Murrumbidgee Catchment Groundwater Vulnerability Mapping

Groundwater Data Sources and Manipulation

The collation and manipulation of hydrogeological data is of the utmost importance in the production of a vulnerability map using the "Modified - Weights of Evidence Method". To manage and process the volume of data required for this method, a Geographic Information System (GIS)[1] is utilised. The component maps (ie Response Variable (EC), Minimum Depth to Groundwater (MDGW), Geology and Soil Permeability) are compiled from varying data sources. Hydrogeological data such as depth to watertable/potentiometric surface and water quality information (EC) is held by NSW-DLWC in two databases;

1. Hydsys Database, a DOS operated database no longer in use for groundwater quality data storage,
2. GDS Database, an Oracle operated Database developed by NSW-DLWC in 1996/97.

Similar data for the ACT region was obtained in hard copy format from the ACT Urban Services Department. This data was input into Excel spreadsheet format, manipulated and added to the NSW data set.

Other groundwater data used in this study came from the Murray Basin Hydrogeological Mapping Series (AGSO and DLWC) and previous DLWC surveys within the Murrumbidgee Region. This ensured that all possible knowledge of the catchment as well as all historical data was available for interpretation and use.

Depth to watertable/potentiometric surface information was extracted from the DLWC's Groundwater Data System (GDS), and from the ACT data set and interpreted by a hydrogeologist for use in the Minimum Depth to Groundwater Component Map. Once collated the three data sets were manipulated (sorted and filtered) in isolation to produce three separate tables of similar end products. The aim of the manipulation was to produce a data set that represented most recent measurements for the upper-most aquifer. Once the data sets were merged a final filter is performed to ensure no duplication of bores. The final component map is a compilation of the three databases as well as additional data used to compile the Murray Basin Hydrogeological Maps.

Similarly, the EC Response Variable is determined from electrical conductivity data extracted from the Hydsys Water Quality Database and the ACT data set. Once extracted, data is viewed spatially and assessed as to its compliance with the spatial requirements of the Weights of Evidence Program (ie even distribution of data). Even spatial distribution is not always possible as bore locations tend to skew/stack towards more favourable hydrogeologic environments (eg. alluvium). As with watertable/potentiometric information, the data is filtered so that the data represents the most recent date as well as the upper most aquifer.

Field Work and Sampling

A two week field trip involved the collection of water quality data and standing water levels (SWL) to supplement the existing historical data for the area as well as allowing for familiarisation of the study area. Due to the size of the catchment, it was unable to extensively cover all the areas where data holes existed. The main areas covered were the upper Murrumbidgee catchment and region between Cootamundra and Griffith. Information and data in the western sector of the catchment was considered to be well documented in the Murray Basin Hydrogeology Map Series.

[1] Department of Land and Water Conservation uses the Genamap Geographic Information System Format.

Groundwater samples were obtained from 44 bores with many more bores were visited and found to be either abandoned or difficult to obtain representative samples from.

Field measurements included electrical conductivity (EC), pH, Dissolved Oxygen (DO), Redox Potential (Eh) and temperature. An unfiltered 1000mL field sample was taken at each sample site for nitrate analysis, which was undertaken within 9 hours of sampling. Two filtered 500mL water samples were collected for determining anion and cation (10 millilitres of nitric acid was added for preservation) analysis by the AGSO Laboratory. The ion analyses were not required for the vulnerability map but it was considered appropriate to obtain the samples at this time to add to a larger data set held at AGSO.

Samples were obtained from already equipped bores or bores which allowed a submersible pump or bailer to be placed in the bore. The bores were purged for three bore volumes or until the EC reading stabilised before being sampled. A summary of the field data collected for the study is presented in Appendix C.

Standing Water Level (SWL) measurements were taken where practical, and readings compared with any historical data on SWL. Any indications of waterlogging, such as saturated ground were noted on the field data sheets map and compared with known SWL data. Information on general landuse, soil texture and characteristics, geology, or additional comments or observations were also recorded on the field data sheets.

Murrumbidgee Catchment Response Variable

The response variable chosen to define the study area as being either vulnerable or non vulnerable is the median value for the EC data set. The EC data set should be representative of the groundwater EC within the study area as well as providing an even distribution of data. In previous studies undertaken by DLWC in NSW, the median EC value for the response variable was found to be between 1200-1500 μS/cm. This range of median EC values is used to broadly represent the division between short residence and longer residence times of groundwaters within NSW. A median EC value, which falls within this range, is considered to be suitable to use with the WOE technique and allows for comparison with other WOE vulnerability maps throughout the state.

Existing historical data from the DLWC groundwater database, previous groundwater investigations in the catchment and the ACT groundwater data set yielded 1473 bores with EC data. The distribution of bores however is heavily weighted, as would be expected, to areas where groundwater quality is good and easily obtained. For example, in the central area around Wagga Wagga, bores in alluvial sediments along the Murrumbidgee River and adjoining creeks far out number bores located in the eastern catchment where low yielding fractured rocks dominate. Field sampling was directed to those areas where information on EC data was limited or not available, in an attempt to provide a better distribution of EC data and a more realistic approximation of the response variable for the study area. The additional field data went some way to correcting the biased distribution of groundwater quality data.

The median value for the EC response variable used to develop the groundwater vulnerability map for the Murrumbidgee Catchment is 1480 μS/cm.

Murrumbidgee Catchment Component Maps

Geology

Geology is an important consideration in understanding groundwater. It is the medium through which the groundwater flows and, therefore, has a control on the quality and distribution of groundwater and is responsible for how the groundwater system operates. Geology is used to help define different hydrogeologic provinces or conditions and provides insight into the type of groundwater conditions, which can be expected.

Existing geology, hydrogeology and geomorphic maps, as well as NSW-DLWC bore logs and reports, have been used to compile the Geology Component map of the catchment. The source material includes:

The Geology of the Murray Basin at 1:1,000,000 Geology Map Sheet, 1991 (mapped at 1:250,000)

Jerilderie, Hay, Narrandera and Deniliquin 1:250,000 Murray Basin Hydrogeology Map Series 1991-1992

Geomorphology of the Riverine 1:250,000

Murrumbidgee Catchment Geology at a scale of 1:4,000,000, NSW Centenary Atlas, 1988.

The Murrumbidgee Catchment Geology (1:4,000,000) was used for the upper half of the catchment. This map was derived from 1:1,000,000 geology, grouped and digitised by NSW Department of Mineral Resources sheets (pers. comm. Peter Bliss (DLWC GIS)). Subsequent to this, the Cainozoic alluvium was added by DLWC staff, digitised from the Wagga Wagga, Cootamundra, Canberra, Bega and Goulburn Geology sheets (1:250,000).

For the purposes of groundwater vulnerability mapping, geological units assessed as having similar hydraulic parameters are grouped together. Based on the geology described on the above map sheets, hydrogeology maps from the Murray Basin, geomorphology maps and Department Water Resources Status Report (1986), six "geologic" units have been defined. They include:

1. Alluvium 1; within the confines of the Murrumbidgee floodplain and major tributaries and extending to encompass high quality groundwater resources contained in the alluvial fan located downstream of Narrandera. This unit comprises of clay, silt, and the water bearing quartz sands and gravels. The alluvium 1 boundary, indicated on the geology map, is based on the alluvial boundary defined in the NSW WRC Status Report "Groundwater Resources of the Upper Murrumbidgee River Alluvium Report" (1986). Downstream of Narrandera this alluvium is described as highly permeable sands of the Calivil Formation known to contain high yielding, high quality (<500 mg/L) groundwater. This unit was digitised onto the Geology Map from Murray Basin Hydrogeological Map Series (first edition). In the western half of the catchment this unit also encompasses the ancestral streams of the catchment which encompass the alluvium associated with the Murrumbidgee River and Yanco Creek.
2. Alluvium 2; outside of the Murrumbidgee floodplain and major tributaries. This unit refers to the remainder of the Cainozoic unconsolidated sediments found in the upper reaches of the rivers and creeks and as well as alluvium associated with prior streams in the western half of the catchment. Also included was the alluvium associated with high yielding bores and water quality 500-1000 mg/L within the Calivil Formation. This latter boundary was taken from the Murray Basin Hydrogeology Map Series (first edition). Although geologically and hydrogeologically distinct, the Tertiary basalts of the catchment have been included within this unit because it has similar proportions of vulnerable and non-vulnerable bores as defined the response variable.
3. Alluvium 3; this unit comprises alluvium predominantly of the Shepparton Formation in the western half of the catchment, poorly consolidated Cainozoic gravelly silts and Quaternary claypans. It is defined as alluvium with inferior aquifer and water quality characteristics.
4. Ordovician and Silurian fractured meta-sedimentary rocks, volcanic and minor intrusive rocks, which dominate the eastern half of the catchment.
5. Weathered granites, granodiorites, and adamellites of Silurian/Devonian age.
6. Pre-Cainozoic Sediments; massive sandstones, shale, mudstone and conglomerates.

The Geological Component Map has been produced from maps at varying scales. The reliability of the geology map reflects the various input scales used. The Geology Map used during the construction of the groundwater vulnerability map necessarily incorporates interpreted hydrogeologic characteristics and geomorphic features of the catchment.

Minimum Depth to Groundwater

The depth to groundwater is one of the major parameters when dealing with vulnerability of groundwater, (ie the shorter the distance to groundwater, the less soil and underlying unsaturated material there is to act as a filter or retardant). Depth to groundwater also affects the transit time available for various abiotic and biotic processes to degrade the pollutant (National Research Council, US, 1993). Minimum Depth to Groundwater (MDGW) in groundwater vulnerability mapping, refers to the depth to the watertable in unconfined conditions and the depth to the potentiometric surface in the semi-confined and confined conditions where watertable conditions are either missing or temporal. Both of these surfaces are defined by the SWL of the bores.

A Minimum Depth to Groundwater Component Map is a representation of the spatial distribution of the depth to the groundwater. Depth to groundwater information and data is obtained from historical records and bore logs, existing reports, as well as specific fieldwork. The resulting map is however quite subjective and represents a simplified model of the groundwater conditions of the catchment.

The construction of the MDGW map relied, in the first instance, on the most recent SWL information available for a data point; or, in the second instance, the SWL value indicating the seasonally highest SWL value. Where semi-confining/confining aquifer conditions were present and/or watertable data was absent the potentiometric surface was plotted. Data points were then contoured with consideration to the groundwater system operating, topography, geology, and local knowledge. In the eastern sector, where relief is much higher, topography was a dominant factor in determining the contour pattern.

The construction of a map portraying water level conditions of a range of aquifer types, ie confined, semi-confined and unconfined, across hydrogeological units is a very complicated task. Data was insufficient to take account for seasonal variations, which particularly effect the unconfined aquifers, and aquifer details in some of the fractured rock areas

In areas where confined or a semi-confined groundwater systems are thought to operate, particularly in the alluvial areas, it was found that the area was often subject to extended periods of waterlogging. This waterlogging is related to poor drainage and a limited opportunity for downwards percolation. Waterlogging, or saturated conditions, will increase the potential for contamination to a groundwater resource or migration offsite to the surface environment.

The MDGW Component Map for the Murrumbidgee Catchment is a generalisation of the depth to groundwater found within the study area, and was produced at 1:250,000 scale. The map was constructed specifically for the purposes of the groundwater vulnerability mapping, and should be used only as a guide to the expected MDGW.

Soil Permeability/Unsaturated Zone Component Map

The unsaturated zone includes all soil and geologic media found within the zone from the land surface to the watertable or top of the aquifer. The characteristics of the soil and geologic media within this zone are responsible for retardation and attenuation of any pollutant moving through to the underlying aquifer. Attenuation and retardation of a pollutant relies upon a number of often complex and inter-related processes, including chemical precipitation, sorption, dilution, dispersion, and biodegradation.

Parameters which are considered important attributes in determining the characteristics of the unsaturated zone include soil and aquifer media type, hydraulic conductivity, soil texture, permeability of the unsaturated zone, thickness of unsaturated zone, thickness of low permeability zones, and preferential flow paths. Quantifying or modelling these parameters in the unsaturated zone is generally difficult, relying upon inferences and extrapolation of both related data indicated above when available, or surrogate data sets. The Murrumbidgee Groundwater Vulnerability map relied upon a soil map as a surrogate for a data set on the unsaturated zone, although there are limitations in the applicability of this approach.

The base map used for the Soil Permeability Component Map was the 1:2,000,000 Soil Map of the Murrumbidgee Catchment compiled by DLWC-Land Information Centre and published in the Atlas of NSW (1987). This map was derived from several sources:

Atlas of Australian Soils (Northcote *et al*, 1966)

Landsat TM at 1:250,000

A Geomorphic Map of the Riverine Plain of South-Eastern Australia (Butler et al, 1973)

The input data was generalised and digitised at 1:1,000,000 and then published at 1:2,000,000 (pers. comm. Glen Atkinson).

Soil permeability was estimated by ranking the 15 different soil types according to permeability. They were then divided into three permeability categories and assigned the following permeability values;

Low = 0-1 mm/hour, Medium = 1-100 mm/hour and High = >100 mm/hour.

The cracking clays were assigned a low permeability, which is valid, when the soils are saturated. Appendix D contains a Table of the soil types, their ranking and permeability values. Soil science experts from CSIRO and AGSO undertook the ranking and permeability assignment.

This process considers only the top few metres of soil and does not consider the unsaturated zone beneath this depth. Soils data, in lieu of data more specific to the unsaturated zone, was used as an indication of what the attributes of the unsaturated zone are likely to be. However its application was not conclusive for use as a surrogate for information within the unsaturated zone.

Groundwater Systems in the Murrumbidgee Catchment

Confined, semi-confined, and unconfined groundwater systems operate in the Murrumbidgee Catchment. As a general rule the metasediments are more likely to exhibit a confined to semi confined groundwater system with the alluvium and granite terrains operating predominantly as unconfined to semi-confined groundwater systems.

Unconfined groundwater systems are predominantly recharged in direct response to a rainfall event occurring above, or a short distance up gradient, of the groundwater resource in question. Standing water level (SWL) measurements taken will approximate the actual depth to the watertable. Groundwater in an unconfined aquifer has greater potential to be impacted upon by overlying surface activities.

In confined, semi-confined conditions groundwater is held under pressure, being confined or bound by a less permeable layer(s). Recharge to the aquifer will generally occur upgradient, where the aquifer unit outcrops at the surface. In a confined or semi-confined situation the water level in a bore will rise up the bore until the water pressure is equal to atmospheric pressure. Contouring of SWL data where this system operates, produces a potentiometric surface map.

Interpretation of water level data requires knowledge of the groundwater system operating. Confined and semi-confined groundwater systems are in general less susceptible to contamination from direct surface infiltration of a pollutant because a less permeable boundary provides a barrier to groundwater movement. Confined and semi-confined groundwater systems are also generally slower to exhibit the impacts of groundwater contamination due to less permeable boundaries, and increased potential for dilution, dispersion and attenuation effects. However contamination can occur to confined aquifer systems from inappropriately sited surface activities in the recharge areas.

The dominant groundwater systems operating within the ascribed geologic units are as follows:

- **Granites**: The dominant aquifer in the granite terrain is found at the base of the weathered zone. Recharge to this groundwater storage zone is predominantly derived locally from rainfall at the surface. The groundwater system operating is therefore considered to be unconfined.

- **Ordovician and Silurian Fractured Metasediments**: Groundwater movement in the metasediments is considered to be structurally controlled (ie groundwater flow is restricted predominantly to cleavage planes and along fracture planes). Recharge is from rainfall infiltrating into the unit where the rock type crops out at the surface and where overlying sediments or clay dominant weathered horizons are thin. Where a unit in these metasediments are overlain by less permeable units or sediments, then confined or semi-confined conditions can be expected.
- **Alluvium**: Groundwater in the alluvium, found within the catchment, is predominantly recharged from rainfall infiltration at the surface. In some areas, dominant recharge is believed to be from upward seepage of groundwater into the alluvium from the valley sides and basement rocks, ie where Ordovician metasediments are in direct contact with the alluvial sediments at Kyeamba Creek near Wagga Wagga. Alluvial sediments along the Murrumbidgee River are, for the purposes of groundwater vulnerability mapping, to be considered to be mainly recharged from direct surface infiltration behaving predominantly as an unconfined to semi-confined groundwater system. Alluvial aquifers in the western sector are confined to semi-confined and recharge occurs by lateral movement of groundwaters from more permeable zones of the Shepparton and Calivil Formations west of Narrandera.

Geomorphology/Prior Streams

Much work has been done in the Riverine with regards to ancestral and prior streams. In the southeastern Riverine two (2) “end member” types of abandoned river channels exist;

1. Ancestral Streams (Pel, 1964b), which include sediments of the Coonambidgal Formation (see alluvium 1 & 2, geology component map).
2. Prior Streams (Butler, 1950), Quiamong and Mayrung members.

It has been postulated by Pels, (1964a) that the remnant channels of ancestral streams are much larger than that of the modern rivers and are represented by belts of sediment about 3m below the level of the adjacent plain. Prior streams on the other hand are described as low, winding, sandy ridges on the clay flood plain and in some cases associated with 1 to 2 m deep winding depression which marks the old stream bed (Butler et al, 1973).

Both members are important hydrogeologically, although it is unclear whether viable bores exist within these sediments. The sediment associated with prior streams are predominantly quartz rich channel sands as well as finer grained floodplain deposits. Due to the scale of catchment, prior streams, whilst considered a very important potential groundwater resource, have not been included in the map development. Alluvial sediments of the Coonambidgal Formation taken from (Murray Darling Basin 1:250,000 Geology) have been included in the geology component map as a surrogate to the likely vulnerability of the prior streams of the area. Where development is proposed in areas where prior streams are known to exist, detailed hydrogeological investigation is required to establish the sensitivities to contamination of individual sites. The mapping scale used in the construction of the Murrumbidgee Groundwater Vulnerability Map has meant that these small indicative features are too small to be observed at the final scale of the map (ie 1:1,000,000). This does not imply that these sediments are considered non-vulnerable. It is unlikely that the addition of the indicative prior stream data would have greatly benefited the end use of the vulnerability map due to scale limitations.

Use and Limitations of the Murrumbidgee Catchment Groundwater Vulnerability Map

The groundwater vulnerability map for the study area, Figure 5, is based on the component maps and uses a median groundwater EC response variable of 1480 μS/cm as the threshold value between vulnerable and non-vulnerable conditions.

The primary function of a groundwater vulnerability map is to assist planners, developers, and resource managers with a tool for use as a "first pass" of the expected vulnerability of the groundwater.

Whilst the map can be used for regional planning purposes and to direct potentially contaminating activities to suitable locations, it is not intended to be prescriptive. Specific site investigations to determine the groundwater vulnerability of sites are still required. Groundwater vulnerability maps rate vulnerability into five (5) classes. This rating is used to distinguish between the relative vulnerability of groundwater within the study area. The map does not preclude development from any area, but serves as an indicator of the expected vulnerability of the groundwater for an area.

The map assesses the potential groundwater vulnerability from surface activities. It does not assess the impact on groundwater from activities, such as landfills, which involve excavation and will therefore may increase the potential threat to groundwater.

The map cannot reflect the likely response caused by the chemical nature of a pollutant, the degree of threat to the groundwater, or the importance of the resource to the community or the environment. It shows only the hydrogeological setting of the area and provides an initial assessment of the potential vulnerability of groundwater in that area.

The Murrumbidgee Catchment groundwater vulnerability map is designed to also assist planners, developers, and groundwater managers, in determining the appropriate level of groundwater protection and corresponding assessment required for new developments. The level of groundwater protection afforded a particular development should be commensurate with the risk the development poses to a groundwater system and the value of the resource. The assessment of groundwater protection required, is based on three variables:

- *threat of activity to groundwater;*
- *groundwater vulnerability;*
- *resource and environmental value of groundwater.*

A more complete description of groundwater protection levels and a corresponding table indicating the type of assessment required for a particular level of protection is provided in Appendix B.

The preparation of a groundwater vulnerability map necessarily involves the simplification of complex geological and hydrogeological concepts. Local site conditions need to be considered when assessing the potential impacts from a development. The groundwater vulnerability map is not intended to replace a site specific investigation.

The Murrumbidgee Catchment groundwater vulnerability map has been produced at a scale of 1:1,000,000. Whilst some of the component map were derived from varying data sources of differing scales, ranging from 1:250,000 to 1:4,000,000, the impact on the resulting groundwater vulnerability map from use of the less detailed geological information is not expected to be significant. The Murrumbidgee Catchment groundwater vulnerability map can be used, with the confidence limits indicated, to predict areas of relative groundwater vulnerability at scales not greater than 1:1,000,000.

When a development application is being prepared or considered it is important that the impact of the development on both surface and groundwater resources be assessed. Where development is located close to a groundwater vulnerability boundary then the level of vulnerability should be that of the higher vulnerability class, unless site investigations demonstrates otherwise.

Groundwater Interaction with the Environment

Groundwater plays an important role in the environment. It provides baseflow, which helps support, a range of streams, rivers, and wetlands. Rising watertables result in lost production and impacts on the environment through waterlogging and land salinisation. Groundwater is therefore an important component when considering natural resource management. Certain areas within the Murrumbidgee Catchment are subject to rising groundwater levels (eg Griffith and Colleambally irrigation areas where groundwater is within one metre of the surface over a large area).

The depth to watertable map has identified areas which have shallow watertables, and which are prone to waterlogging. Whilst these shallow watertable areas are not necessarily groundwater resources they are important to consider when evaluating the suitability of an area for a particular development and its impact on the environment. An area with shallow watertables, will have implications for any development which proposes to rely on the sorption capabilities of the soil in its disposal of wastewater onsite. Shallow watertables can result in contaminants being transported via shallow subsurface flow or surface flow to other parts of the environment, including streams, rivers, and wetlands.

Validation of Groundwater Vulnerability Map with Nitrate Field Data

Nitrogen occurs in water as nitrite or nitrate anions (NO_2^- and NO_3^-) or in the cationic form as ammonium (NH_4^+). Anionic species such as nitrate are readily transported in water and are stable over a considerable range of conditions. The presence of the anionic species is generally considered to be an indicator of pollution through disposal of sewage or organic waste.

Field sampling of nitrates has been trialed as a simple technique to validate the vulnerability rating assigned in the Murrumbidgee Catchment groundwater vulnerability map. The technique relies on some degree of nitrate contamination being already present in the groundwater from the existing landuse activity. Sampling is restricted to a relatively small number of samples, 31 groundwater samples were tested for nitrate whilst in the field. Historical nitrate and nitrite data was also extracted from the Hydsys Water Quality Database and a total of 364 bores contained some form of nitrate data.

Nitrate level above 5mg/L was used to indicate whether the hydrogeologic setting is susceptible to contamination. The results indicate that elevated nitrate levels can be found over different hydrogeologic settings, which cover all of the vulnerability classifications. Elevated nitrate levels were found in areas highlighted as having a low groundwater vulnerability rating as well as those areas tagged with a high vulnerability rating. It should be noted that high loadings of nitrogen or any other potential contaminant, even in a low groundwater vulnerability classification, has the potential to contaminate the underlying groundwater.

Concerns in regard to using nitrate for validation of groundwater vulnerability mapping include:

- limited data size;
- data biased to available bore holes during field trip as well as those bores invariably of good water quality with a full chemical analysis;
- potential for contamination to occur at time of sampling from surface sources as grab samples were sometimes taken;

The variety of landuses and different nitrogen loadings found within the study area as well as the aforementioned factors can give no conclusive validation of groundwater vulnerability rating using nitrates as an indicator.

Groundwater Vulnerability Assessment

The Murrumbidgee Catchment Groundwater Vulnerability Map has identified those areas which are more susceptible to groundwater contamination relative to other areas based on the geology, soil permeability and minimum depth to groundwater component maps using the modified Weights Of Evidence (WOE) technique.

The Murrumbidgee Groundwater Vulnerability Map indicates that the alluvium along the Murrumbidgee River and some of its tributaries upstream of Wagga Wagga are the most highly vulnerable groundwater systems of the catchment. This vulnerability classification extends for some 50km downstream of Narrandera as a fan shaped area covering high yielding aquifers of the Shepparton Formation. Further west, the Great Cumbung Swamp has also been identified as a highly vulnerable part of the catchment due to the presence of shallow watertables. The lower reaches of the Murrumbidgee River and Yanco Creek systems are also classified as highly vulnerable.

Moderately-High groundwater vulnerability is associated with high yielding aquifers of the Calivil and Shepparton Formations (downstream of Narrandera) and fractured granite terrains (upland areas of the catchment) where watertables are less than five metres deep (ie Colleambally and Griffith Irrigation Districts as well as areas near Murrumbateman, east of Cootamundra and northwest of Yass) and where soil permeability is medium. This classification extends downstream along the alluvial sediments of the Murrumbidgee River north of Colleambally west to the Great Cumbung Swamp and alluvial sediments of Yanco Creek south of Colleambally west to the border of the catchment.

Moderate groundwater vulnerability have been defined in the mapping process as those areas of the Shepparton Formation where soil permeabilities are low and watertables are deep. This classification is represented by a fan-shaped area with its bounds extending to approximately twenty kilometres east of Hay and twenty kilometres northwest of Jerilderie. This classification extends downstream to include alluvial sediments of the Coonambidgal Formation. The map does not include a vulnerability assessment of the prior streams of the catchment due to the final scale of the map, however areas which are known to contain prior streams should include a site specific assessment to determine the particular sensitivities of each site. In the upland part of the catchment this classification encompasses mostly granites and fractured rocks coupled with depth to water of 5-15 metres and low - medium soil permeabilities.

Low - Moderate groundwater vulnerability is the classification whose area covers the largest portion of the catchment and is indicative of all geological classes coupled with deep groundwater of poor quality and low-medium soil permeabilities.

The lowest vulnerability classification corresponds with areas where watertables are deep, groundwater quality is poor and soil permeability is predominantly medium. The geology is restricted to predominantly clay rich alluvium as well as the Pre-Cainozoic sediments of the catchment.

Groundwater vulnerability map provides planners, developers and groundwater managers with the expected vulnerability to groundwater for a particular area. This will assist in directing those developments with the potential to threaten groundwater resources or the environment, to more appropriate sites.

The groundwater vulnerability classification for the area will assist groundwater managers and planners with determining the appropriate level of protection afforded to groundwater for a particular site and activity. Groundwater vulnerability, in combination with an assessment of the potential threat of a particular resource, and appraisal of resource/environmental value is used to determine the appropriate level of protection to be afforded to a groundwater system. A table indicating the six levels of protection as adapted from the 1995 Guidelines for Groundwater Protection in Australia is found below.

Groundwater Protection Assessment

Groundwater protection afforded to a particular area is to be determined by the risk the development poses to a groundwater system and the value of the resource. New developments requiring development consent need to base the assessment on three important variables including;

- ***threat of activity to groundwater***. The type of activity proposed will determine the potential threat to the groundwater and groundwater related environments. Not all activities pose the same threat to groundwater resources, a chemical factory disposing of wastewater onsite will pose more serious threat than a dairy operation at the same location.
- ***groundwater vulnerability***. Groundwater vulnerability looks at the potential of the hydrogeologic setting to offer protection to the groundwater. A groundwater vulnerability map determines the relative vulnerability of groundwater for a particular catchment or area. Where a groundwater vulnerability map is not available then a site specific information is required to determine groundwater vulnerability.
- ***resource and environmental value of groundwater.*** The planner and groundwater manager make a subjective assessment of groundwater resource in relation to the reliance the community and the environment have on the resource. A groundwater resource which is the only source for a town drinking water supply, or which feeds an important wetland will have a greater value than if the groundwater resource was of poor quality and not relied upon.

The process of determining the necessary level of protection is subjective, guidance in selecting the correct level should be sought from professional sources. A table listing the six levels of protection starting from a low level (Level I) and increasing to a very high level of protection (Level VI) is provided , Table A-1 indicates the assessment considered necessary to achieve each level. This approach is based on the Agriculture and Resource Management Council of Australia and New Zealand 1995 “Guidelines for Groundwater Protection in Australia”.

Vulnerability Classification	**Groundwater Assessment Requirements**
Low	**<u>Groundwater Contamination Assessment Report</u>** 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 hydrogeologic report would most likely result.
Moderately Low	**<u>Site Investigation with Monitoring</u>** 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	**<u>Detailed Site Investigation and Monitoring</u>** 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	**<u>Demonstrated Groundwater Protection System</u>** 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	**<u>Demonstrated Remedial Action Plan/Prohibition</u>** 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.

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