Explanatory Notes for the Aquifer Classification Map of South Africa

R Parsons • J Conrad

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Explanatory Notes for the Aquifer Classification Map of South Africa.

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prepared by:

Roger Parsons

Parsons and Associates Specialist Groundwater Consultants cc

Julian Conrad

Division of Water, Environment and
Forest Technology, CSIR

Parsons & Associates

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Mr E Braune	Department of Water Affairs and Forestry
Mr L Bredenhann	Department of Water Affairs and Forestry
Mr HM du Plessis	Water Research Commission
Mr D Dziembowski	Department of Water Affairs and Forestry
Dr G Green	Water Research Commission
Ms A Hinsch	Department of Water Affairs and Forestry
Prof. FDI Hodgson	Institute for Groundwater Studies
Mr A Moldan	SA Oil Environment Committee
Mr W Orpen	Department of Water Affairs and Forestry
Mr AG Reynders	Water Research Commission
Mr J Wates	Wates Meiring Barnard

1 INTRODUCTION

Exploration, development and protection of aquifers is receiving unprecedented attention as a result of the efforts of the Reconstruction and Development Programme (RDP) and the National Water Act to ensure equitable access to water for all. Groundwater is a particularly important resource for meeting water requirements in remote areas where rainfall is low and surface water resources are scarce. Provision of appropriate information to national water resource managers and planners is a critical part of the process which aims to provide some 12 million people with adequate access to potable water supplies.

Significant effort has already gone into mapping the country's groundwater resources. The national Groundwater Resources of the Republic of South Africa map produced by Vegter (1995) for the Water Research Commission (WRC), regional 1 : 500 000 scale hydrogeological maps produced by the Department of Water Affairs and Forestry (DWAF) and the national groundwater vulnerability map prepared by Reynders and Lynch (1993) are examples of this.

Simultaneously, protection of the quality of groundwater has also received greater attention. The development of a groundwater quality management strategy (Braune et al.,1991; DWAF, 1997) identified a differentiated protection approach as the only viable means of implementing an effective strategy with the resources available for such a task. In preparation for the adoption of such a strategy, an aquifer classification was developed (Parsons, 1995) as a means of identifying important aquifers which require priority attention. This classification has now been applied to the country and a map produced in order to provide national planners and managers with an overall perspective.

It was also recognised that certain aquifers are more vulnerable to contamination than others. The National Research Council (1993) in the USA defined groundwater vulnerability to contamination as "the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer." A combination of the aquifer classification and vulnerability thus would have to be considered when implementing the groundwater quality management strategy. The concept of susceptibility was proposed as a means of achieving this.

Due to the wide range of definitions used in the literature, a distinction should be made between *aquifer vulnerability* and *aquifer susceptibility* as used in this study. Aquifer susceptibility is used to indicate *both* importance and vulnerability. Importance is defined using an aquifer classification based on Parsons (1995) while vulnerability is defined using the DRASTIC method proposed by Aller et al. (1987). Aquifer vulnerability and susceptibility differ from risk in that they are based on the intrinsic characteristics of the aquifer, while risk assessment considers extrinsic factors such as the source, loading and characteristics of the pollutant itself (Lynch et al., 1994).

Parsons and Associates Specialist Groundwater Consultants[cc] and the Cape Water Programme of the CSIR submitted a joint proposal to the WRC, DWAF and SA Oil Industry Environment Committee to prepare a map presenting groundwater susceptibility to contamination at a national scale. Submission of this explanation booklet and the accompanying map marks the completion of the project as set out in the Terms of Reference.

This booklet is intended as a reference to the approach and techniques used to develop the aquifer system management classification map, aquifer vulnerability map and aquifer contamination susceptibility map. For those readers requiring more detail regarding underlying principles and sources of data, the listed references should be consulted.

2 TERMS OF REFERENCE

The Terms of Reference of the project required that an aquifer contamination susceptibility map be produced, together with a set of explanatory notes. The hardcopy of the map was expected to be at a scale of 1 : 2 000 000 and of a quality produced by an electrostatic plotter.

The aquifer contamination susceptibility map was to be based on the classification and vulnerability of the country's aquifers. A national aquifer classification map and the printing of a national vulnerability map currently being compiled by Reynders (1997) were envisaged as insert maps for the final product and hence formed important by-products of the project. The final scale of the two inserts was to be decided during the execution of the project.

3 PURPOSE OF MAPS

The principal purpose of the maps is to facilitate national planning. It is, however, expected that the maps will have a wide range of applications and uses. For example, the maps can be used to identify those areas, on a national scale, where susceptibility of groundwater contamination is high should contaminants enter the subsurface. This will provide industry and other potential polluters with information to assess the risk which they pose to the groundwater environment and allow them to plan and implement effective mitigation measures. Further, the maps will provide valuable support to those responsible for planning the development of community water supplies as part of the RDP. This in turn will enable the appropriate allocation of resources to a particular area so that water requirements can be met. It is also expected that the maps will play an important role in education and promoting an awareness of the national groundwater resources of South Africa.

Accuracy of the data used in the development of the various maps precludes application of the maps at a detailed scale. The maps can be used as a guide at a regional level, but where possible, should be supported with additional data. The maps are not intended for site-specific use nor for use at a local scale. Use of the maps at a detailed scale is thus not recommended.

4 INFORMATION SOURCES

Prior to developing the maps it was decided that only existing data would form the basis of the derived maps. The work of Vegter (1995) and Reynders (1997) provided a unique opportunity to add value to the groundwater and vulnerability maps by developing further user-defined specific products based on their work. It was also decided that the maps prepared during the current project would be based on their findings and no attempt would be made to modify or improve the existing maps. Readers are referred to the work of Vegter (1995) and Reynders (1997) for detailed information.

5 GIS PROCESSING

The processing tool used was Arc/Info version 7.0.3 (including the GRID module), residing on a Sun Sparc 20 workstation. All coverages, including vulnerability and susceptibility, were projected to the Albers Equal Area Conic projection, with the Clarke 1880 spheroid. The first and second standard parallels used were 19°00'S and 27°00'S, with 25°00'E being the central meridian. The latitude of origin was set at 0°00' (the equator) and no false eastings or northings were used.

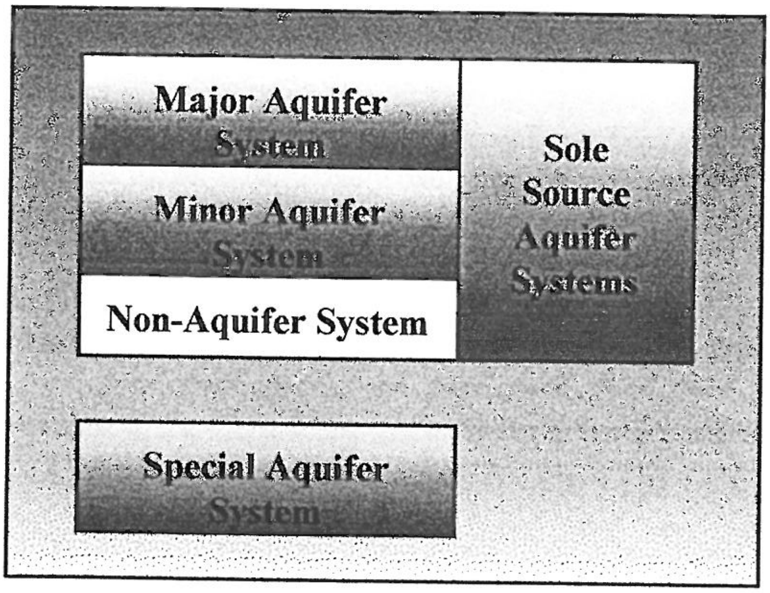
6 AQUIFER SYSTEM MANAGEMENT CLASSIFICATION MAP

The DWAF initiative to develop a strategy for managing groundwater quality required that an aquifer classification system be developed to provide a framework to support the regulatory system being developed. After a literature study of classification systems used elsewhere in the world and a series of Scoping Workshops to define the desired features and characteristics, a classification was developed and presented to a Technical Workshop for discussion and finalisation (Parsons, 1995).

The aquifer system management classification developed (Figure 1) was based on the British Geological Survey aquifer vulnerability classification (NRA, 1992), but also recognised the need to consider two important South African management aspects, namely:

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

Figure 1: 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
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
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

It was also recognised that a single classification would not meet all of the needs and that modifications would be required for specific tasks. A flexible decision-support tool was therefore developed by Parsons (1995) which related the aquifer system management classification to a user defined variable by means of a simple weighting and rating approach. This decision-support tool formed the basis of developing the aquifer contamination susceptibility map prepared during this study ie. aquifer contamination susceptibility was defined using both the aquifer system management classification and aquifer vulnerability.

The work of Vegter (1995) was used as the basis for classifying geohydrological units as major, minor and poor groundwater regions. Terminology used differed slightly from that proposed by Parsons (1995) in order to accommodate the concepts used in developing the national groundwater maps (Table 1). Further, the term *poor aquifer system* replaced that of *non-aquifer system*.

Table 1: Modified aquifer system management classification

Aquifer Type	Description
Sole source aquifer	An aquifer used to supply 50% or more of urban domestic water for a given area and for which there are no reasonably available alternative sources of water.
Major aquifer region	A high-yielding aquifer system of good quality water.
Minor aquifer region	A moderately-yielding aquifer system of variable water quality.
Poor groundwater region	A low to negligible yielding aquifer system of moderate to poor water quality.
Special aquifer region	An aquifer system designated as such by the Minister of Water Affairs and Forestry, after due process.

Consultation was held with Mr Vegter to ensure that the method and underlying principles adopted in developing the national groundwater maps were sufficiently well understood. Criteria used by Vegter (1995) to develop the borehole prospects map were then used to identify the various aquifer classes (Figure 2). Groundwater quality and recharge characteristics of each polygon on Vegter's (1995) map were then considered in terms of the assigned classification. A large degree of correlation between the classification based on borehole prospects, groundwater quality and recharge characteristics was found. It was thus decided that only major aquifers which yielded poor quality water would be down-graded to a minor classification. A Total Dissolved Solids (TDS) limit of 1 500 mg/L was used for this.

A draft classification map was then presented to a group of experienced groundwater specialists. Though some comments about specific areas were given, consensus was that the approach used and results obtained were reasonable and acceptable. Those consulted, however, stressed that the map was only useful at a national scale.

No comprehensive data set was available regarding groundwater usage in South Africa. To provide a data set which could be used to assess the effect of mapping sole source aquifers and special aquifers at a national scale, data collected by DWAF's Directorate of Geohydrology in 1995 during a national survey of groundwater usage by local authorities was considered. From the 640 replies received by the Directorate, 126 sole source aquifers were identified (Appendix A). Further, 15 subterranean control areas are at present proclaimed. In accordance with the aquifer system management classification, these were classified as *special aquifers* and mapped accordingly.

Figure 2: Application of the aquifer system management classification to the borehole prospect map of Vegter (1995).

	Exploitability					
Accessibility	*< 10 %*	*10% - 20%*	*20% - 30%*	*30% - 40%*	*40% - 50%*	*> 50%*
> 60 %	poor	minor	minor	major	major	major
40 % - 60 %	poor	poor	minor	minor	major	major
< 40 %	poor	poor	poor	minor	minor	major
Q and TQc						major

It was recognised that the groundwater usage data used to compile the maps was not comprehensive. The lack of a comprehensive data set regarding rural and village water supply is regarded as a shortcoming as not all sole source aquifers could be identified. However, the data set used represents the best data currently available. Once better data are available, the aquifer system management classification map can be updated. It is recommended that a national scale project be initiated to quantify groundwater usage in South Africa. Such information will facilitate better planning and management.

The aquifer classification was derived from the borehole prospects coverage (Vegter, 1995) and classification shown in Figure 2. An additional coverage was generated by unioning the borehole prospects coverage with the groundwater quality coverage. This coverage was then used for the reclassification of major aquifers with poor quality water (mean TDS > 1500 mg/L) to minor aquifer status. The resolution scale of these coverages is 1:1 000 000. Owing to data limitations the special aquifers and sole source aquifers were defined only as points. Ideally they should be represented as polygons. This aspect should receive attention in the future.

7 AQUIFER VULNERABILITY MAP

A preliminary vulnerability map of South Africa was derived by Reynders and Lynch (1993). The map was based on the well-known DRASTIC method (Aller et al., 1987) with some modifications made to accommodate South African conditions. Owing to the difficulty of assigning representative hydraulic conductivity values to fractured rock aquifer systems, the C component was excluded.

Subsequent to the publication of the national groundwater resources maps by Vegter (1995) and the availability in electronic form of the analysed and interpreted data used to compile the maps, it was decided to recompile the component maps. Hence the vulnerability map presented as an insert on the accompanying map sheet was based on the data used by Vegter (1995) and was compiled under direct instruction and supervision of Reynders (1997).

In the DRASTIC method, vulnerability is determined within hydrogeological settings by evaluating seven parameters denoted by the acronym:

- **D**epth to groundwater
- **R**echarge
- **A**quifer media
- **S**oil media
- **T**opography
- **I**mpact on vadose zone
- hydraulic **C**onductivity

Each of the parameters is weighted according to its relative importance. The DRASTIC Index is determined by rating each parameter according to a set of tables, multiplying the assigned rating by the parameter weighting and summing the resultant products. The higher the DRASTIC Index, the higher the vulnerability to contamination. The rating tables presented by Aller et al. (1987) were modified by Reynders (1997) to accommodate South African conditions. The revised vulnerability map was prepared using a cell size of 400 m by 400 m, the resolution of the National Digital Elevation Model. The DRASTIC Index of each cell was calculated and the vulnerability map prepared using the GRID module.

8 AQUIFER CONTAMINATION SUSCEPTIBILITY MAP

The aquifer contamination susceptibility map is simply a product of the aquifer system management classification map and the aquifer vulnerability map. The classes used for each base map were used to develop susceptibility classes as shown in Figure 3. Poor groundwater regions with a low vulnerability are thus defined as having a low susceptibility to contamination.

Conversely, major aquifer regions with a high vulnerability are regarded as having a high susceptibility to contamination. After consultation with various parties regarding the appropriateness of the approach used, the categories were defined and mapped.

The aquifer contamination susceptibility map was produced by multiplying the reclassified aquifer systems management classification grid with the reclassified aquifer vulnerability grid (Figure 3). This final map had a range of values between 1 and 9.

Figure 3: Basis for assigning aquifer contamination susceptibility classes

	Vulnerability Class		
Aquifer System Management Class	*low (1)*	*medium (2)*	*high (3)*
poor groundwater region (1)	low susceptibility (1)	low susceptibility (2)	medium susceptibility (3)
minor aquifer region (2)	low susceptibility (2)	medium susceptibility (4)	high susceptibility (6)
major aquifer region (3)	medium susceptibility (3)	high susceptibility (6)	high susceptibility (9)

9 THE WAY FORWARD

An aquifer classification map of South Africa has been developed. The map was based entirely on existing data and on the work of Vegter (1995) and Reynders (1997). In addition, national aquifer vulnerability and aquifer contamination susceptibility maps were also produced. The maps indicate the relative importance and vulnerability to contamination of South African aquifers. The information presented is useful for providing a *first pass* in assessing the impacts of human activities on our national groundwater resources. However, data limitations are recognised since some physical properties which control contamination are not adequately addressed. As a result, the maps are applicable for national planning purposes, but cannot be used at a local or site specific scale.

This set of explanatory notes has recorded the basis and protocols on which the maps were developed. This information will be of assistance when updating the maps over time as more data and information becomes available.

The maps were developed specifically to support the Groundwater Quality Management Strategy initiative, but are expected to have a wide range of applications within the limitations described above. It is specifically naoted that use of the maps at a local or site-specific scale is inappropriate.

It is recommended that a methodology be developed that will allow a classification map, vulnerability map and susceptibility map to be developed for each 1 : 500 000 scale hydrogeological map currently being prepared by DWAF. Such maps will provide essential groundwater quality management tools at a more detailed scale than the national map. Further, routine enhancement of the 1 : 500 000 scale will add value to the current DWAF mapping programme.

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GLOSSARY

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.

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

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

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

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

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

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).

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 region: a high-yielding aquifer system of good quality water.

minor aquifer region: a moderately-yielding aquifer system of variable water quality.

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

non-aquifer system: 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.

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.

poor groundwater region: a low to negligible yielding aquifer system of moderate to poor water quality.

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.

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

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

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.

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

sole source aquifers: an aquifer used to supply 50% or more of urban domestic water for a given area and for which there are no reasoably available alternative sources of water.

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

susceptibility: a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification.

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.

total dissolved solids: the quantity of dissolved chemicals in water (mg/L).

vulnerability: the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer.

APPENDIX A

LIST OF SOLE SOURCE AND SPECIAL AQUIFERS

Sole Source Aquifers

MUNICIPALITY	MUNICIPALITY	MUNICIPALITY
ABERDEEN	KAMIESKROON	RICHMOND
ADELAIDE	KENHARDT	RICHMOND (NATAL)
AMALIA GES. KOM.	KENTON-ON-SEA	RIEBEEK-KASTEEL
BEAUFORT WES GAMKA	KESTELL MUN	ROEDTAN GESH KOM
BETHULIE	KHAYAMNANDI	SANNIESHOF
BITTERFONTEIN	KLIPPLAAT	SILINDILE DORPS KOM
BLOEMHOF	KOMGA MUN	SMITHFIELD
BLYTHEDALE	KOSTER	SOMERSET-OOS
BOESMANS RIVIERSMOND	KRANSKOP HEALTH COM	STELLA
BOICHOKO DORPSRAAD	KURUMAN MUN	STEYTLERVILLE
BOIKHUTSO DORPS KOM	KWAMBONAMBI DEV S	STRYDENBURG
BOLOKANANG TOWN C	KWANOMZANMO TOWN C	STRYDENBURG MUN
BOTLENG TOWN COM	KWAZAMUXOLO T COUNC	THABAZIMBI STADSRAAD
BRANDFORT	LAINGSBURG	TLHAKALATLOU
BREDASDORP	LAMBERTSBAAI MUN	TROMPSBURG
BRITSTOWN MUN	LEEUWDOORNSTAD	TWEESPRUIT
BULTFONTEIN MUN	LERATSWANA DORPSK	VAN STADENSRUS
CALVINIA	LOERIESFONTEIN	VANWYKSVLEI
CARNARVON	LOUIS TRICHARDT	VERWOERDBURG
CEDARVILLE TOWN B	LUCKHOFF MUN	VICTORIA WES
CLOCOLAN	LUXOLWENI DORPSRAAD	VOLKSRUST
COLSBERG	MADIKGETLA	VRYBURG STADSRAAD
DANIELSKUIL	MARYDALE MUN	VRYHEID MUN
DE AAR	MASAKHANE TOWN CON.	WALVISBAAI
DELMAS	MASAKHANE TOWN COUN	WARMBAD
DEVELOPMENT	MASHISHING	WEPENER MUN
DEWETSDORP MUN	MATATIELE	ZINKWAZI BEACH H.COU
DORDRECHT	MATLHOMOLA TOWN C	
EDENBURG MUN	MC GREGOR	
EXCELSIOR	MEYERTON	
FAURESMITH MUN.	MIDDELBURG MUN KP	
FOCHVILLE STADSRAAD	NABOOMSPRUIT STADSR	
GANSBAAI	NAPIER	
GRAAFF-REINET	NEWCASTLE	
GRAAFWATER MUN	NIEU BETHESDA MUN	
GROOTFONTEIN SWA	NIEUWOUDTVILLE	
HARDING	NKULULEKO T COM	
HERBERTSDALE	NYARHA	
HOFMEYR MUNISIPALITE	NYLSTROOM	
HUMANSDORP	PAUL ROUX	
INLAND	PETRUS STEYN MUN	
INLAND DISTRICT	PETRUSVILLE	
IPOPENG TOWN C	PIETERSBURG	
JAGERSFONTEIN OVS	POSMASBURG	
JAMESTOWN	PRETORIA	
JANSENVILLE MUN	QUMRHA DORPSRAAD	
JEFFREYSBAAI	REIVILO	

Special Aquifers

MUNICIPALITY
BADEN CONTROL AREA
BO-MOLOPO CONTROL AREA
CROCODILE RIVER CONTROL AREA
DORPSRIVIER OPVANG GEBIED (POTGIETERSRUS) CONTROL AREA
HOTENBRAK (DENDRON) CONTROL AREA
KROONDAL-MARIKANA CONTROL AREA
LOWER-BERG RIVER VALLEY CONTROL AREA
NYLS RIVER VALLEY
SALDANHA CONTROL AREA
SCHOONSPRUIT CONTROL AREA
STRANDFONTEIN CONTROL AREA
TARLTON CONTROL AREA
UITENHAGE CONTROL AREA
WADRIF CONTROL AREA
YSERFONTEIN CONTROL AREA

APPENDIX B

TABLES OF THE VALUES USED FOR THE DRASTIC RATINGS

Depth to Groundwater (D)

RANGE	RATING	DRASTIC RANGE	DRASTIC RATING
<10m	10	0-2m	10
10-20m	5	2-5m	9
20-30m	3	5-10m	7
30-50m	2	10-17m	5
>50m	1	17-25m	3
		25-33m	2
		>33m	1
weight: 5	pesticide weight: 5		

Recharge to Groundwater (R)

RANGE	RATING	DRASTIC RANGE	DRASTIC RATING
0-10mm	1	0-50mm	1
10-25mm	2	50-100mm	3
25-37mm	3	100-175mm	6
37-50mm	5	175-250mm	8
50-75mm	6	>250mm	9
75-110mm	7		
110-160mm	8		
160-200mm	9		
>200mm	10		
weight: 4	pesticide weight: 4		

Aquifer Media (A)

RANGE	RATING
Fractured dolomite and limestone with solution channels (karstified)	10
Massive dolomite and limestone	8
Sand and gravel	8
Compact sedimentary rocks: weathered and fractured	7
Compact sedimentary rocks: fractures directly below groundwater level	5
Igneous and/or crystalline metamorphic rocks: fractured and weathered	4
Igneous and/or crystalline metamorphic rocks: fractured	3
Compact sedimentary rocks with widely spaced fractures	2
weight: 3	pesticide weight: 3

Soil media (S)

RANGE	RATING
Sand	8 - 10
Shrinking and/or aggregated clay	7 - 8
Loamy sand	6 - 7
Sandy loam	5 - 6
Sandy clay loam and loam	4 - 5
Silty clay loam, sandy clay and silty loam	3 - 4
Clay loam and silty clay	2 - 3

Topography (T)

% SLOPE	RATING
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

Impact of the Vadose Zone (I)

RANGE	RATING
Dolomite, chert and subordinate limestone	10
Porous unconsolidated to semiconsolidated sedimentary strata	9
Consolidated porous to compact sedimentary strata	7
Compact, dominantly arenaceous strata	6
Compact, dominantly argillaceous strata	5
Compact arenaceous strata	5
Compact sedimentary strata	5
Mainly compact tillite, shale and sandstone (Dwyka Formation, Ecca Group)	4
Assemblage of compact sedimentary, and extrusive rocks	4
Assemblage of compact sedimentary, extrusive and intrusive rocks	4
Mainly compact tillite and shale (Dwyka Formation, Ecca Group	3
Acid and intermediate lava	3
Mafic/basic lavas	3
Acid, intermediate and alkaline intrusives	3
Mafic/ultramafic, basic/ultrabasic intrusives	3
Mainly compact tillite	2
weight: 5	pesticide weight: 4