A

SOUTH AFRICAN AQUIFER SYSTEM MANAGEMENT CLASSIFICATION

BY WRC & DWAF

WRC REPORT NO KV 77/95

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SOUTH AFRICAN

AQUIFER SYSTEM

MANAGEMENT CLASSIFICATION

prepared for

Water Research Commission

and

Department of Water Affairs and Forestry

prepared by

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EXECUTIVE SUMMARY

A need for a South African aquifer classification system has existed for some time. An initiative by the Department of Water Affairs and Forestry to develop a strategy for managing groundwater quality has required that such a system, together with the classification of South Africa's aquifers, be given attention as a matter of some urgency. The classification system is required to provide a framework to support the regulatory system currently being developed by DWAF.

A literature study of classification systems used elsewhere in the world was undertaken. The study was supported by a series of Scoping Workshops at which the desired features and characteristics were discussed. A proposed classification was then developed and presented to a Technical Workshop for discussion after which the final classification was formulated.

The aquifer system management classification developed during the study (overleaf) is based on the British Geological Survey aquifer vulnerability classification, but also recognises the need to consider two important management aspects, namely:

- the high value of sole source aquifers in South Africa, and
- the need for a pragmatic approach which allows for special factors to be considered.

It was also recognised that a single classification could not meet all needs and that modifications would be required for specific tasks. A flexible decision-support tool was hence developed which relates the aquifer system management classification to a user defined variable by means of a simple weighting and rating approach.

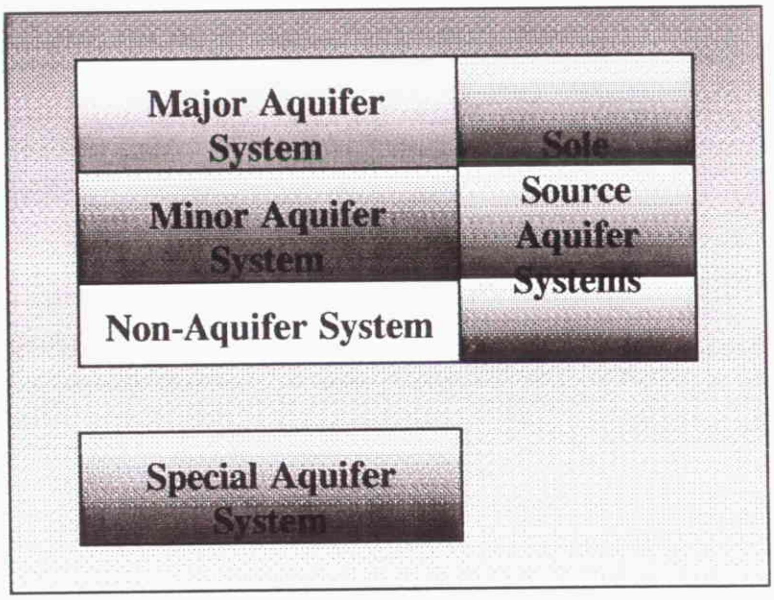
Using this decision-support tool, a Groundwater Quality Management classification was developed. The aquifer system management classification was linked to an aquifer vulnerability classification in order to define the level of protection required in a particular area. The Groundwater Quality Management classification can therefore be used to support the national Groundwater Quality Management Strategy.

The process of implementing the classification still needs to be addressed as do the implications of adopting the approach. It is recommended that a national scale classification map be prepared and distributed as a means of gaining widespread support for the aquifer system management classification and the associated decision support tools.

The classification system presented is a **useful planning tool** that provides a starting point for national and regional classification of South Africa's aquifers. It is unlikely that the Groundwater Quality Management classification can be used for site specific applications. The proposed classification is not, however, cast in stone and, as available information and knowledge grows and the national Groundwater Quality Management Strategy evolves, so too will the need to extend or modify the aquifer classification. A degree of flexibility needs to be applied when classifying aquifers in order to accommodate our limited knowledge and the precautionary principle.

Classification System

Aquifer System Management classification



Definitions of Aquifer System Management classes.

Sole Source Aquifer System	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

ACKNOWLEDGEMENTS

The joint funding of this project by the Water Research Commission and the Department of Water Affairs and Forestry is gratefully acknowledged.

The research reported on in this document was guided by two discussion groups held in August 1994 and April 1995. The participants of these discussions are thanked for their input and constructive approach to the problem:

Mr AG Reynders	Water Research Commission
Mr E Braune	Department of Water Affairs and Forestry
Mr L Bredenhann	Department of Water Affairs and Forestry
Mr SAP Brown	Department of Water Affairs and Forestry
Mr M Simonic	Department of Water Affairs and Forestry
Mr Y Xu	Department of Water Affairs and Forestry
Mr J Wates	Wates, Meiring & Barnard
Mr G Wells	Wates, Meiring & Barnard

A draft classification was then presented at a workshop held at the Rob Roy Hotel on 19 September 1995. The workshop delegates are thanked for their constructive input.

The support of my colleagues of the Groundwater Programme in helping to develop and expand the concepts presented here is also gratefully acknowledged.

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1. INTRODUCTION

A need for a South African aquifer classification system has existed for some time. However, an initiative by the Department of Water Affairs and Forestry (DWAF) to develop a strategy for managing groundwater quality has required that such a system, together with the classification of South Africa's aquifers, be given attention as a matter of some urgency. The classification system is required to provide a framework to support the regulatory system currently being developed by DWAF.

A number of geohydrological classification schemes have been proposed or presented in South African literature (DWAF, 1994; Vegter, 1994, 1990; Jolly and Reynders, 1993; Simonis and Kok, 1989). None of these have, however, led to a formalised aquifer classification system. The classification system proposed in this document is based on a study of aquifer classification systems used elsewhere in the world. It was important that public support be gained for the proposed classification system in order that a South African classification could be put in place. Particularly, support must be obtained from those individuals or groups which would implement and use the system.

It is common for aquifer classification systems to be linked to groundwater protection initiatives (Jolly and Reynders, 1993; AWRC, 1992; NRA, 1992; Xu et al., 1991; US EPA, 1990; US EPA, 1984) as the classification can be used to reduce the complexity of implementing a protection policy. This is particularly true when adopting a policy of differentiated protection. However, the use of classification systems is widespread and varied. Public education is but one important application. This document concentrates on the evaluation of classification systems and not the use to which they can be put. It is nonetheless accepted that a chief use of the classification system will be linked to groundwater quality management.

It needs to be accepted that the aquifer classification system presented in this report provides a starting point for the national and regional classification of South Africa's aquifers. The proposed classification is not cast in stone and as available information and knowledge grows and the national Groundwater Quality Management Strategy evolves, so too will the need to extend or modify the aquifer classification. Further, a degree of flexibility needs to be applied when classifying aquifers in order to accommodate our limited knowledge and the precautionary principle.

2. TERMS OF REFERENCE

Based on the Scoping Workshop held at DWAF offices on 16 August 1994 and subsequent correspondence, the *Terms of Reference* for the project were:

> *The project deliverable is a fully developed proposal for a national aquifer classification system for South Africa which is to be integrated into the groundwater quality management strategy presently under development.*

The Groundwater Programme, Watertek, CSIR was to conduct a literature review in order to evaluate aquifer classification systems used elsewhere in the world. Using this information, a national-scale aquifer classification system suitable for South Africa was to be proposed. In developing such a system, the following aspects had to be considered:

a. dovetailing, as far as is possible, with the policy objectives and strategies of the National Groundwater Quality Management Strategy presently under development.
b. the linkage between classification and other prioritization approaches at different levels and the possible need for a hierarchical classification system for different scales (ie. national, regional and local scale).
c. the nature of the classification is expected to evolve over time.
d. the main function of the national aquifer classification system, the purposes to which it can be put, the information requirements and the level of resolution.
e. approaches developed in the current regional hydrogeological mapping.

A short document was to be prepared in which the background to the project, special considerations and constraints and possible systems are to be presented. This document was to be no more than 25 pages in length. The document was to be distributed to the Scoping Workshop participants by the end of January 1995 for comment. Once comment was received by no later than mid-February, the document was to be revised. The revised document was then to be used as a basis for the Aquifer Classification Workshop, which was to have be held in mid-March. A final version of the national aquifer classification system document was then to be prepared and submitted to the Water Research Commission (WRC) for publication. The submission of the document to the WRC constitutes the conclusion of the project.

3. REPORT STRUCTURE

Following the introduction and setting of the Terms of Reference (Chapters 1 and 2), the method of research (Chapter 4), current initiatives for developing a national Groundwater Quality Management Strategy and the role of the aquifer classification in the management strategy (Chapter 5) are described. Common features and factors used for aquifer classification are presented in Chapter 6 while the proposed national Aquifer System Management classification is documented in Chapter 7. The application and implications of adopting the system are highlighted in Chapters 8 and 9. Conclusions and recommendations are presented in Chapter 10.

Owing to the wide variety of people from different disciplines who may read this document, it was important that terms used in the report be clearly defined so as to avoid any misunderstanding. A glossary was thus compiled and is presented at the end of the report.

4. RESEARCH METHOD

Following the submission and acceptance of a research proposal to the WRC and DWAF, a scoping workshop was held at DWAF's offices on 16 August 1994. The purpose of the meeting was to ensure that the aquifer classification system developed during the project would meet the needs of the Department and ensure that it could be used as part of the Groundwater Quality Management Strategy. A literature review was then carried out on classification systems used elsewhere. Most of the literature merely presented the classification systems with little critical appraisal. It also appeared that most of the systems were applicable to primary aquifer systems. A South African Aquifer System Management classification was then prepared and presented to the scoping workshop participants during April 1995.

Based on this meeting the report was modified and presented to a broader spectrum of water scientists and managers at a technical workshop held on 19 September 1995 (Appendix A). The purpose of the workshop was to obtain consensus regarding the acceptability of the proposed classification. Delegates were given the opportunity of discussing the classification during the workshop as well as providing written comment and suggestions for the modification and improvement. As no wriiten comment was received, the classification system was modified based on discussion during the workshop and submitted to the WRC for publication.

5. GROUNDWATER QUALITY MANAGEMENT STRATEGY

5.1. Strategy Development

DWAF accepts responsibility as the custodian of South Africa's limited water resources. To this end and in response to a perceived decline in groundwater quality in many areas, the development of a groundwater quality management strategy and policy was initiated in the early 1990's. Initially a group of groundwater specialists was assembled to investigate groundwater quality issues (Braune et al., 1991). This work was then followed by water managers from DWAF who addressed the topic from a management perspective, as opposed to the earlier scientific viewpoint (DWAF, 1992). Ensuring that groundwater quality remained fit-for-use was identified as an important goal of the strategy development. Some of the important findings of the work included:

a. that no clear objectives and established management systems exist for groundwater quality management in South Africa;
b. the Receiving Water Quality Objectives approach and the precautionary approach are two important pillars in the Departments' approach to water quality management;
c. a differentiated protection policy is preferred, particularly in the case of groundwater;
d. an aquifer classification system would form the basis of a strategy to implement the differentiated protection policy;
e. a strong need exists to start implementing integrated water management of both surface and groundwater resources.

In addition to the adoption of the precautionary approach and differentiated protection, Xu and Braune (1995) note that sustainable development is also an important principle endorsed by DWAF.

Based on this earlier work, a Groundwater Quality Management Strategy is now being developed and is expected to be completed by March 1996 (Wells et al., 1994). A unique feature of the strategy and policy development is the wide consultation with parties either interested in or affected by the policy. The Groundwater Quality Management Strategy is to be used as a basis for developing and implementing groundwater quality protection and conservation regulations. The aquifer classification system addressed in this report not only provides part of the framework for the development of the strategy, policy and regulation but also provides a framework for decision-making in the on-going implementation of the management process.

5.2. Role of the Aquifer Classification System in Groundwater Quality Management Strategy

The use of a classification system is a convenient tool aimed at *simplistically* grouping similar items or objects in order to facilitate information sharing and decision-making. Classification also provides a means of promoting consistency in decision-making (US EPA, 1984) and has been used as an effective planning tool. Heath (1982) notes that the classification of groundwater provides a useful basis for the transfer of hydrologic knowledge from one area to another and for enhancing the public's understanding of groundwater.

The application of an aquifer classification system in South Africa could be both varied and widespread. Some of the more general, national scale applications include:

a. prioritising aquifers;
b. developing and implementing policy and regulations;
c. allocating limited groundwater management resources;
d. setting water quality standards;
e. defining monitoring requirements; and
f. general public education.

More detailed applications at a smaller scale could include:

a. providing information for policy formulation and implementation;
b. setting of controls regarding groundwater abstraction;
c. regional physical and land-use planning;
d. urban zoning; and
e. setting of permitting and siting requirements.

In terms of the Groundwater Quality Management Strategy, however, the classification system would provide a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection. This would facilitate the adoption of a policy of differentiated groundwater protection. Other uses could include:

a. defining levels of investigation required for decision-making;
b. setting of monitoring requirements; and
c. allocation of manpower resources for pollution control functions.

As many of these aspects need to be addressed at national, regional and local scale, it is expected that a hierarchy of classification systems could be required. The national aquifer classification system proposed in this report should, however, form the basis of further more detailed aquifer classification systems suitable for regional and even local scale application.

It is unlikely that any one classification system can be used for multiple purposes. Minor modifications can be expected for specific application. A certain amount of flexibility must hence be accommodated. This can be achieved by linking an aquifer classification to second classifications such as a vulnerability classification or a usage classification. The coupling of the various classifications promotes both flexibility and adaptability. However, the common denominator in the decision-making process remains the aquifer classification system.

6. AQUIFER CLASSIFICATION SYSTEMS

6.1. Features

On evaluating geohydrological classifications used elsewhere in the world (Appendix B), a number of common features were readily apparent:

a. most systems use between 3 and 5 classes;
b. a wide range of criteria are used, many of which are related to aspects of aquifer usage considerations as opposed to the physical characteristics of the aquifer itself;
c. the classifications tend to be quite general, with only Total Dissolved Solids content being used quite specifically; and
d. most systems appeared to be geared toward general decision-making (national scale) with more detail being required for more focused judgments (local scale).

It must be remembered that *classification systems are merely information tools*. It is hence often customary to start using a simple approach which is based on generalised concepts and information. As the need dictates and the scale of classification reduces, more detailed classification systems and information could be required until site-specific models are needed.

To accommodate varying detail, many of the classifications seemed to incorporate a *spirit* of grouping rather than using hard and fast limits. Because of the diverse nature of geological systems and variable use of geological terminology (Midmer, 1985), a degree of subjectivity in the application of the system must be expected. The adopted system should thus not only accommodate flexibility, but it must also be applied with sensitivity.

6.2. Factors Used

A wide range of geohydrologically related factors can be used in classifying aquifers. A list of some of the factors used is presented in Table 1. However, many of them should not be used in South Africa owing to the predominantly fractured nature of the prevailing aquifer systems. Individual borehole yield, for example, is particularly unsuitable to use for fractured rock environments. Borehole yields can vary by an order of magnitude over a short distance. Further, many of the ill-informed regard borehole yield as a measure of aquifer yield or productivity. This is certainly not the case, particularly under South African secondary aquifer conditions. Even the use of aquifer yield is limited by the difficulty in defining aquifer extent and safe yield. It is thus recommended that such considerations be used with great caution if included into a South African based classification system.

Table 1: Factors used to classify aquifers

HYDROGEOLOGICAL CHARACTERISTICS aquifer material lithostratigraphic unit aquifer yield borehole yield borehole prospects map depth to water table time of travel	WATER QUALITY ISSUES present quality current extent of contamination and potential for successful clean-up degree of water treatment required for potable use	USAGE current and potential users designated beneficial use current and planned land tenure and use
SUSCEPTIBILITY vulnerability to contamination assimilative capacity time of travel	INTEGRATED APPROACH hydraulic relationship with other resources availability of alternative sources	VALUE social value economic value environmental value

Many of the terms used in classification systems do not relate to aquifer properties, but rather to indirect aspects such as the value of an aquifer or land use. AWRC (1992b) seem to be particularly confused in the attributes that could be included in an aquifer classification system. Attributes such as land use, social value and availability of alternative water sources are independent of aquifer characteristics, but are rather water resource management attributes.

If the classifications were to be based on purely geohydrological aspects, the terms *aquifer*, *aquiclude* or *aquitard* could be used. The term *aquifer classification* may thus be slightly inaccurate. As the classification is geared towards management and decision-making, the term *aquifer management classification* may thus be more appropriate. This term may be particularly apt as the system being developed is to be used initially for defining appropriate levels of aquifer protection.

Before considering a possible South African classification, the term *aquifer* needs to be defined. For the purpose of this project a definition similar to that of Vegter (1994) was adopted:

> ***strata or a group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to borehole(s) and / or springs.***

As a guide, a supply rate of 0.1 L/s was considered to be a usable quantity. Further, it is implied that the quality of the water should be fit-for-use by the end user.

Vegter (1992) makes the point that the mapping of individual secondary aquifers is not practical and that aquifer systems (which may include both aquicludes and aquitards) need to be considered. In a similar fashion, the classification needs to consider aquifer systems and the classification should hence be regarded as an *aquifer system management classification*.

Three levels of aquifer systems emerged from the literature (Appendix B), namely:

a. highly productive aquifers;
b. aquifers of lower potential, but of local importance to their user or potential user; and
c. poor aquifers.

This grouping conforms closely to that of the British Geological Survey (BGS) presented in Appendix B (NRA, 1992). The classification has a number of positive attributes which make it attractive for adoption in South Africa:

a. the system can accommodate both primary and secondary aquifer types;
b. the BGS classification uses descriptive, meaningful terminology (eg. major aquifer) as opposed to some form of nondescript index (eg. GA);
c. the classification avoids the use of relative terms such as *important* and *insignificant*, as proposed by Jolly and Reynders (1993);
d. confusion is avoided by the non-use of the term *primary*, which has different meanings when used in the USA and South Africa; and
e. even though specific parameters and limits are not used (as is also the case in defining an aquifer), the classification does allow for a *spirit of classification* to be embraced (Section 6.1.).

Two management aspects which are not included in the BGS classification, but are used in other classifications, are sole source aquifers and the question of exemption. Both can be regarded as special cases of the BGS classification and need to be considered in the implementation of a protection policy in South Africa.

The semi-arid nature of the country, the urgent need for large portions of the population to be supplied with safe drinking water, the lack of economically acceptable alternative water sources and the large distances between the point of water source and the point of water demand highlight the high value of groundwater in parts of the country. It is widely argued that groundwater will play a major role in meeting the water supply goals of the Reconstruction and Development Programme (DWAF, 1994b). Aquifers that could be developed in this role will thus require a high level of protection. A policy of non-degradation would thus be appropriate. It is thus proposed that a class be included to accommodate sole source aquifers. The definition of sole source aquifers, adopted from the US EPA (1987b) by Jolly and Reynders (1993), is a basis on which such aquifers can be distinguished. A sole source aquifer is hence defined as:

> ***an aquifer which is needed to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted***

It is important to note that in defining a sole source aquifer, the aquifer yield and natural water quality are immaterial.

The consideration of providing some form of exemption or over-riding considerations to particular aquifers may not prove to be popular, but is a pragmatic approach required to address many contamination problems. The concept has been used in the New Mexico UIP Classification (Wilson and Holland, 1984) as well as in South Africa in the arena of sewage sludge management (Ekama, 1993). It also conforms to the concept of beneficial use proposed by AWRC (1992a) by recognising that some beneficial use other than water supply may exist. It is proposed that this class of aquifer system be referred to as a *special aquifer system*. Here, an aquifer may be given a classification based on factors other than those considered in defining the other four aquifer system classes. Areas proclaimed as Subterranean Water Control Areas are examples of such a classification. Similarly, aquifers classed as major aquifer systems may be awarded a lower status based on, say, the unlikely development of the aquifer owing to distance from potential user.

This approach allows for greater flexibility in resource management and *does not imply that uncontrolled degradation is allowed*. However, in adopting a special aquifer system class, great care will be required in designating such a status (see Appendix C). It is hence recommended that only the Minister of Water Affairs and Forestry be empowered to grant such a classification. Further, such a classification should only be made after all relevant information has been collected and studied. It should hence be mandatory that an Environmental Impact Assessment be performed.

7. PROPOSED CLASSIFICATION TOOLS

7.1. Aquifer System Management Classification

The proposed Aquifer System Management classification is presented in Figure 1 while the definition of each class is presented in Table 2. It is noted that the classification has two components, namely:

a. classes based on aquifer characteristics (ie. major, minor and non-aquifer [1] systems); and
b. classes based on non-technical and water supply considerations.

The single most important use for the classification, at a national scale, is to provide a means of defining the importance of an aquifer in order that sound and consistent decision-making with respect to groundwater management is promoted.

Other envisaged general uses of the national classification include:

a. to provide general geohydrological information for policy and regulation formulation;
b. for national water resource planning;
c. for allocation of national manpower, financial and equipment resource allocation;
d. for general geohydrological education of the public; and
e. to identify and prioritise national groundwater quality monitoring needs.

In the same way that the development of a national scale geohydrological map is impeded by the multi-dimensional nature of groundwater systems, the limitations of a simple aquifer classification system must also be recognised. It is nonetheless important that such classification take place in order to illustrate the value of South African groundwater bodies to the hydrogeological layman. The presentation of such information on maps is regarded as being highly desirable.

7.2. General Groundwater Management Decision-Support Tool

The Aquifer System Management classification presented in Figure 1 is fixed in terms of the variables considered. The need for a more flexible secondary level, task dependant classification is, however, two-fold:

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1 During the technical workshop in September 1995, some delegates objected to the term *non-aquifer*. As no alternatives were forthcoming, the term has been retained.

Figure 1: Proposed South African Aquifer System Management classification

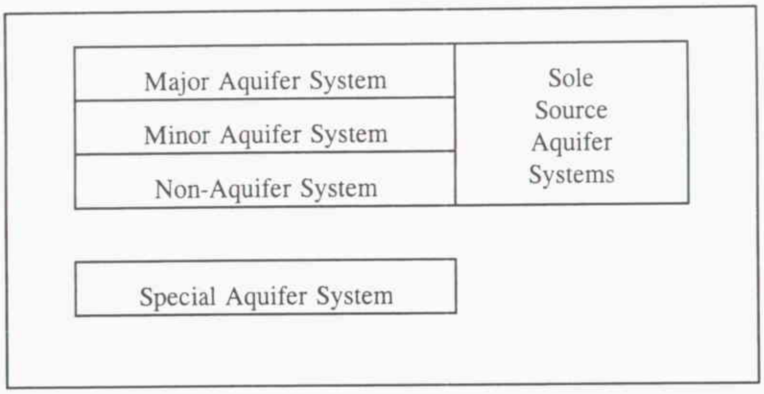

Table 2: Definitions of Aquifer System Management classes.

Sole Source Aquifer System	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

a. it is unlikely that any one classification system can be used for multiple purposes as minor modifications would be needed for specific application; and

b. a flexible system needs to be adopted to accommodate more detailed regional information.

The allocation of manpower and financial resources for aquifer protection, for example, would not only be guided by the ability of an aquifer to yield water to a particular user, but also by the vulnerability of the aquifer to contamination. Sound decision-making would in this instance be facilitated by combining two parameters. Similarly, the allocation of resources for drought relief using groundwater could be guided by information pertaining to those areas with highest need and those areas in which groundwater is capable of meeting such need. Additional information needs and flexibility can be accommodated by considering the Aquifer System Management classification together with other independent factors.

By using a simple weighting and rating approach, sound decision-making is readily facilitated. In order that a standard decision-support management tool can be developed, a second user-defined variable is used. The second variable would consist of three generic classes (high, medium and low). Each variable is rated using the guidelines presented in Table 3. The two ratings are then multiplied to yield a groundwater management decision-support index. This index is then linked to a management action guide table which would specify the most appropriate management action required. Table 5 is an example of such a guide.

Table 3: Ratings for the Aquifer System Management and second variable classifications.

AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		SECOND VARIABLE CLASSIFICATION	
Class	Points	Class	Points
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	Medium	2
Minor Aquifer System	2	Low	1
Non-aquifer System	0		
Special Aquifer System [1]	0 - 6		

The second classification could consist of *any parameter* required in a particular decision-making

1 The designation as a special aquifer system would be done on a case by case basis - the points awarded would hence reflect the desired level of importance for each individual case eg. A Special Aquifer System which is an important source of water would get a higher number of points than an aquifer of lower value.

process. Examples include many of the factors listed in Table 1 as well as rural water availability, population density, drought risk indices etc. By leaving the second variable to be specified by the user results in the decision-support tool being extremely versatile and powerful. Further, the system is suitable for use at both a national and regional scale and could be used for:

a. general regional planning and scenario planning;
b. infrastructure and land-use planning;
c. urban zoning and planning;
d. contamination source control planning;
e. resource allocation (financial, manpower and equipment);
f. setting groundwater abstraction control measures in order to ensure long-term sustainablity;
g. setting groundwater protection requirements;
h. setting permitting and siting requirements; and
i. community and educational programmes

One of the advantages of adopting the proposed groundwater management decision-support tool is that it can be employed effectively using GIS technology. Once an Aquifer System Management classification of the country has been compiled (either at national or regional scale), the capture of the second variable classification information and the subsequent data interpretation would be relatively rapid.

7.3. Groundwater Quality Management Classification

It was recognised at the outset that the Groundwater Quality Management Strategy initiative required a classification as a basis for policy and regulation development and implementation. This is a very specific task for which the classification is required. Further, the classification needs to be clear with little room for misinterpretation or discretionary freedom. The Aquifer System Management classification presented in Section 7.1. does not satisfy this need. However, by adopting the decision-support tool described in Section 7.2., the needs of the groundwater quality management can be met.

One of the fundamental responsibilities of DWAF is to protect groundwater and groundwater quality. In an ideal world, the same level of protection would be afforded to all aquifer systems. However, due to cost of the availability of other resources, there was a need to classify aquifers and to exercise differentiated protection. The adoption of a differentiated groundwater protection policy is regarded as a practical means of achieving acceptable levels of protection. The level of aquifer protection required, however, seems to be a function of:

a. the strategic value of a groundwater user or potential user;

b. the vulnerability of the aquifer to contamination; and

c. the threat posed to the aquifer by land use.

The land use permitted in a certain area (ie. the threat) would be based on the importance of the aquifer and aquifer vulnerability. A decision regarding the level of protection for an aquifer can hence be based on aquifer importance and vulnerability characteristics. A decision-support tool for implementing a policy of differentiated groundwater quality can thus be developed by using these two factors in a tool similar to that described in Section 7.2.

The national vulnerability classes presented by Reynders (1994) are used as the second variable of the Groundwater Quality Management (GQM) classification (Table 4). After rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a GQM index. This index in turn is compared to Table 5 in order to define the level of groundwater protection required.

Table 4: Ratings for the Groundwater Quality Management classification system.

AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		AQUIFER VULNERABILITY CLASSIFICATION	
Class	Points	Class	Points
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	Medium	2
Minor Aquifer System	2	Low	1
Non-aquifer System	0		
Special Aquifer System	0 - 6		

Table 5: Appropriate level of groundwater protection required, based on the Groundwater Quality Management classification.

GQM INDEX	LEVEL OF PROTECTION
< 1	Limited protection
1 - 3	Low level protection
3 - 6	Medium level protection
6 - 10	High level protection
> 10	Strictly non-degradation

For example, a sole source aquifer which is vulnerable to contamination would yield a GQM index of 18. Such an aquifer system would require a strictly non-degradation management approach. A minor aquifer which has a low vulnerability rating would yield a GQM index of 2 points and hence require a lower level of protection.

The above decision-support tool is well suited to defining the required level of protection at a national or regional scale. For the approach to become effective, clear definition is required for each protection level. It is recommended that this task form part of the Groundwater Quality Management Strategy initiative currently being undertaken for DWAF. It is, however, unlikely that the Groundwater Quality Management classification can be used for site specific applications. For example, the demarcation of wellhead protection areas must be based on local scale data, particularly owing to the fractured nature of South African aquifers and the technical nature of applying the technique. This suggests that classification is suited more towards resource (or aquifer system) protection than to source (or wellhead) protection. The classification may, however, be used to define whether a wellhead protection programme is needed in a particular area.

8. APPLICATION

The implementation of the aquifer classification is crucial for the successful establishment of a national Groundwater Quality Management Strategy. Much debate exists whether a *top-down* approach or a *bottom-up* approach should be employed. Even though the selection of the approach to be used falls within the ambit of those parties responsible for the national Groundwater Quality Management Strategy, a possible approach to implementation is presented in Appendix C. This proposed approach considers the fact that groundwater remediation is extremely difficult and expensive to acheive and hence adopts the precautionary principle. The preparation of a national scale Aquifer System Management classification map and a Groundwater Quality Management classification map (described in Section 7.3) is, however, regarded as fundemental to initating the widespread use of the aquifer classification in South Africa.

Duba and Johnson (1987) note that aquifer classification can be a controversial concept because:

a. it is based on the presumption that all groundwater is not equally important or vulnerable for present or future uses and may warrant different levels of protection; and
b. it would result in an institutional mechanism that could hold programmes accountable for their actions.

In adopting an aquifer classification system, it is intrinsically implied that not all aquifers are of equal importance. Concepts such as differentiated protection, the precautionary principle and fitness-for-use are being considered in the development of the Groundwater Quality Management Strategy. Owing to the size of the country and limited financial and manpower resources, it needs to be recognised that not all aquifers can be protected to the same degree. The more important aquifers are hence to receive a high level of protection while less important aquifers and aquifer systems with a lower vulnerability to contamination are to receive a lower level of protection. This in fact represents a compromise aimed at buying time until such point that technologies and / or finance are available to prevent aquifer degradation or to adopt effective water treatment practices.

The Aquifer System Management classification is to initially be used to provide national-scale information (particularly on maps) and as a decision-making tool regarding groundwater management in South Africa. The tool does, however, have a wide range of applications (Section 5.2.), including:

a. focusing limited financial and manpower resources in areas of greatest need (those aquifers that are currently or may in the future provide high quality drinking water); and
b. facilitating consistent decision-making.

However, by linking the Aquifer System Management classification to a second variable, a simple but powerful decision-support tool becomes available. The use of vulnerability as the second variable yields a classification well suited to supporting the development of Groundwater Quality Management Strategy.

9. IMPLICATIONS OF ADOPTING CLASSIFICATION

The introduction of a groundwater classification will provide global information and a power planning tool which has previously not been available. Further, the system will facilitate consistent decision-making and allow for the effective allocation of resources. The community served or potentially served by a groundwater resource will have information available to them with which they can make informed decisions when participating in the decision-making process.

However, a number of consequences could result from the adoption of the classification. Three important implications which will have to be given attention during the development of the Groundwater Quality Management Strategy are discussed below:

- It would appear that the classification would be most useful in making decisions regarding current or further land use planning. Dealing with established activities would be more difficult. If the Cape Flats aquifer, for example, were to be regarded as a major aquifer system, all current activities capable of degrading the aquifer would have to be halted, moved or engineered such that the threat to the aquifer system were removed or significantly decreased. Owing to the significant economic implications of such actions to the industrial sector and the local authority, this may not be a feasible or appropriate approach. A policy is thus required to deal with existing polluting activities located on sole source or major aquifer systems.

- A second major implication of adopting an Aquifer System Management classification involves the legal implication. It is accepted that DWAF are the custodians of water and water quality protection in South Africa (Section 5.1.). However, under the Water Act (Act No. 54 of 1956), groundwater is regarded as private water. It is thus extremely debatable whether the Department has the legal or moral right to permit degradation of somebody else's property. An urgent need therefore also exists to reconsider current groundwater law if DWAF are to be able to manage South Africa's groundwater quality effectively.

- The application of the Aquifer System Management classification is not based on exact limits, but rather on a spirit of grouping (Section 6.1.). This suggests that the same aquifer system could be given different classification by different people. An arbitration mechanism needs to be developed to decide which is the more appropriate grouping.

10. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

10.1. Summary

a. The need for the classification of South Africa's aquifers has existed for some time. The classification is required to promote sound and consistent decision-making related to groundwater matters and, more specifically, to provide a framework to support the Groundwater Quality Management Strategy currently being developed by DWAF.

b. A study of literature concerning aquifer classifications used elsewhere in the world and discussions with various parties were carried out before developing possible classification systems. Cognisance was taken of current geohydrological initiatives in South Africa, the perceived role of such classification systems and the various scales of application.

c. Three proposed products resulted from the study, namely:

    - an Aquifer System Management classification;

- a general groundwater management decision-support tool; and
- a Groundwater Quality Management classification.

It is submitted that the three products be adopted for use in South Africa.

d. The implementation of the Aquifer System Management classification requires a careful consideration and should form part of the development of a National Groundwater Quality Management Strategy.

e. The proposed products have a wide range of applications. The Aquifer System Management classification will provide national-scale information for planning and decision-support while the Groundwater Quality Management classification is specifically targeted at supporting the adoption of a policy of differentiated protection. The groundwater management decision-support tool has a more general role to play, depending on the user-defined task. It must nonetheless be noted that the classification system presented is a **useful planning tool** that provides a starting point for national and regional classification of South Africa's aquifers. Further, it is unlikely that the Groundwater Quality Management classification can be used for site specific applications.

f. Three implications of adopting groundwater classifications systems were recognised:
   - the implication of existing land use on implementing policy guided by the classification;
   - the implication of DWAF controlling allowable levels of protection of private resources; and
   - the need for arbitration mechanisms to deal with disputes arising from the use of the classification systems.

   These implications and the method of dealing with them need to be considered more closely.

10.2. Conclusion

a. A groundwater classification system is not a panacea for sound aquifer management decision-making. A multitude of political, legal and environmental problems preclude the classification from being completely effective. The Aquifer System Management classification does, however, provide an initial guide and effective planning tool to decision-makers regarding the value of the resource and a framework for the implementation of the groundwater quality management process.

b. The application of the Aquifer System Management classification should be guided by the scale of interest and available data. Insufficient data should not, however, preclude the development of information. A phased approach was identified as a means of readily implementing the classification effort.

c. A degree of flexibility must be accommodated when applying classification systems. Further, classification should also be applied with sensitivity owing to subjective nature of the groupings. Public consultation and participation are to form an important component of implementing the classification.

d. Great care is, however, required when designating special status to an aquifer system owing to the long-term impact of such a decision. Appropriate EIA's are needed for this.

e. The national Aquifer System Management classification proposed in this report can form the basis of more detailed planning and decision-support tools suitable for regional or even local application. A versatile and powerful groundwater management decision-support tool results by linking the Aquifer System Management classification to a second classification by means of a rating and weighting technique.

f. The use of the Aquifer System Management classification in conjunction with GIS yields a definitive means of providing national-scale information.

g. The proposed Aquifer System Management classification can support a differentiated groundwater protection policy and embraces the concepts of a precautionary principle, fitness-for-use and sustainable development. The linking of the classification to national vulnerability data is proposed for this specific purpose.

h. The limitations of classification systems need to be recognised by the users. Further, the implications, particularly legal ramifications and economic consequences, of implementing an Aquifer System Management classification also need to be appreciated.

10.3. Recommendations

a. It is recommended that the support of the greater South African geohydrological community for the proposed classification tools be sought through the preparation, publication and distribution of an Aquifer Systems Management classification map and a Groundwater Quality Management map. The Aquifer System Management classification map must be based on the work of Vegter (1994) while clear graphical representation will enhance the final decision-making tool by reducing the complexity of the task at hand.

b. The approach to implementing the classification in terms of the National Groundwater

Quality Management Strategy requires further consideration by those responsible for developing the strategy.

c. For the Groundwater Quality Management classification to become effective, clear definition is required for each level of protection. It is recommended that this task form part of the Groundwater Quality Management Strategy initiative currently being undertaken for DWAF.

d. It is recommended that a full environmental impact assessment be carried out before an aquifer is granted special status. The results of the impact assessment should then be forwarded to the Minister who has final say on the appropriate classification.

e. A procedure needs to be designed and implemented to facilitate and assist the public in petitioning DWAF to have a classification changed.

f. It is recommended that the implications and consequences of adopting a classification be looked at in more detail in order that they can be overcome. Decision-making and arbitration mechanisms may be required to deal with conflict situations.

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GLOSSARY

aquiclude: a bed, formation or group of formations essentially impervious to water.

aquifer: strata or a group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to borehole(s) and / or springs (a supply rate of 0.1 L/s is considered as a usable quantity). Latin: *aqua* water and *ferre* to carry.

aquifer system: a heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.

aquitard: a geological formation or group of formations which does not readily transmit water and hence restricts groundwater movement.

artesian aquifer: see *confined aquifer*.

attenuation: the breakdown or dilution of contaminated water as it passes through the earths material.

base flow: sustained low flow of a stream, usually groundwater inflow to a stream channel.

beneficial use: the use of the environment or any element of the environment that is conducive to the benefit of legitimate users.

borehole: generic term used for any drilled or hand-dug hole used to abstract or monitor groundwater, irrespective of diameter or construction.

brackish: water that contains between 1 000 and 10 000 mg/L of dissolved solids.

brine: water that contains more than 35 000 mg/L of dissolved solids.

coefficient of storage: see *storage coefficient*.

confined aquifer: an aquifer which is overlain by a confining layer of significantly lower hydraulic conductivity, the groundwater is confined under pressure greater than atmospheric pressure such that if the aquifer is penetrated the water level may rise above the top of the aquifer, also known as an artesian aquifer.

confining layer: a layer of low permeability material adjacent to an aquifer which restricts the vertical movement of water.

conjunctive use: combined use of ground and surface water.

connate water: water entrapped in the interstices of sedimentary rocks at the time of deposition.

conservation : to keep or protect from harm, decay or loss, implies wise use of a resource.

conservative pollutants: pollutants which move readily through the aquifer with little reaction with the rock matrix and which are unaffected by biodegradation.

contamination: the introduction into the environment of any substance by the action of man.

dedicated land: see *sacrificial land*.

degradable pollutants: pollutants which readily breakdown.

differentiated protection policy: recognises that some resources require different levels of protection or even no protection at all.

diffuse pollution sources: see *non-point sources of pollution*

discharge area: an area in which subsurface water, including water in the vadose and saturated zones, is discharged to land surface, to surface water or the atmosphere.

dissolved solids: minerals and organic matter dissolved in water.

drawdown: the difference between the observed water level during pumping and the non-pumping water level.

fissures: a general term to include natural fractures, cracks and openings in consolidated rock caused by bedding planes, joints, faults, etc.

fitness-for-use: water quality is such that it meets the requirements for a particular use, five major groups of water users recognised as domestic, agricultural, industrial, recreational or environmental users.

formation: general term used to describe a sequence of rock layers.

fracture: cracks or breaks in the rock which can enhance water movement.

fracture flow: water movement that occurs predominantly in fractures or fissures.

freshwater: water that contains less than 1 000 mg/L dissolved solids.

groundwater: all subsurface water occupying voids within a geological stratum.

groundwater body: a rock or group of rocks comprising of saturated earth material.

groundwater flow: the movement of water through openings and pore space in rocks.

hard-rock: igneous, metamorphic and sedimentary rocks which lack adequate primary interstices to function as a primary aquifer.

heavy metals: those elements with atomic numbers greater than 36 in Group III through V of the Periodic Table.

head: see *hydraulic head*.

hydraulic conductivity: measure of the ease with which a fluid will pass through earth material, defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient (in m/d).

hydraulic gradient: the rate of change of hydraulic head per unit distance in a particular direction.

hydraulic head: the height of a column of water above a reference plane.

infiltration: movement of water into soil or a porous rock.

integrated management: a management approach which serves to co-ordinate management of the environment as a whole, as opposed to individual parts.

intergranular flow: flow that occurs between individual grains of rock.

interstice: an opening or space in a rock capable of holding water.

isotropy: the condition of having properties that are uniform in all directions.

leachate: any liquid, including any suspended components in the liquid, that has percolated through or drained from human-emplaced materials.

limited degradation policy: aims to maintain groundwater at as high a quality as possible, but allows contamination up to a certain set protection levels and standards.

lithology: the physical character of rocks.

local scale: this scale would typically consider water users or groups of users such as farms, irrigation boards, towns, local authorities etc.

major aquifer system: highly permeable formations, usually with a known or probable presence of significant fracturing, may be highly productive and able to support large abstractions for public supply and other purposes, water quality is generally very good.

minor aquifer system: fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability; aquifer extent may be limited and water quality variable; although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.

national scale: this scale covers the total area of South Africa and would be measured in millions of km^2.

non-aquifers: groundwater bodies which are essentially impermeable, do not readily transmit water and / or have a water quality which renders it unfit for use.

non-aquifer systems: formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities, water quality may also be such that it renders the aquifer as unusable, groundwater flow through such rocks does take place and needs to be considered when assessing the risk associated with persistent pollutants.

non-degradable pollutants: pollutants that do not readily breakdown.

non-degradation policy: a protectionist approach which strives to preserve all resources in their pristine state.

non-point source of pollution: pollution from broad areas rather from discrete points.

outcrop: the occurrence of rock at the ground surface; when a rock is visible in, for instance, cliffs and quarries, the rock is said to be *exposed*.

perched ground water: unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

percolation: slow laminar movement of water through openings in a porous media.

permeability: refers to the ease with which water can pass through a porous medium and is defined as the volume of water discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d).

piezometric level: the elevation to which the water level rises in a borehole which penetrates confined or semi-confined conditions.

piezometric surface: an imaginary surface representing the artesian pressure or hydraulic head throughout all or part of an artesian or semi-confined aquifer, analogous to the *water table* of an *unconfined aquifer*.

point source of pollution: pollution from discrete points as opposed to from broad areas.

pollution: the introduction into the environment of any substance by the action of man which is or results in significant harmful effects to man or the environment.

pollution plume: area of degraded water in a stream or aquifer resulting from migration of a pollutant.

porosity: ratio of the volume of void space to the total volume of the rock.

potable water: water that is safe and palatable for human use.

potentiometric surface: see *piezometric surface*.

precautionary principle: promotes the adoption of a conservative approach, particularly in those cases where knowledge is limited or risk unknown, requires that people err on the safe side when taking decisions.

prevention : to defend from harm, decay or loss, implies limited or no use of a resource.

primary aquifer (South Africa): an aquifers in which water moves through the original interstices of the geological formation.

primary aquifer (USA): an aquifer currently being used by a major municipal water supply system

primary interstices: interstices that were made contemporaneously with the rock formation.

principal aquifer (USA): highly productive formations that are not intensively used as water supplies at present, are viewed as potential water supplies but their yields have not been fully established.

recharge: process of the addition of water to the groundwater system by natural or artificial processes.

recharge area: an area over which recharge occurs.

regional scale: this scale is equatable to surface water catchment areas and would typically be measured in thousands to hundred of thousands of km^2.

rehabilitation : to restore to a former condition or status.

remediation : to restore to health, requires that impact is reduced to some acceptable level.

renewable water supply: rate of supply of water available in area on an essentially permanent basis.

rock: any consolidated or unconsolidated earth material, specifically excluding soil.

rock unit: any geological formation, or part thereof, which can be mapped and evaluated as to its general water-bearing and water quality characteristics.

sacrificial land: land used for spreading sewage sludge, above the normal requirements for agricultural land, regarded as land that could be impaired as a result of the spreading practice.

safe yield: amount of water that can be withdrawn from an aquifer without producing an undesired effect.

saline water: water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids.

saline intrusion: replacement of freshwater by saline water in an aquifer, usually as a result of groundwater abstraction.

saturated zone: that part of the geological stratum in which all the voids are filled with water under pressure greater than that of the atmosphere.

secondary aquifer (South Africa): an aquifers in which water moves through the secondary interstices, which are a result of post-depositional processes.

secondary interstices: openings in the rock that were developed by processes that affected the rocks after they were formed.

sediment: particles derived from rocks or biological material that have been transported by air or water.

semi-confined aquifer: an aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur.

soil: the usually thin surface layer of the earth, comprising of mineral products formed by the break-down of rocks, decayed organic matter, living organisms, water and the atmosphere.

sole source aquifers: an aquifer which is needed to supply 50 % or more of the domestic water for a given area, and for which there are no reasonably available alternative water sources should the aquifer be impacted upon or depleted.

special aquifer system: an aquifer designated as such by the Minister of Water Affairs, after due process.

specific capacity: the rate of discharge of a water well per unit of drawdown, usually expressed as $m^3/d/m$

specific yield: ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity from that mass.

storage coefficient: the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

sustainable development: use, development and protection of natural resources in a way and at a rate which allows for social, economic and cultural needs of people and communities to be met without compromising the ability to meet the needs of future generations

transmissivity: the rate at which a volume of water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d).

unconfined aquifer: an aquifer whose upper surface (water table) is free to fluctuate.

unsaturated zone: see *vadose zone*.

vadose zone: that part of the geological stratum above the saturated zone in which the voids contain both air and water.

vulnerability: a relative measure of the susceptibility of a groundwater body to be contaminated by anthropogenic activities; governed by the physical, chemical and biological properties of the soil and rock.

water-bearing: water-yielding in terms of carrying or conveying.

water table: top of the saturated zone in an unconfined aquifer at which pore water pressure is at atmospheric pressure; marked by the position of the water surface.

water year: a continuous 12-month period selected to present data relative to hydrologic or meteorologic phenomena, usually runs from 1 October to 30 September.

well: see *borehole*.

well field: a group of boreholes in a particular area, usually used for groundwater abstraction purposes.

yield: quantity of water able to be removed from an abstraction source.

APPENDIX A

Delegates at National Groundwater Quality Management Strategy Technical Workshop,

Rob Roy Hotel

19 September 1995

DELEGATE	AFFILIATION
Mr Eberhard Braune	DWAF
Mr Leon Bredenhann	DWAF
Mr Richard Bush	Anglo America Corporation
Dr Vic Cogho	Kroonfontein Mine
Mr Paul de Mattos	Institute of Waste Management
Mr Lin Gravelet-Blondin	DWAF
Ms Tisha Greyling	Greyling Liaison
Prof. Frank Hodgson	Institute of Groundwater Studies
Dr John Howard	Umgeni Water
Dr John Kilani	Chamber of Mines
Ms Georgina King	Dwaf
Dr TS Kok	DWAF
Dr Mannie Levin	Geo Specialists Inc.
Mr Ricky Murray	Rural Support Services
Mr Charl Nolte	DWAF
Mr Roger Parsons	CSIR
Mr Roger Porter	Natal Parks Board
Mr Bill Pullen	Goldfields of South Africa Ltd.
Mr Gavin Quibell	DWAF
Mr Tony Reynders	Water Research Commission
Mr J Rivett Carnac	Appropriate Technology Information
Mr Dave Salmon	Amcoal Environmental Services
Mr Steve Shone	Natal Agricultural Union
Mr Miloslay Simonic	DWAF
Dr Gideon Tredoux	CSIR
Mr Leo van den Berg	DWAF
Dr Johan van der Merwe	DWAF
Mr Sakkie van der Westhuizen	DWAF
Dr Louis van Dyk	Agricultural Research Council
Mr Theo van Niekerk	Borehole Water Association
Prof. Balthazar Verhagen	Schonland Research Centre Group
Mr Dave Walker	Wates Meiring & Barnard
Mr John Wates	Wates Meiring & Barnard
Mr Yongxin Xu	DWAF

APPENDIX B

Selected Groundwater Classification Systems

Australian Aquifer System Classification

Unconsolidated Sediments	These are mostly made of clays, silt, sand and gravel, which are usually shallow and provide large volumes of groundwater.
Porous Rocks	These can be in very large rock basins extending over enormous distances. A well known example of this type of groundwater system is the Great Artesian Basin.
Fractured Rocks	These rocks have joints and partings. The volume of groundwater these rocks contain is mostly affected by climatic conditions, vegetation, soil cover, lie of the land and the type of fractured rocks.

Reference: Ross (1990)
AWRC (1992)

NOTES

- used by Ross (1990) to define Groundwater Management Areas (GWMA)

Australia Beneficial Use Classification

Human consumption / Food production	Groundwaters which are currently (or have the potential to be) used for drinking water supply or production of food which would provide a direct pathway affecting human health (for example irrigation of vegetable crops).
Agriculture, industry and mining usage	These systems are of lower value because they generally have poorer quality waters and are not for direct human consumption (for example irrigation of pastures and stock).
Ecosystem support	The water quality criteria applied to this class are highly variable , especially since the chemical criteria for some species on aquatic ecosystems are more stringent than for human consumption.
No definable beneficial use / controlled degradation	The groundwater is of such poor quality that there is no foreseen commercial use or ecological need for the water.

Reference: AWRC (1992)

NOTE

- the level of protection afforded to ecosystem support is variable and dependant on local conditions.
- system implies a level of prioritization with one user being considered more important than another.
- a policy of controlled degradation may be appropriate when classified as *no definable beneficial use*.
- a limitation of the classification is the definition of water quality; owing to the large number of variables (each with their own water quality criteria and standards) the term can only be considered at the broadest level.
- more than one set of water quality criteria may apply to each class.
- water quality criteria are often relatively subjective and arbitrary.

British Geological Survey Aquifer Vulnerability Classification System

Major Aquifer	These are highly permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. These aquifers generally have less capacity for attenuating contaminated recharge entering at their surface.
Minor Aquifer	These can by fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Although these aquifers will seldom produce large quantities of water for abstractions, they are important both for local supplies and in supplying base flow for rivers. In certain local circumstances minor aquifers can be highly vulnerable to pollution.
Non-Aquifers	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with very slowly degrading pollutants.

Reference: NRA (1992)

NOTES

- linked groundwater vulnerability to aquifer classification to identify areas of high protection priority.
- vulnerability defined by three soil classes based on leaching potential (ie. ability to prevent contaminated water from reaching the groundwater body).

Colorado Groundwater Classification System

Category 1	suitable for all uses; TDS less than 3 000 mg/L
Category 2	suitable, but not ideal, for most beneficial uses; TDS between 3 000 and 10 000 mg/L
Category 3	generally unsuitable for most beneficial uses; TDS greater than 10 000 mg/L

Reference: USGS (1986)

NOTES

- based on water quality and the concept of beneficial use
- used in conjunction with a mapping program that identified critical areas and resources for protection.

Florida Groundwater Classification System

Class G-I	*Single Source Aquifers* - for potable water use with TDS content of less than 3 000 mg/L
Class G-II	*Potable water use* - groundwater in aquifer has TDS of less than 10 000 mg/L, unless otherwise classified by the Environmental Regulatory Commission
Class G-III	*Non-potable water use* - groundwater in unconfined aquifer which has a TDS of greater than 10 000 mg/L, or has a TDS content of between 3 000 and 10 000 mg/L and either has been reclassified by the Commission as having no reasonable potential as a future source of drinking water, or has been designated by the Department as an exempted aquifer.
Class G-IV	*Non-potable water use* - groundwater in confined aquifers which has a TDS content of 10 000 mg/L or greater.

Reference: US EPA (1985)

NOTES:

- The Environmental Regulatory Commission, a lay-body appointed by the Governor, has the authority to classify groundwater.
- have adopted quality standards approach.
- State has not embarked on a classification program, rather classify aquifers as permit applications are submitted.
- an aquifer classified as a single source if:
    - the aquifer or portion of the aquifer is the only reasonable available source of potable water to a significant segment of the population, and
    - if the designated use is attainable, upon consideration of environmental, technological, water quality, institutional, societal and economic factors.
- when granting discharge permits, the State must rely on the "good faith" testimony of the applicants (and their consultants) - this requires enforcement measures and strong monitoring program.

New Mexico Underground Injection Control Program Aquifer Classification System

Protected Aquifer	any rock unit which is a present source of drinking water; or which is not now a source of drinking water and has not been explicitly classified into one of the remaining the UIC classes.
Salt-water Aquifer	Rock units which contain water having a TDS in excess of 10 000 mg/l.
Non-aquifer	Rock units which are not able to yield usable amounts of water to a well or spring.
Exempted Aquifer	Rock units which are excluded as a potential source of drinking water for reasons of economics, technology, gross contamination, or relationship to subsidence or collapse zones.

Reference: Wilson and Holland, 1984

NOTES:

- system used specifically for UIC program.
- base classification on hydrogeological maps and cross-sections which display rock permeability and Total Dissolved Solid information.
- use a flow chart to set out the classification process and to unify terminology.
- system is based on a series of yes - no type questions using general terms only.
- US EPA specifically suggests that the use of a series of maps and cross-sections showing TDS isocons, depth to base of fresh water, aquifer thickness and saturated thickness, water level in different aquifers etc.
- in testing the method, Wilson and Holland found that 3 alternative classifications could be obtained - in deciding on the most appropriate classification, they had to consider available information, technical feasibility, economic feasibility, public opinion and concurrence to regulations.
- it is interesting to note that in two of the three cases the economic consequences of a particular classification being applied was a major consideration - this leads to the question of why geohydrological aspects were even considered at all.
- Wilson and Holland found that the classification was practical but not simple to implement - if precise classifications were not needed, then the cost of implementation was reduced.

New York Groundwater Classification System

Class GA	best usage is as a source of potable water supply, are fresh ground waters found in the saturated zone of unconsolidated rocks and consolidated rock and bedrock.
Class GSA	best usage is as a source of potable mineral waters, for conversion to fresh potable water or as a raw material for the manufacture of sodium chloride or its derivatives or similar products; is saline water found in the saturated zone.
Class GSB	best usage is as a receiving water for disposal of wastes; saline water with a Cl concentration in excess of 1 000 mg/L or a TDS in excess of 2 000 mg/L.

Reference: US EPA (1985)

NOTES

- no groundwaters had been classified as GSB by mid- 1985, some 17 years after the system had been adopted.

Proposed South African Aquifer Classification System

Class 1	Sole Source Aquifers	An aquifer which is needed to supply 50 % or more of drinking water for a given area, and for which there are no reasonably available alternative sources should the aquifer become contaminated. Aquifer yields and quality are immaterial.
Class 2	Important aquifers	Aquifers of good to moderate quality of groundwater, of high to moderate yield, and used partly for domestic supply, but where alternatives are available at comparable costs.
Class 3	Minor Aquifers	Aquifers of moderate to poor quality groundwater and yield, used predominantly for non-domestic purposes.
Class 4	Insignificant aquifers	Aquifers of poor quality and low yield, where alternative water supplies exists, or where no current or future use is expected.

Reference: Jolly and Reynders (1993)

NOTES:

- use of terms *important* and *insignificant* should be avoided, as should linking to specific quality criteria and borehole yield.

United States Environmental Protection Agency Groundwater Classification System

Class 1	*Special groundwater* which is highly vulnerable, irreplaceable (in that no reasonable alternative source of drinking water is available) or ecologically vital, has significant water resource value and requires an extremely high level of protection, strictly non-degradation category.
Class 2	*Current and potential sources of drinking water and waters having other beneficial uses.* (All other groundwater use available for drinking or other purposes). Majority of usable groundwater in USA, requires moderate to high levels of protection.
Class 3	*Groundwater not considered potential sources of drinking water and of limited beneficial use.* Heavily saline or heavily contaminated groundwater. Requires low level of protection (if discharge to surface water resources precluded).

Reference: US EPA (1984)
Kozlovsky (1985)
Gilbert (1986)

NOTE

- based on value and vulnerability to contamination

United States Geological Survey Classification System

GAA	Public and private drinking water supplies without treatment; Discharges are restricted to waste waters of human or animal origin and other minor cooling and clean water discharges.
GA	Private drinking water supplies without treatment; Restricted to waste waters of predominantly human, animal or natural origin that pose no threat to untreated drinking water supplies.
GB	Groundwater unsuitable for potable use unless treated because of existing or past land uses; May receive certain industrial waste waters when the soils are an integral part of the treatment system; Discharges shall not cause degradation of groundwater that could preclude its future use for drinking without treatment.
GC	The aquifer is more suitable for receiving permitted discharges than for development as a public or private water supply; Discharges shall not cause degradation of surface water quality below established classification goals.

Reference: US EPA (1985)
USGS (1986)

NOTES

- used successfully in the state of Connecticut - proved to be a powerful tool for industrial and local planning
- based on present and future water use, defined by ambient water quality.
- classification to be revised every 3 years
- a major problem in classify groundwater bodies as GC was the lack of public acceptance
- classification found to be consistent, thorough and closely co-ordinated with other protection bodies (US EPA, 1985).

APPENDIX C

Possible Approach for Implementing the

Classification Systems

IMPLEMENTATION OF CLASSIFICATION SYSTEMS

The implementation of the systems described in Chapter 7 of the report will depend on the goal of the task at hand and the scale of interest. Xu and Braune (1995) note that a three phased approach is required to implement a policy of differentiated protection. This three tiered approach could be expanded to consider a greater spectrum as the scale of interest generally defines the nature and detail of information required (Table 1).

1. Aquifer System Management Classification

The effective implementation of the Aquifer System Management classification is crucial for it to support the Groundwater Quality Management Strategy initiative. However, a number of political, institutional, data and regulatory framework needs must be satisfied before successful implementation can occur. For implementation to occur, some of the concepts and approaches identified below need to be accepted.

Table 1: Levels of information requirements

LEVEL	AQUIFER SYSTEM MANAGEMENT CLASSIFICATION aquifer system management classification	DECISION-SUPPORT TOOL variable task dependant	GROUNDWATER QUALITY MANAGEMENT CLASSIFICATION groundwater quality protection
1 st Tier national scale not data intensive	base classification	national scale data	policy and strategy
2 nd Tier regional scale	classification improvement	regional scale data	regional planning and land-use zoning
3 rd Tier local scale data intensive	reclassification	local scale data	wellhead protection zoning

1.1. Base Classification

Simplistic and empirical approaches are most suitable to national scale classification while finer detail is required for regional or local scale application. A suitable means of starting the national Aquifer System Management classification would be to adopt the approach used in Arizona (Braune et al., 1994) and Australia (Ross, 1990) where a blanket classification was first used. The classifications can then be changed as additional knowledge becomes available or the owners of the resource petition the state to have the classification changed. A three step process is proposed to implement an initial Aquifer System Management classification in South Africa:

a. embracing the precautionary principle, all aquifer systems in South Africa should be classified as major aquifer systems;
b. the borehole prospects and groundwater quality maps of Vegter (1994, 1992) will be invaluable for defining non-aquifer systems;
c. the area within a 10 km radius of all towns which obtain more than 50 % of their water supply from groundwater systems can be identified as sole source aquifer systems.

A draft national scale Aquifer System Management classification map would result. The map would clearly indicate the locality of non-aquifers systems and identify those areas where groundwater is the principal source of urban water.

1.2. Classification Improvement

The aim of the second step would be to regularly improve the accuracy of the classification map using either national and regional scale information. As the custodians of water resources in South Africa, DWAF will ultimately be responsible for the classification, but geohydrologists and the public familiar with a region also need to be used in the process:

a. synergy with the national and regional scale mapping should be established in order to differentiate between major aquifer systems, minor aquifer systems and non-aquifer systems - public participation should be an important process in this regard and should therefore be promoted;
b. a process needs to be established whereby anybody (local authorities, farmers, non governmental organisations, individuals or groups of individuals, etc.) may petition the state to have an aquifer classified as a sole source aquifer system - this would allow interested and affected parties to help focus attention on high priority, strategically important, vulnerable groundwater resources; and
c. the granting of a special status to aquifer systems will require a full environmental impact assessment (as set out by DEA, 1992), including full public participation - the information would then be provided to the Minister of Water Affairs who would have to decide whether to issue the exemption or not.

Because of the technical inability to restore contaminated aquifers, great care has to be taken when issuing an aquifer with a special status. Further, as groundwater systems form part of the larger hydrological cycle, an integrated approach is deemed essential (Braune, 1994).

1.3. Reclassification

As part of the on-going process of classifying aquifers, a system should be implemented whereby individuals and organisations can then petition the state to have the classification modified (either to a higher or lower class). Such a process would typically be based on either regional or local scale information. Waste site permit applications could, for example, play a role in the reclassification process.

2. Groundwater Management Decision-Support Tool

The groundwater management decision-support tool is variable and depends on the objectives of the task at hand. Continual updating of the national Aquifer System Management classification map, particularly in electronic format, will be valuable for the production of task dependant classification maps by groundwater practitioners.

3. Groundwater Quality Management Classification

Once the Aquifer System Management classification has been adopted and a national map produced (Section 1.), the information can be combined with vulnerability data (Reynders, 1993) to develop a Groundwater Quality Management classification. Both input variables would have to be regularly updated to accommodate new data as it becomes available.