Groundwater vulnerability map explanatory notes

Murray Region

NSW Department of Land and Water Conservation

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Acknowledgments
The author would like to thank, Jim Dwyer for continued diligence with respect to GIS manipulations, Michael Williams and Peter C. Smith for review and technical input and Nimal Kulatunga (Albury Office) as well as Saji Joseph, Mohammed Alamgir and Arun Mahendren (Deniliquin Office) for their local knowledge, additional data, proofing and patience.

Published by:
Centre for Natural Resources
NSW Department of Land and Water Conservation
10 Valentine Avenue, Parramatta NSW 2150
August 2001

ISBN 0 7347 5193 1
CNR 2001.019

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1. Introduction

The Murray Region Groundwater Vulnerability Map has been produced as part of the NSW Government's Water Reforms introduced in an effort to achieve more sustainable water use. The ultimate aim, as part of these water reforms, is to complete vulnerability and availability mapping for the whole State of NSW.

There are a variety of uses of the groundwater resources within the Region, ranging from stock and domestic use to irrigation, town water supply, mining and industrial use, as well as environmental and recreational uses.

Groundwater vulnerability mapping has proven to be a technique in assisting the development of groundwater protection strategies as outlined in the *1995 Guidelines for Groundwater Protection in Australia* (ARMCANZ and ANZECC). These guidelines are part of the National Water Quality Management Strategy.

Groundwater vulnerability mapping is used as a guide in determining which areas are more susceptible to groundwater contamination within the mapped area.

It should be noted that groundwater vulnerability maps are accurate to the scale at which they are produced. The Department of Land and Water Conservation (DLWC) does not endorse the expansion of this scale.

The preparation of groundwater vulnerability maps involves the simplification of complex geologic and hydrogeologic situations. It is therefore important to take into account local site conditions when assessing a particular development. Vulnerability maps are designed only as a guide and are not intended to replace an environmental impact assessment.

GEOGRAPHIC SETTING

The Murray Riverina (Lower Murray) and Lake Hume (Upper Murray), secondary catchment areas are located along the southern border of NSW and encompass approximately 36,000 square kilometres. For the purposes of this report and map, they will be known as the Murray Region. The southern boundary of the Murray Region is defined by the Murray River. To the north lies the Murrumbidgee Region with the eastern boundary of the Upper Murray partially bounded by the Snowy Region.

A number of towns are located in the Murray Region, these include; Albury, Deniliquin, Finley, Holbrook, Mathoura, Moulamein, Mulwala, Tumbarumba and Wakool.

The Murray Region has a number of rivers which flow in a westerly direction; namely Murray, Wakool, Edward and Niemur Rivers as well as Billabong creek and Lake Hume which lies on the southern boundary of the Upper Murray catchment.

Groundwater usage in the Region is substantial with a number of irrigation areas; Tullakool, Wakool, Denimein and Berriquin as well as a number of irrigation trust districts and water trust areas. Rainfall in the Region varies from almost 1600 mm/yr in the Upper Murray (ie extreme east of the Region) to <400 mm/yr in the western riverine plains. Relief varies from flat in the riverine plain in the west to mountainous in the east where weather resistant rocks control topography.

2. Groundwater vulnerability maps

WHY DO WE NEED THEM?

Pressure for the development of the concept of groundwater vulnerability has been generated by the worldwide concern about the problems of groundwater contamination. Groundwater quality issues are receiving widespread attention, and hydrogeologic information is essential for the effective protection and management of groundwater quality. Effective protection should be primarily aimed at the prevention of problems and requires a sound information base to determine, on a continuous basis, the groundwater quality problems that exist and those that may develop in the future.

Groundwater vulnerability maps are used as a guide for the location of future developments in an area, in order to minimise the impact the projected development will have on the surrounding water resources.

The *Draft Guidelines for Groundwater Protection* (AWRC, 1992) states that the 'amount of protection to be afforded an aquifer should be commensurate with both the risk the aquifer is under and the value that the community places on the aquifer'. It should be remembered that, as groundwaters are often linked to surface waters, they too are also indirectly protected by the appropriate siting and management of potentially polluting industry.

GROUNDWATER VULNERABILITY MAPPING

Almost all groundwater resources are vulnerable to various degrees. Vulnerability of groundwater is a relative, non-measurable, dimensionless property. The accuracy of its assessment depends, above all, on the amount and quality of representative and reliable data available. The required data is often not available and thus scale of mapping is often limited to broad scale Region maps.

The fundamental concept of groundwater vulnerability is that some land areas are more vulnerable to groundwater contamination than others. The ultimate goal of the vulnerability map is the subdivision of an area into several units showing the differential potential for a specified purpose and use. Results of vulnerability assessment are portrayed on a map showing various homogeneous areas, sometimes called cells or polygons, which have different levels of vulnerability. The differentiation between the cells is arbitrary, because vulnerability maps only show relative vulnerability of certain areas to others, and do not represent absolute values.

The original concept of groundwater vulnerability was based on the assumption that the physical environment may provide some degree of protection (*referred to as the barrier zone*) with regard to contaminants (*the threat*) entering the subsurface water (*groundwater resource*). The earth materials may act as natural filters to screen out some contaminants. Water infiltrating at the land surface may be contaminated but is naturally purified to some degree as it percolates through the soil and other fine grained materials in the unsaturated zone.

A groundwater vulnerability map has been developed for the Murray Region as part of the NSW water reforms. This will provide the Department of Urban Affairs and Planning (DUAP),the Region Management Board, the Councils of the Murray Region, and other regulating agencies with a regional tool using a Geographical Information System (GIS) for determining the suitability of various developments in the region in a spatial context. In order to achieve this, a number of spatial attributes need to be mapped, such as geology, depth to watertable, soil properties, slope and any other attribute considered relevant. These are then weighted, and ranked, and are combined to produce a final ranking value using the appropriate algorithm, which defines the groundwater vulnerability. The method used for creating the Murray Region groundwater vulnerability map is a modification of the DRASTIC approach, first devised by the US EPA.

The following section discusses the modified DRASTIC approach in relation to the Murray Region study.

VULNERABILITY MAPPING—AN ANALYSIS OF THE DRASTIC TECHNIQUE

The DRASTIC vulnerability mapping technique can generally be referred to as a composite description of all the major geologic and hydrogeologic factors that affect and control groundwater movement, into, through, and out of an area. Similar hydrogeologic parameters therefore produce similar vulnerability. It involves the overlaying of various hydrogeologic settings that are available at the time of the map's production, via a Geographical Information System (GIS).

Each hydrogeologic setting describes topography, soil type, bedrock type, estimate of rainfall and net recharge, depth to watertable (DTWT), aquifer yield, relative hydraulic conductivity (K) and any particular features associated with the setting that are available.

DRASTIC is an acronym for the most important mappable features within the hydrogeologic setting which control groundwater pollution.

These features are:

- D Depth to watertable
- R (Net) Recharge
- A Aquifer media
- S Soil media
- T Topography (slope)
- I Impact of Vadose Zone Media
- C Conductivity (Hydraulic) of Aquifer.

To assess groundwater pollution potential within hydrogeologic settings, numerical ranking is used on the DRASTIC features. There are 3 significant parts, Weights, Ranges, and Ratings.

Weights

Each DRASTIC feature is assigned a weight relative to each other in order of importance from 1–5; the most significant is allocated five, the least significant is allocated one.

The DRASTIC technique, by its inference, attempts to identify those features important in determining vulnerability of groundwater resources. However, each study area will need to be assessed as to the importance of each specific feature for its area. For example, topography is obviously more important in a mountainous area than in the flat plains country. Also, some features will be taken into consideration in the production of other features. For example, topography will influence the production of a depth to watertable map in a fractured rock terrain, as well as represent itself in a topographic (slope) map.

Table 1. Assigned weights for DRASTIC features for the Murray Region

Feature	Weight
Depth to watertable	4
Net recharge	2
Aquifer media	5
Soil media	2
Topography	1
Impact of Vadose Zone media	5
Hydraulic conductivity of aquifer	Not used

Ranges

For each DRASTIC feature, ranges or significant media types for the feature's upper and lower limits within the Region have been devised based on its impact on pollution potential.

Ratings

The ratings for each DRASTIC feature are assigned a value between 1 and 10. The rating enables the ranking of the ranges found in each DRASTIC feature map. These ratings provide a relative assessment between ranges in each feature.

The DRASTIC Index, that is the pollution potential (*vulnerability*) at any one cell or polygon on the map, is determined as:

Pollution Potential = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw
where r = rating and w = weight

The computed (*via GIS*) DRASTIC index identifies areas which are likely to be susceptible to groundwater contamination relative to one another. *The higher the DRASTIC index the greater the groundwater pollution potential.*

It must be remembered that the DRASTIC technique provides a relative evaluation tool and is not designed to provide absolute answers. It offers planners and developers a categorisation of areas, based on the level of site investigation expectation, when considering the groundwater resources for an area.

FEATURE DEFINITION

Depth to watertable

This is an important feature as it determines the depth of material through which a contaminant must travel before reaching the watertable. In general, attenuation capacity increases as the depth to water increases. This is due to the fact that deeper water levels result in a longer travel time, therefore residence time, for any potential contaminant. The presence of low permeability layers, which confine aquifers, will also limit the travel of contaminants into an aquifer. Where an aquifer is confined, depth to water should be redefined as the depth to the top of the aquifer. For semi-confined aquifers a decision must be made as to whether it is more appropriate to consider the aquifer as unconfined or confined.

The Depth to Watertable (DTWT) feature, for the Murray Region, was created by combining actual DTWT data with topography as the principal surface aquifers are located in unconsolidated sediments and fractured aquifers, and are therefore considered to be unconfined. The groundwater is predominantly contained in the fractured and unconsolidated sediment aquifer system, which generally recharge locally. A depth to watertable map was constructed from the departmental records of standing water levels, with 5 metre contour intervals.

Recharge

Net Recharge represents the amount of water that penetrates the ground surface and reaches the watertable. This recharge water is available to transport a contaminant vertically to the watertable and horizontally within the aquifer. In addition, it controls the volume of water available for dispersion and dilution of the contaminant in the vadose and saturated zones. In general, the greater the recharge, the greater the potential for groundwater pollution.

The components incorporated in the recharge feature for the Murray Region were slope, rainfall and soil permeability. A more detailed breakdown of the factors employed, as well as the resulting equation and ratings are discussed in the range and ratings tables devised for the Region.

Aquifer media

Aquifer medium governs the route and path length (*groundwater flow system*), within the aquifer. The path length is important in determining the time available for attenuation processes, such as sorption, reactivity, and dispersion, to occur. The aquifer medium also influences the amount of effective surface area of materials with which the contaminant may come in contact within the aquifer. The route which a contaminant will take can be strongly influenced by fracturing, porosity, or by an interconnected series of openings which may provide preferential pathways for groundwater flow.

For the Murray Region, the aquifer media was defined by its geology. Geology has been grouped into 8 broad categories including, alluvium 1 and 2 (*unconsolidated sediments of varying permeabilities*), porous consolidated sediments (*sedimentary rocks*), limestone, volcanic (*Tertiary volcanics differentiated from other volcanic rocks due to their columnar nature*), plutonic/igneous 2 classes (*Carboniferous intrusions*, *Devonian to Ordovician aged intrusions*) and metasediments (*fractured Palaeozoic rocks including volcanics*).

Soil media

Soil has a significant impact on the amount of recharge which can infiltrate to the watertable, and hence on contaminant movement. The presence of fine-textured materials, such as silts and clays, can decrease relative soil permeability and restrict contaminant migration. Moreover, where the soil zone is thick, the attenuation processes of filtration, biodegradation, sorption, and volatilisation may be significant. Soil media can be described in terms of its textural classification and ranked in order of pollution potential.

For the Murray Region vulnerability map, a soil permeability map was produced using 1:250,000 soil landform information (MDBSIS, 1999). The map was compiled by approximating soil permeability for soil landforms in the Murray Region. A soil scientist from the CNR Cowra Research Station (Dr Brian Murphy) classified the soil landforms of the Region into five classes. This map was suitable to be used for the soil media vulnerability feature map, as well as a component map for the development of the impact of Vadose Zone map.

Topography

Topography is considered as the slope, and slope variability of the land surface. Topography helps to control pollutant run off or retention on the surface. Slopes that provide a greater opportunity for contaminants to infiltrate will be associated with higher groundwater pollution potential. Topography influences soil development and therefore has an effect on contaminant attenuation.

Slope percentages for the Murray Region were calculated using the Digital Elevation Model (DEM) data. Slope was then classified and ranked for use in the topography component map.

Impact of the Vadose Zone

The Vadose Zone refers to the zone above the watertable which is unsaturated or discontinuously saturated. The type of Vadose Zone media determines the attenuation characteristics of the material including the typical soil horizon and rock above the watertable. The media also controls the path length and routing, thus affecting the time available for attenuation and the quantity of material encountered. The routing is strongly influenced by any fracturing present.

The factors considered important in defining the impact of Vadose Zone in the Murray Region include soil permeability, and depth to watertable. A more detailed breakdown of the factors employed, as well as the resulting equation and ratings, are discussed in the range and rating tables devised for the Region.

Hydraulic conductivity

Hydraulic conductivity is defined as the ability of aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient. The rate at which the groundwater flows, also controls the rate at which it enters the aquifer. Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer that may occur as a consequence of intergranular porosity, fracturing and/or bedding planes.

For the purposes of the Murray Region groundwater vulnerability map, hydraulic conductivity has been incorporated into the soil media map in the form of soil permeability. The absence of spatially complete data for hydraulic conductivity has meant that this component of the map has been removed. The soil media component map has been classified into ranges where high permeability is associated with higher pollution potential and slow permeability is associated with lower pollution potential.

3. Range and rating tables for the Murray Region groundwater vulnerability map

Within the Murray Region, the features, which were deemed important in the development of the groundwater vulnerability map, include depth to watertable, recharge, aquifer media, soil media, topography, and impact of vadose zone.

Ranges and ratings for the DTWT, topography, and aquifer media are given in Tables 2, 3, and 4 respectively.

Table 2. Ranges and ratings for depth to watertable

Range (m)	Rating
< 5	10
5–10	8
10–15	6
15–20	4
>20	1
Weight 4	

Table 3. Ranges and ratings for topography

Range (slope %)	Rating
< 2	10
2–10	8
10–20	5
20–33	2
>33	1
Weight 1	

Table 4. Ranges and ratings for aquifer media

Range (geology type)	Rating
Alluvium 1	10
Alluvium 2	6
Porous Sedimentary	6
Volcanic (Tertiary)	7
Igneous (Devonian & Ordovician)	3
Metasediments	1
Weight 5	

The derivation of the Recharge, Vadose Zone Impact, and Soil Media maps is discussed in the following text.

RECHARGE

This feature is generated as a map, which is specific to the study area. The map is generated from an equation that incorporates available features, which are believed to be important to the recharge component of the study area. The equation calculates the ability of an area to act as a recharge zone relative to another area. The factors used to generate the recharge map for the Murray Region include slope, soil permeability and rainfall. DTWT and aquifer media are considered to be minor contributors. However, as they are used as other component maps, they will not be used in the recharge map. Assigning relative permeability factors to the basic soil classification groups within the Region has created the soil permeability map.

The following equation is used to generate a *recharge value*. This recharge value is then grouped into a range of values that are given a rating for use in the final DRASTIC calculation.

Recharge value = Slope % + Rainfall + Soil permeability
Where:

Slope

Range (%)	Factor
<2	4
2–10	3
10–33	2
> 33	1

Rainfall

Range (mm)	Factor
>900mm	4
700 – 900mm	3
500 – 700mm	2
<500mm	1

Soil permeability

Range	Factor
High	5
Mod-high	4
Moderate	3
Slow	2
Very slow	1

The maximum recharge value is: 13
The minimum recharge value is: 3
The rating table for recharge is shown in Table 5.

Table 5. Ranges and ratings for recharge

Range	Rating
11–13	10
9–11	8
7–9	5
5–7	3
3–5	1
Weight 2	

IMPACT OF VADOSE ZONE

As discussed previously this feature attempts to classify that zone of soil and regolith (*saprolite*) found above the watertable, known as the Vadose Zone, with regard to its ability to allow any potential contaminant to move to the aquifer. The Vadose Zone for the purposes of the Murray Region vulnerability map incorporates soil permeability and DTWT. The equation used incorporates the factors believed to be important to the Vadose Zone for the study area. The equation provides a *Vadose Zone Value* for a particular area that is defined by these factors, and is relative to another zone within the context of the study area. This *Vadose Zone Value* is then grouped into a range of values, which are given a rating for use in the final DRASTIC calculation.

Impact of Vadose Zone = Soil Permeability + DTWT
Where:

- Soil attenuation type is unavailable at the required scale, and it does not exist over the entire Region. Hence soil permeability is used, and factored for its contribution to the Vadose Zone impact.
- Depth to watertable has previously been used, but it is factored for its contribution to the Vadose Zone impact.

Soil permeability

Range	Factor
High	5
Mod-high	4
Moderate	3
Slow	2
Very slow	1

Depth to watertable (m)

Range	Factor
< 5	5
5–10	4
10–15	3
15–20	2
>20	1

The maximum *Vadose Zone impact value* is: 10
The minimum *Vadose Zone impact value* is: 2
The ratings for *Vadose Zone impact* are displayed in Table 6.

Table 6. Ranges and ratings for Vadose Zone impact

Range	Rating
8–10	10
6–8	8
4–6	5
3–4	3
2–3	1
Weight 2	

SOIL MEDIA

The soils feature attempts to classify the unique soil of the study area with regard to its ability to allow any potential contaminant to move through this zone towards the aquifer. The soil media component map for the Murray Region was constructed using 1:250,000 soil landform data from the Murray Darling Basin Soil Information Strategy (MDBSIS, 1999). Soil landforms were assessed as to their likely saturated soil permeability for the dominant soil landform. These were then classified into one of the five classes listed as follows.

The ranges and ratings for soils have been classified as outlined in Table 7.

Table 7. Ranges and ratings for permeability in soil media

Range	Factor
High	10
Mod-high	8
Moderate	6
Slow	4
Very slow	1
Weight 3	

4. Groundwater vulnerability classification in the Murray Region

Five classes of vulnerability ranking have been chosen to describe the relative assessment of the probability of a groundwater resource to contamination: '*low*', '*moderately low*', '*moderate',* '*moderately high*' and '*high*'. These classes are shown as distinct colours on the vulnerability map.

HIGH

High vulnerability ranked groundwater resources are restricted to the unconfined, shallow, highly permeable alluvial aquifers of Billabong Creek near the town of Holbrook as well as the alluvial sediments associated with the Murray River upstream of Lake Hume. These areas generally exhibit shallow watertables alluvial geology, high soil permeability and flat topography. They are also sensitive due to there ability to act as potential recharge areas.

MODERATELY HIGH

Moderately high vulnerability ranked groundwater resources are similarly characterised by mostly unconfined and shallow fractured groundwater systems in the upland part of the Region. This vulnerability class is not limited to one geological group and in fact reflects the importance of depth to watertable and the Vadose Zone on groundwater vulnerability. Areas where these conditions occur include the meta-sedimentary terrains north of Orange and granite terrains around Bathurst, Mudgee, and the Murray River from Narromine down to and encompassing the Murray Marshes.

MODERATE

Moderate vulnerability areas are associated generally with moderate slopes, porous geology, watertable greater than 10 metres, and moderate recharge. This vulnerability class includes the Tertiary basaltic terrains upstream of Coolah as well as the Triassic and Jurassic sedimentary rocks of the Sydney and Great Artesian Basins (GAB intake beds). Although depth to water is relatively deep in the GAB intake beds, care should be taken when siting development in these areas due to the nature of the GAB's importance as a groundwater resource to the farming community. This area is considered very sensitive due to its recharge potential. A considerable part of the south of the basin is recharged from this area and thus development should be carefully considered for its pollution potential prior to consent being granted. Alluvium downstream of Dubbo with moderate to slow soil permeability and low rainfall also falls into this class.

LOW–MODERATE

Low–Moderate vulnerability is the dominant classification with the majority of the western part of the Region falling into this category. Fractured Palaeozoic meta-sediments and the wide expanses of alluvium west of Narromine characterised by low rainfall, flat slopes and an often-deep watertable are in this class. The meta-sediments (including the Palaeozoic volcanics) in the upland part of the Region also largely fall within this classification class due to a deeper watertable and steep slopes.

LOW

Low vulnerability ranked groundwater resources are generally characterised by a deep watertable, meta-sedimentary geology and very steep slopes (i.e. greater than 33% slope). These areas are limited to the upland part of the Region upstream of Lake Burrendong.

LEVEL OF ASSESSMENT REQUIRED

Groundwater vulnerability maps do not consider the chemical nature of the pollutant in assessing vulnerability. They are concerned only with the hydrogeologic setting, which makes the groundwater susceptible to contamination from a surface source.

When a development application is being prepared, or considered, it is important that the impact of the development, on both surface and groundwater resources is assessed. It is important to know who uses these resources (beneficial use) and the current groundwater quality. Potentially polluting groundwater developments should not be allowed within highly vulnerable areas. Where such activities are proposed, significant engineering measures would be necessary to minimise the risks of pollution.

The following Table is a guide to the amount of groundwater assessment required for a development that requires consent in any of the five-aquifer vulnerability classes.

Table 8. Groundwater assessment for developments that require consent

Vulnerability classification	Groundwater assessment requirements
Low	Groundwater contamination assessment report A desk study is required to identify the concerns and potential risk to groundwater or the environment, and the need for any further action to be presented in the development application. A standard format hydrogeological report would most likely result.
Low-moderate	Site investigation with monitoring A potential risk is indicated by the vulnerability map requiring site investigation and groundwater monitoring. The extent of work should involve a limited amount of site investigation, soil and water sampling and testing, definition of flow systems and reporting, in addition to a desk study.
Moderate	Detailed site investigation and monitoring For moderate vulnerability areas, or where the previous levels of investigation indicate a demonstrated risk to groundwater, a detailed groundwater site investigation is required. The work should include an ongoing monitoring program, details on the protection design factors, (natural attenuation, physical barriers, etc) in addition to the previous levels of investigation.
Moderately high	Demonstrated groundwater protection system The risk to groundwater, as demonstrated by the vulnerability map, is an area in which contamination to groundwater cannot be tolerated. The work should include a desk study, detailed site investigation, and implementation of an on-going monitoring program, as indicated above. In addition, the protection design system incorporating natural attenuation, hydraulic barriers, physical barriers etc, needs to be demonstrated, to be effective. The proposal will need to include a feasibility plan for a clean-up, in addition to a detailed monitoring and ongoing assessment program.
High	Demonstrated remedial action plan/prohibition This classification identifies the area as having a potential risk so great as to warrant a demonstrated remedial action plan. The work should include a desk study, site investigations, ongoing monitoring, plus a demonstrated remedial action plan for clean-up, which analyses the effectiveness of the remediation approach in achieving designated water quality criteria. The financial capacity of the responsible party to enact the plan should also be evaluated. In the event that the risk to groundwater is unacceptable, an activity may be banned by the responsible authority.

Source: Modified from the Australian Water Resources Council (AWRC), *Draft Guidelines for Groundwater Protection,* (1992).

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