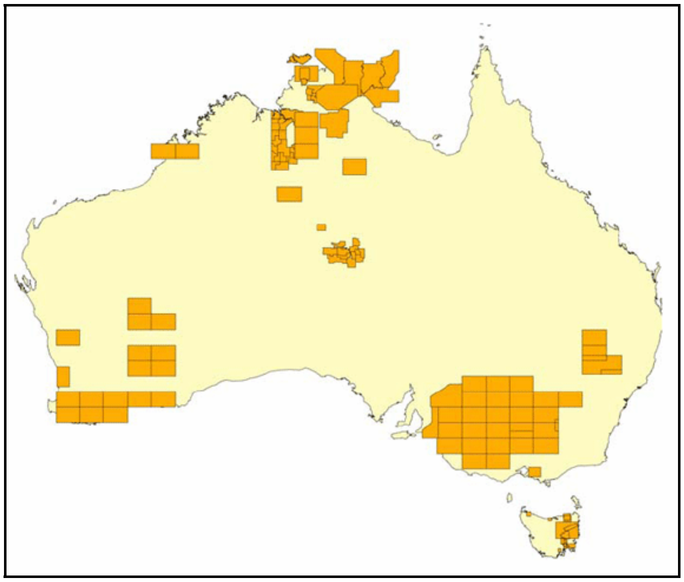


Figure 6.2: Extent of published hydrogeological maps at 1:250 000 or larger, after Brodie (2002

Efforts are being made to understand the requirements of groundwater-dependent ecosystems (GDEs), and to incorporate these into planning and regulation. According to the National Water Commission website (http://www.nwc.gov.au/www/html/225-groundwater-dependent-ecosystems.asp) six types of GDEs are conventionally recognised in Australia:

- Terrestrial vegetation that relies on the availability of shallow groundwater
- Wetlands such as paperbark swamp forests and mound springs ecosystems
- River base flow systems where a groundwater discharge provides a baseflow component to the river's discharge
- Aquifer and cave ecosystems where life exists independent of sunlight
- Terrestrial fauna, both native and introduced, that rely on groundwater as a source of drinking water
- Estuarine and near-shore marine systems, such as some coastal mangroves, salt marshes and sea grass beds, which rely on the submarine discharge of groundwater.

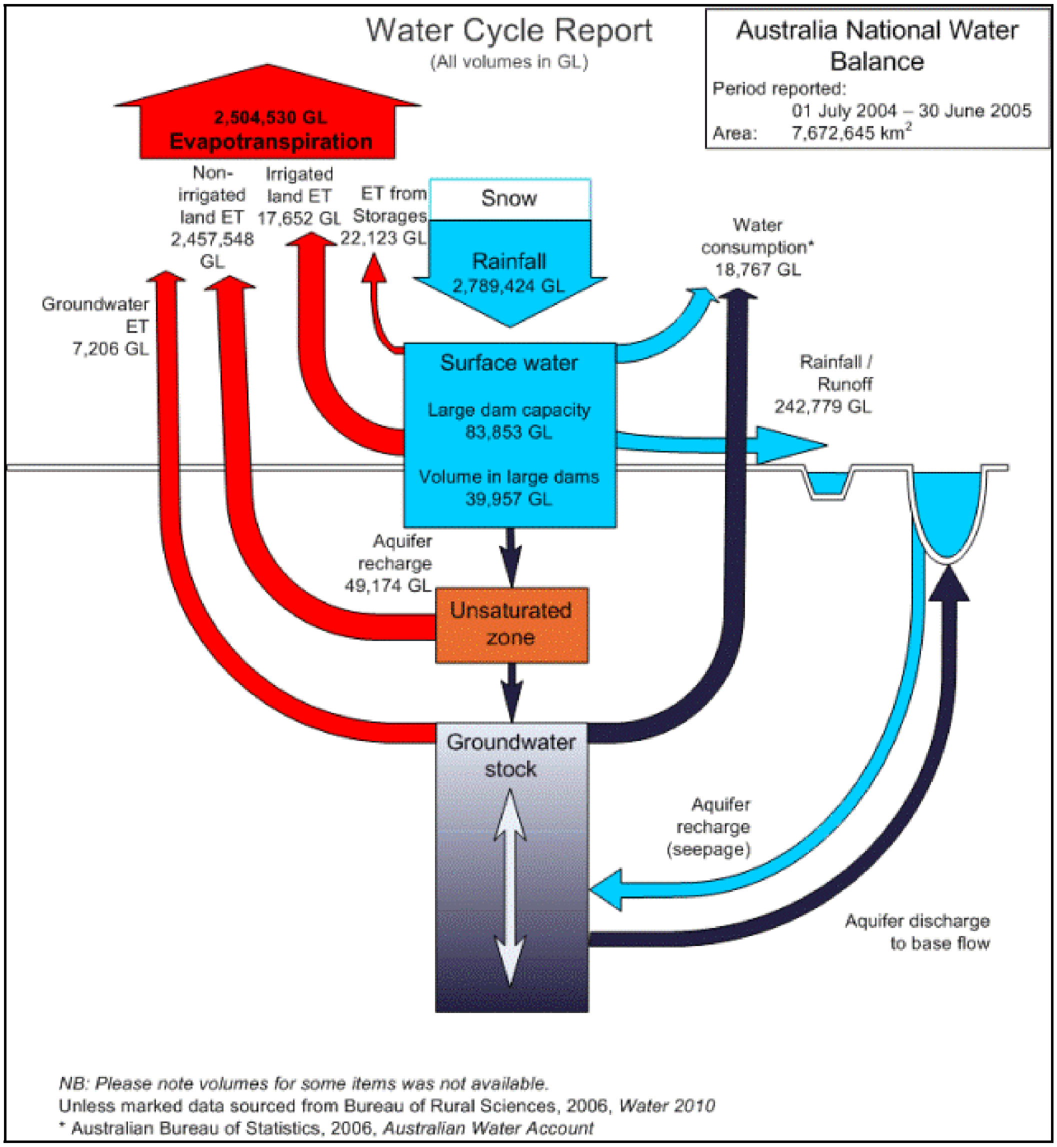
6.2.4 Assessment methodologies

Better groundwater data is recognised as a big factor in improving groundwater assessment and management in Australia, and the shift from paper or map-based data to digital GIS coverages has been taking place since the mid-1980s. Data formats are also being standardised (Brodie, 2002). These developments make it easier to tailor data to a specific use, such as planning and managing new abstractions, and also make data more accessible. A working group, with representatives from Australian groundwater institutions, is responsible for drafting national groundwater data standards (The Australian National Groundwater Data Transfer Standard). At the same time, there appears to be growing concern in Australia over a number of groundwater related issues:

- The country is semi-arid to arid, and highly vulnerable to droughts and to the effects of climate change. Severe droughts have endangered economic output in recent years. There is now an Australian national Minister for Climate Change and Water, and the Department of Climate Change was established in December 2007.
- Water resources in Australia, including groundwater, are over-allocated in some areas, and are also threatened by pollution. Different users compete for water.
- Groundwater does not receive the recognition that it merits in terms of its strategic or economic importance.
- Environmental flows and groundwater-dependent ecosystems are imperfectly understood.
- Current management arrangements related to groundwater are likely to be inadequate.
- There are gaps in the scientific understanding of Australia’s groundwater resources, and a lack of skilled groundwater scientists.

- Groundwater and surface water should be seen as interdependent, but this is not always the case.
- There are inadequate legal and management instruments (such as trading of entitlements) to facilitate better groundwater management.

Estimates of national groundwater recharge, runoff and evapotranspiration in Australia depend mainly on water balance modeling (conceptual, analytical and numerical), with data derived from a variety of sources and organizations. The Australian Water Resources 2005 Water Availability Assessment (part of the National Water Commission's work) depended on water balance assessments undertaken for 51 priority geographic areas. This methodology is known as the "water accounting approach", a method being developed in Australia which takes the dynamic nature of water resources into account (i.e. different time-scales may apply to surface water and groundwater, and a single year may well not be representative of the resource) (see Figure 6 3). The work is still underway, as part of the Water 2010 Project and Australian Water Availability Project being carried out by the Bureau of Rural Sciences (2008). The project aims to release reports summarising average annual water availability and use for every River Basin and Drainage Division in Australia. Essentially, the aim is "to develop an operational system for estimating soil moisture and other components of the water balance, at scales ranging from five kilometres (km) to all Australia, over time-periods ranging from daily to decades" (Bureau of Rural Sciences, 2008). This will help with future planning, decision making and risk assessment. Reports released to date for the Australian Water Availability Project can be downloaded for free from the Bureau of Rural Sciences shop at http://affashop.gov.au/.



NB: Please note volumes for some items was not available.
Unless marked data sourced from Bureau of Rural Sciences, 2006, *Water 2010*
* Australian Bureau of Statistics, 2006, *Australian Water Account*

Figure 6.3: Diagram of Australian approach to water balance assessment (National Water Commission website)

It is acknowledged that there is a great variation in groundwater recharge, depending on topography, surface morphology, vegetation, geology and other factors. The National Land and Water Resources Audit (NLWRA) estimated total national water inflows at 291 953 gigalitres (1 gigalitre = 0.001 km3) for the 2004–05 year, which includes a total surface water runoff of 242 779 gigalitres and groundwater recharge of 49 174 gigalitres. The volume stored in large dams (wall height greater than 15 m) was 44 164 gigalitres as at 1 July 2004, making a total water resource estimate for Australia of 336 117 gigalitres (or just over 336 km3). The NLWRA did not recognise the close interaction of surface water and groundwater resources. As a result, 'double accounting' of the water resource (i.e. counting a parcel of water as contributing to both surface water yields and groundwater yields) was recognised as an issue that was not adequately addressed in NLWRA, which may have led to over-estimating of the quantity of the resource in that report. The total storage capacity of large dams across Australia in 2004–05 was 83 853 gigalitres (84 km3). This figure excludes small dams (such as farm dams) which are much more difficult to assess.

Local groundwater management in Australia should therefore be seen against a background of growing concern over national water resources, and a move towards more efficient and conjunctive prediction and management of water amidst predictions of worsening shortages. Greater transparency and consultation is also desirable. Depending on the location, a plan to exploit groundwater locally would start with an interrogation of existing data (and/or maps), but should ultimately rest on a conceptual (or better a numerical) model of local water resources, taking into account climate variability and the local and regional environmental requirements. Groundwater policy at both national and state level would need to be followed, and all necessary permissions and licences obtained. Continued use of the groundwater resource would be based on a broadening understanding of the state of the resource, based on better data collection and focused research. Meeting of demand for water would depend not only on better exploitation of the resource (taking into account sustainability concerns), but also on demand control (limits to entitlements) through education, water-saving measures and pricing. These measures would be enforced at state/territory water planning level.

6.3 CALIFORNIA

6.3.1 Introduction

California is the most populous state in the United States of America, and the third largest by land area (414 000 km2). Geographically it ranges from deserts to high mountains, with deserts making up about a quarter of the surface area, and forests covering another third. The most important aquifer is the basin-fill Central Valley Aquifer, which is extensively used for water supply and irrigation. On less than 1 percent of the total farmland in the United States, the Central Valley supplies 8 percent of the national agricultural output by value – mainly due to irrigation, part of which is groundwater from the Central Valley aquifer (Reilly et al, 2008). Most of the other major aquifers in California are also basin-fill, consisting of sediments which have filled structural depressions. Volcanic rock and carbonate aquifers provide smaller, local groundwater resources.

Groundwater today meets about 30 % of California's urban and agricultural water needs on average, rising to about 40 % in drought years (DWR, 2003). Many small to medium size towns such as Fresno (pop. > 400 000) or Lodi (pop. > 55 000) in California are entirely dependent on groundwater for their water supplies, and nearly half of Californians rely on groundwater for at least part of their water supply (DWR, 2003). In many parts of the State there is evidence of a steady decline in groundwater levels, and in other areas declines are expected if current management strategies are continued. Good data is available for the most heavily used aquifers, but in many other areas data is scarce.

6.3.2 Legal setting and institutions

Law in the United States operates at both national (Federal) and State level. States have their own constitutions and state governments, and pass laws on a wide range of issues not covered by Federal law (which is based on the US Constitution). Water law principles differ depending on the state. California adheres to the “prior appropriation” system of surface water rights, which means that a right to water is not necessarily owned by the property owner, but can be sold or mortgaged like a piece of property. Each surface water right has an appropriation date (date first used) and a yearly quantity. The oldest or “senior” appropriation has prior right to the water, in cases where not all allocations can be met. In terms of groundwater, the owners of the land overlying an aquifer in California have a right to a reasonable amount of that groundwater for their own use. The amount depends partly on the surface area of the land owned. This is similar to the riparian system for surface water use. It is not known how interaction between groundwater and surface water is accommodated legally in California. Water allocations and regulation are overseen by the state government and its agencies, and this can devolve to county level – for example Sonoma County has a Water Agency which is responsible for water planning in the county.

The United States Geological Survey (USGS) is the main water, earth, and biological science and civilian mapping agency in the United States, and employs around 10 000 people. The USGS head office is in Reston, Virginia, and it has a Region Office in Colorado and another in California. Offices which are part of or affiliated to the USGS exist in every state.

The United States Environmental Protection Agency (USEPA) is headquartered in Washington DC, has ten regional offices and employs around 17 000 people. The USEPA implements environmental law by writing and enforcing regulations (for example the Clean Water Act), provides grants, works in partnerships with other environmental organisations, and conducts scientific research into environmental issues. The USEPA also publishes information and teaches people about the environment. The USEPA’s Office of Ground Water and Drinking Water works to ensure safe drinking water, and to protect groundwater.

The Superfund

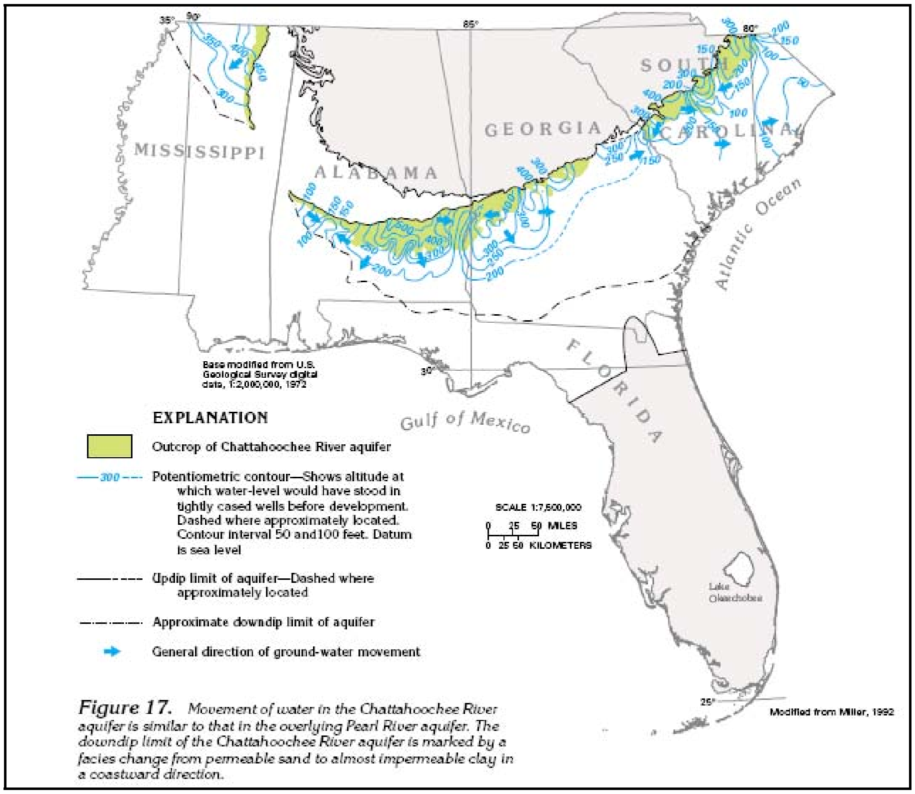
In 1980 the Comprehensive Environmental Response, Compensation, and Liability Act (known as "Superfund") was passed in the United States, beginning a programme of cleaning up hazardous waste sites, including groundwater contamination, across all 50 states. Superfund gives the USEPA authority to find parties responsible for pollution of the environment, and compel them to cooperate in cleaning up the pollution. In the case of sites where the owner or responsible party cannot be found, the USEPA is enabled to direct the cleanup themselves, and recover costs through a variety of mechanisms where possible. The USEPA works closely with the relevant state environmental agencies and other parties in the work. The Superfund legislation has been responsible for several notable groundwater pollution remediation projects at "superfund sites" across the United States.

Figure 6.4: Box introducing Superfund legislation in the USA

The California Environmental Protection Agency was formed in 1991, and has six boards or departments under it employing about 5 000 people. It is headed by the Office of the Secretary, who is responsible for coordinating and overseeing the activities of the boards, for strategic planning and for budget review. The Board tasked with water regulation and protection is known as the California State Water Resources Control Board. The State Water Board has primary responsibility for balancing the needs of various water users, including industry, agriculture, domestic users, and the environment. The Board was created in 1967 by merging two former boards. The Board allocates water rights, adjudicates water right disputes, develops state-wide water protection plans, and establishes water quality standards. One of the stated goals of the State Water Board is that "groundwater is safe for drinking and other beneficial uses". The Board has five full-time, salaried members. Nine Regional Water Quality Control Boards are located in the major watersheds of California, and are the main implementing agencies for both state and federal water pollution laws. Each Regional Board has nine part-time members. State and Regional Water Board members are appointed by the State Governor and must be confirmed by the State Senate. A Basin Plan exists for each watershed and provides a scientific and regulatory basis for basin water protection work. The regional Boards are semi-autonomous and are responsible for setting water quality standards, issuing waste-discharge permits, and checking and enforcing compliance. The State Water Resources Control Board recently formed the Groundwater Resources Information Sharing Team (GRIST) consisting of several State and federal agencies with groundwater-related programs, in an attempt to better coordinate data exchange and avoid duplication of effort (DWR, 2003).

6.3.3 Maps and resources

The Ground Water Atlas of the United States (Miller, 2000) is published by the United States Geological Survey (USGS) and describes the location, extent and hydrogeological characteristics of major aquifers in the United States. The atlas has 14 chapters - an introductory chapter and 13 chapters covering regional areas called “segments”, which together cover the land area of the United States. The segment covering California (Segment 1) also includes the state of Nevada. The atlas as written so that it would be accessible to non-specialists and it avoids technical jargon where possible. Each segment begins with an overview of the climatic, geological and hydrological conditions. Aquifers are described in terms of their location, extent, thickness, water level conditions and water quality (Miller, 1994). The atlas was intended to improve public information and awareness regarding groundwater as one of its functions, as well as providing a useful planning and overview document. It is freely available on the USGS website.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

EXPLANATION

🟩 Outcrop of Chattahoochee River aquifer

—300--- Potentiometric contour—Shows altitude at which water-level would have stood in tightly cased wells before development. Dashed where approximately located. Contour interval 50 and100 feet. Datum is sea level

———---- Updip limit of aquifer—Dashed where approximately located

—·—·—· Approximate downdip limit of aquifer

➜ General direction of ground-water movement

Figure 17. Movement of water in the Chattahoochee River aquifer is similar to that in the overlying Pearl River aquifer. The downdip limit of the Chattahoochee River aquifer is marked by a facies change from permeable sand to almost impermeable clay in a coastward direction.

Figure 6.5: Detail from the Introductory Chapter of the Ground Water Atlas of the United States (Miller, 2000)

The USGS Ground-Water Resources Program’s Circular 1323 “Ground Water Availability in the United States” (Reilly et al, 2008) describes groundwater in the USA, including major aquifers, water level and water quality trends, and a description of regional scale resource assessment.

The USGS and its affiliates maintain a network of boreholes to provide statistics on ground-water levels across the United States. The USGS also has a large database of borehole and groundwater information which is managed at state or local level. It includes surface water, groundwater and water quality data, and the groundwater database alone contains records from about 850 000 boreholes or wells. Some of these records are a century old. Water levels at about 20 000 of these sites are monitored annually, for a variety of reasons including state monitoring programs or as part of local and regional research projects (e.g. the High Plains Aquifer Monitoring Program). Data and information about the records are available to the public over the web at the National Water Information System Web Interface site at http://groundwaterwatch.usgs.gov/. In the State of California it is estimated that there are about 10 000 boreholes or wells which are monitored for water levels. The distribution of these tends to be biased towards the main aquifers or basins (DWR, 2003)

6.3.4 Assessment methodologies

No single "assessment methodology" for the whole state of California appears to be accepted state-wide. Certain trends can however be identified. There appears to be a shift towards more local (county level) groundwater assessment and management in California, following legislation passed in the early 1990s. There are efforts being made towards making or improving local groundwater management plans, and integrating these plans with other agencies such as water suppliers. These plans often call for more data, and local governments are becoming involved in data collection and interpretation. However there is no obligation on the part of local planners to submit groundwater management plans to the State Department of Water Resources. Cooperation between local (county) level agencies sharing an aquifer is sometimes not adequate for effective management purposes. Local groundwater management plans ideally need to be integrated with regional or basin scale aquifer assessments, such as are conducted by the USGS (e.g. their "RASA" or Regional Aquifer-System Analysis Program, begun in 1978), although it is not known whether there is a formal mechanism for this at present. Regional scale aquifer assessments would typically aim to develop a numerical model of all or part of the regional aquifer system, based on as much data as possible.

Table 6-1: Comparison of the three international examples with South Africa

Case study country	Land area (km^2 x 1000)	Pop. (M)	Groundwater dependence (domestic supply) estd.	Digital groundwater data availability	Notes
United Kingdom	244	61	30 %	Descriptions and data normally for sale. Incomplete digital availability.	High groundwater dependence in populated SE of country. Moves towards numerical modeling (hydrodynamic methods) for regional assessment.
Australia	7 600	21	15 %	Descriptions and data are free to download, much available digitally. Moves towards common digital data standards.	Higher priority now given to groundwater. Efforts to limit abstractions. “Water accounting” approach developed for groundwater assessment.
California	414	36	30 %	Descriptions and data are free to download. Good digital coverage.	Groundwater very important for domestic supply and agriculture. Local or county management. Assessment appears to be done on an ad-hoc basis, preferably based on numerical model results.
South Africa	1 200	49	60 %	Some descriptions free to download, state data currently available free on request (NGDB) – plans for web access to groundwater data.	Process of devolution of groundwater management to water management areas from national level. Serious efforts being made to increase groundwater resource assessment. Available resource potential is between 7.5 km^3/a and 47.7 km^3/a depending on what factors taken into account.

6.4 INTERNATIONAL ASSESSMENT DISCUSSION

The concept of “safe yield” is often used when planning groundwater abstractions – i.e. the volume of water that can be extracted without undesirable consequences such as loss of baseflow to rivers, ingress of saline water or excessive lowering of the water table. Undesirable consequences need to be defined first of course, and the definition of these can change with time. There are several groups of methodologies available for assessing “safe yield” (UNESCO, 2004):

- Hydrodynamic methods – these involve analytical and numerical calculations, and include numerical modeling. These methods require sufficient data, such as knowledge of boundary conditions and initial water levels, to be successful.
- Hydraulic methods – based on empirical observations and measurements of pumped boreholes, surface water features, etc. These methods have the advantage in that they constitute real observations of the system, but it is difficult to extrapolate test data beyond what is observed – which is a common requirement.
- Method of hydrogeological analogy – this refers to the transfer of knowledge from an aquifer system which is well known, to another where information is scarcer. Success depends on the similarity of the two systems, and the degree of accuracy required.
- Method of expert assessments – this is basically the ability of an experienced groundwater professional to give estimates for a system where data is scarce. Success will depend on the skill (and any unconscious bias) of the professional, and the complexity of the system.

In all three case studies discussed above, hydrodynamic methods appear to be favoured for all but the simplest systems. Other methods are also used however, if only to provide first approximations and in the construction of conceptual models. On-going monitoring of water levels, surface water flows, etc will normally be carried out, and management decisions made according to the flow of information. Hydrodynamic methods need good data, at sufficient density, and therefore can be expensive to implement. Decisions about groundwater development are often taken in the context of growing pressure on the resource, and better knowledge of the consequences of over-abstraction. It appears from the case studies that there is an increasing concern about groundwater resource depletion or degradation, and a growing demand for greater certainty in hydrogeological prediction and management. This is likely to imply a further shift towards numerical modeling of local and regional aquifers, with all of the attendant data requirements and conceptual modeling that this implies. The following brief conclusions can be drawn from the case studies, with relevance to our situation here in South Africa:

- Increasing moves towards better and more accurate determination of groundwater resources is driven by increasing competition for water resources, a better appreciation of the ecological role of groundwater, and an expanding awareness of possible water supply disruption or variation due to climate change.

- Awareness of the importance of groundwater outside of a relatively small community of experts needs to grow, partly to help ensure funding and political/institutional support for assessment programs.
- There does not appear to be a single methodology for groundwater assessment, although numerical modeling of one sort of another is often seen as desirable. The Australian “accounting” system may be the most ambitious and technically demanding. Integration with surface water assessment is necessary.
- Assessment methodologies should ideally be able to predict what might occur in future, as well as providing a snapshot of the present. This is necessary for planning and the mitigation of risk.
- Institutional cooperation is vital in groundwater assessment, since almost all methodologies are very data intensive. This requires strong coordination at the national level.
- Appropriate legislation is likely to greatly facilitate national and regional assessments, with the institutional collaboration and coordination which is required.

The large increase in Australian efforts to quantify and manage groundwater in recent years is a result of specific legislation. In all the three cases reviewed there is a clear link between the planning and legal framework and groundwater assessment requirements.

The Australian case study in particular presents a lot of lessons for South Africa on the strategic nature of groundwater. It demonstrates that a high level of financial investment into groundwater management is supported by robust institutional arrangements at national to state then regional and local levels.

7. CONCLUSIONS

It is necessary to reach a better quantitative understanding of South Africa's groundwater resources, including that portion which can be used sustainably, for reasons that include:

- More effective implementation of national environmental legislation, including the Water Act.
- Better water resources planning and more efficient service delivery
- Greater recognition of groundwater as a reliable and sustainable national water resource – groundwater needs to take its "rightful place" along with surface water as a key national resource, in the eyes of decision makers as well as scientists.
- The facilitation of new developments in the most streamlined and cost-effective ways possible (industrial, agricultural and others).

Earlier efforts in South Africa, up to and including GRA2, have relied mainly on existing data (such as held in the NGDB), applied in various ways and with a variety of quality control techniques and modes of filling data gaps. Better quantification of the nation's water resources will inevitably rely on more data, as well as better data assessment techniques.

International examples indicate that numerical techniques (hydrodynamic methods) are currently most favoured for estimating local groundwater availability, including the impact of abstractions on adjacent groundwater systems and users. These are often done on an ad-hoc basis, with more attention and resources being given to those areas where pressures are greatest on the resource, and comparatively little attention paid to less pressured areas. There is no "one size fits all" groundwater assessment methodology, and methodologies appear to have developed organically against a changing background of data, human resources, legal requirements, growing demand, and water restrictions. Indeed, changes in groundwater assessment methodologies over the years in the international examples suggest that fixation on a single methodology for this country may not be appropriate. In South Africa, with our historical bias towards surface water, there may be a subconscious desire to choose a single groundwater assessment methodology (such as the surface water system currently in use) and adapt data collection, staff deployment and other policies towards that methodology. This should be resisted.

In Australia it is recognised that the different time scales or variations inherent in water resource assessment (e.g. between groundwater and surface water, or due to unpredictable drought cycles) demands some kind of annual accounting system which begins each year with a "statement" of the resource carried over from the previous year. It is likely that South Africa would benefit by moving towards such a “dynamic” system – although it is acknowledged that this would be very data intensive. The case of Australia also demonstrates the role of robust and well-funded groundwater institutions in assessing groundwater and driving groundwater policy.

All of the international examples show a move towards more data-intensive groundwater assessment methodologies, and increasing data density and availability in South Africa should be a core part of GRA3. This need not mean collecting new data only – much data that is already generated in South Africa (e.g. by private consultants and drillers) is currently difficult to access. It is likely that a process to centralize “private” data would be a very cost effective and rapid way of expanding national groundwater data archives in South Africa.

Finally, the coordination of databases, implementation of legislation and policy, initial assessment of promising regional groundwater resources and many other functions all depend (to an extent) on a capable and well-resourced Department of Water Affairs, with a strong groundwater capacity in particular. At present concerns exist as to the capacity of the Department in this regard, and support needs to be given to the various initiatives aimed at remedying the situation.

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