WAGGA WAGGA LGA GROUNDWATER VULNERABILITY MAP

Introduction

Since late 1995, the Department of Land and Water Conservation has provided seed funding to further develop the concept of groundwater vulnerability, and assist local government, planners, developers and groundwater managers in the assessment of vulnerability of groundwater to surface activities within NSW. The groundwater vulnerability mapping project is aimed at providing a simplified, relative and spatial assessment of the vulnerability of groundwater to contamination from surface activities, within the context of the study area.

In February 1996 Wagga Wagga City Council was approached by the Department with a proposal for producing a groundwater vulnerability map for the Wagga Wagga Local Government Area. The project was designed to develop a map which identified those areas which are more susceptible to groundwater pollution and assist planners and developers in determining the most suitable sites for potentially polluting activities. The map will complement Wagga Wagga's Land and Water Management Plan, providing an additional layer of information for strategic planning and future development within the Wagga Wagga Local Government Area.

Geographical Setting

Wagga Wagga Local Government Area, covering an area of over 4,800 km^2, forms part of the south west slopes and plains of New South Wales. The topography in the eastern part of the area is undulating to hilly with the Murrumbidgee Valley gradually widening out to a moderately wide valley along which the river has built up rich alluvial flats. A short distance west of Wagga Wagga the River leaves its valley and enters the plains tract of the area. In its plains tract, in the western part of the LGA, the Murrumbidgee is typical of all westward-flowing rivers of NSW. There is only a very slight fall in the river, the flow is sluggish, and there is an extensive development of meanders; in times of heavy rain the area is liable to flood.

In general, the present climate is one of cool, relatively wet winters, and hot, relatively dry summers. The area is just within the zone of winter-rainfall dominance, with the predominance of winter rains decreasing from south to north.

Wagga Wagga Groundwater Vulnerability Mapping

Field Work and Sampling

A 10 day field trip involved the collection of water quality data and standing water levels to supplement the existing historical data for the area as well as allowing for familiarisation of the study area. Over 70 bores were visited and samples taken from 56 bores.

Electrical conductivity (EC) and pH were measured in the field, and unfiltered 250ml water samples were collected for determining field nitrate values. A number of the samples were frozen and sent to the laboratory for nitrate analysis and compared with field results.

Samples were obtained from already equipped bores or bores which allowed a 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. 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, or stands of unhealthy or dead trees, or evidence of salinity, were noted on the field map and compared with known SWL data. Information on general landuse, soil texture and characteristics, geology, or additional comments or observations were recorded on the field sheets and 1:25,000 maps.

Areas of waterlogging or salinity and bore locations where located on 1:25,000 sheets. This data was then transferred onto the appropriate 1:100,000 sheets and component maps and digitised into the GIS. The scale at which most of the mapping was carried out is 1:100,000.

Wagga Wagga Response Variable

The response variable chosen to identify an area as being either vulnerable or non vulnerable within the study area, was generally the median value for the EC data set. It is therefore very important that the data set approximates as closely as possible the range of EC values within the study area as well as providing an even distribution of data. In previous studies, throughout the State the EC value for the response variable was found to be between 1200-1500 μS/cm. This range of EC values is considered to broadly represent the range between short residence and longer residence times in groundwaters. A median EC value which falls within this range is considered to be suitable for use using the WOE technique and to allow for comparison through the State.

Existing historical data from the DLWC groundwater database and previous groundwater investigations in the Wagga Wagga area yielded over 250 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. In the Wagga Wagga area bores in alluvial sediments along the Murrumbidgee River and adjoining creeks far out number bores located in the hard rock areas.

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 EC value from the groundwater collected in the field and from the database is 1105 μS/cm EC. This value fell outside of the range of 1200-1500 μS/cm used for the purposes of groundwater vulnerability mapping, to distinguish between vulnerable and non-vulnerable groundwaters within the State.

To counter the uneven distribution of bores within the study area Predicted Response Variables were used to represent the groundwater at that point. These predicted response variables provide de facto groundwater information at sites within the study area where actual data points do not exist. The effect of the PRV's is to move the median EC value, used to determine the vulnerability of groundwater, towards a more representative value for the study area. PRV's are used to remove the bias from areas where there is a biased distribution of bores and water quality. Approximately 10% of the final number of bores, or 35 bores of the total 337 bores used, in the Wagga Wagga map were predicted response variables PRV's.

The median value for the EC response variable of the 337 bores, including the 35 PRV's, used to develop the groundwater vulnerability map for Wagga Wagga is 1320μS/cm.

Wagga Wagga Component Maps

Geology

Geology is an important consideration in understanding groundwater. It often controls 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 geological maps and data, as well as Department of Land and Water Conservation bore logs and reports, have been relied upon for the geology within the study area. The source material includes the Wagga Wagga 1:100,000 geology map 1996, the Wagga Wagga 1:250,000 geology map sheet 1966, the Jerilderie 1:250,000 geology map sheet 1976, the Cootamundra 1:250,000 geology map sheet 1967, and the Narrandera 1:250,000 geology map sheet 1977.

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 map sheets and Department Water Resources Status Report, 5 "geologic" units have been defined. They include:

1. Alluvium 1; within the confines of the Murrumbidgee floodplain and major tributaries. 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 1986 Status Report "Groundwater Resources of the Upper Murrumbidgee River Alluvium Report", Hydrogeological Section, Water Resources Commission.
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 western plains of the study area.
3. Poorly consolidated Cainozoic gravelly silts and Quaternary claypans.
4. Ordovician siltstone, slates and phyllite; which dominate the eastern part of the study area.
5. Weathered granites, granodiorites, and adamellites of Silurian/Devonian age.

The geological component map has been produced from two different scales; 1:100,000 for the area bounded by the Wagga Wagga 1:100,000 sheet and 1:250,000 for areas outside of this. The reliability of the geology map will reflect the two scales of mapping used.

Depth to Water Table

The shorter the distance to groundwater, the less soil and underlying unsaturated zone 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). Depth to the water table (DTWT), in groundwater vulnerability mapping, refers to the depth to the watertable in unconfined conditions and the depth to the top of the aquifer for confined conditions.

A depth to watertable map is a representation of the spatial distribution of the depth to the groundwater. Depth to water table 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.

The construction of the DTWT 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 watertable value. Data points were then contoured with consideration to the groundwater system operating, topography, geology, and local knowledge of areas prone to waterlogging.

Complications arise in the construction of a depth to water table map when attempting to portray different hydraulic conditions, ie confined, semi-confined, and unconfined conditions, across hydrogeologic units. Unconfined aquifers in some areas are subject to large seasonal variations of the watertable. Where data is available on the seasonal nature of the watertable, a conservative approach is adopted, with the seasonally highest watertable levels used to produce the DTWT component map.

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. In semi confined groundwater environments with high piezometric heads the area was represented on the DTWT map as having a shallow watertable.

The DTWT map for the Wagga Wagga LGA is a generalisation of the depth to groundwater found within the study area, being produced at 1:100,000 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 DTWT.

Groundwater

Confined, semi-confined, and unconfined groundwater systems are believed to operate in the Wagga Wagga area. 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 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 bounded 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. Interpretation of waterlevel 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 or from excessive loadings.

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

- 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.
- Groundwater movement in the vertically to sub vertically dipping metasediments is considered to be structurally controlled along the tilted bedding planes. Recharge is from rainfall infiltrating into the unit where the rock type crops out at the surface. Groundwater flow is restricted predominantly to bedding and cleavage planes and along fracture planes. Where a unit in the metasediment unit is bounded by a less permeable unit or sediment then confined or semi-confined conditions can be expected.
- Groundwater in the alluvium found within the Wagga Wagga area 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 the base where Ordovician metasediments are in direct contact with the alluvial sediments, ie Kyemba Creek. Alluvial sediments within the Wagga Wagga area 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.

Groundwater Field Observations

The groundwater within the study area was found to be subject to seasonal variations in the SWL. The relatively wet winters can cause rises in the SWL, which in combination with soil characteristics can create areas of extended periods of waterlogging and saturated soil conditions.

During the fieldwork, areas of waterlogging were encountered which are subject to seasonally saturated conditions. Whilst these saturated soils do not strictly pose a direct or immediate threat to the underlying confined/semi-confined groundwater resource, due to low permeabilities of sediments between the resource and the surface, concerns are held with regard to impact on surface waters and the environment from overland flows. Low permeabilities and saturated soils can create problems for surface activities, such as effluent disposal practices, which rely upon the sorption characteristics of the soils to contain the migration of the contaminant. There is potential for a pollutant to migrate offsite via overland or shallow subsurface flows in areas subject to waterlogging.

Unsaturated Zone

The unsaturated zone includes all soil and geologic media found within the zone from the land surface to the water table 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, aquifer 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 and the unsaturated zone is generally the most difficult, relying upon inferences and extrapolation of both related data indicated above when available, or surrogate data sets. The Wagga Wagga vulnerability map relied upon soils data as a surrogate for a data set on the unsaturated zone.

Soils

Soil scientists from the Soil Survey Unit of DLWC were engaged to determine soil characteristics for the study area. Soil permeability and soil attenuation characteristics, considered to be important parameters impacting upon groundwater vulnerability potential, were derived from existing soil landscape mapping for the Wagga Wagga LGA. Whilst this makes use of the best available data it considers only the top 1.5 - 2.0 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. In the case of the Wagga Wagga area, the use of soil derivative maps to represent the unsaturated zone provided some insight into likely unsaturated zone attributes. However its application was not conclusive for use as a surrogate for information within the unsaturated zone.

The final vulnerability map did not make use of the soil attenuation map due to lack of data reliability and to data inconsistencies. Further work on the use of soil derivative maps, in particular soil attenuation characteristics is required to determine the usefulness and reliability of the data. A description of both derivative maps is provided for analysis.

Soil Permeability

Soil permeability was determined using selected geomorphological data collected during the Wagga Wagga Soil Landscape mapping undertaken by DLWC Soil Survey Unit. Soil scientists from DLWC used a modified version of McKenzie & Jacquier (in press) to estimate the saturated hydraulic conductivity of the soils. Parameters used to determine saturated soil hydraulic conductivity included; field texture(clay estimates), structure grade, soil dispersibility, exchangeable sodium percentage (ESP), and a crude estimate of porosity.

When classifying soil permeability the dominant soil types were considered and the more restrictive or less permeable of the dominant soil types was chosen. If one soil type was more dominant than others then the permeability attached to this soil would be used regardless of whether a less permeable or more restrictive sub dominant soil type was present within the soil landscape. (D. McKane pers. comm. Jan 97).

The derivative map, was constructed using data taken from both the Soil Landscapes of the Wagga Wagga 1:100,000 Map Sheet (Chen and McKane in press), and soils data extrapolated from broad scale mapping, local experience and topographic maps, for the remainder of the study area. The reliability of the soils information in the areas outside of the Wagga Wagga 1:100,000 Map Sheet is much less than that for the area within the Wagga Wagga 1:100,000 Map Sheet.

Soil Attenuation

DLWC soil scientists used parameters obtained from the Wagga Wagga soil landscape mapping to derive soil attenuation values and classes. Soil attenuation considers only the top 1.5m of the soil providing an indication and relative distribution of soils rather than as an absolute property.

The following parameters were used to derive the soil attenuation values and classes:

- Cation Exchange Capability (CEC) values
- sum of exchangeable bases
- phosphorous sorption values
- depth of the B horizon

Whilst soil attenuation is considered an important attribute which will influence the vulnerability of groundwater from pollution, the map produced from the existing soils landscape information was not considered to be of sufficient reliability over the entire study area to justify its use. The soil attenuation map with variations in detail and scale of information presented resulted in inconsistencies and undermined the reliability of the groundwater vulnerability map when included as a component map. The exclusion of the soils attenuation map resulted in a more consistent and intuitively meaningful groundwater vulnerability map.

The final groundwater vulnerability map for Wagga Wagga did not include the soil attenuation derivative map. Inclusion of soils attenuation maps in future groundwater vulnerability maps will require further development.

Use and Limitations of the Wagga Wagga Vulnerability Map

The groundwater vulnerability map for the study area is based on the component maps described in the preceding paragraphs and uses a median groundwater EC value of 1320 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 determining the groundwater vulnerability of a site 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 to surface activities. It does not assess the impact on groundwater of activities, such as landfills, which involve excavation and will therefore increase the potential threat to groundwater.

The map cannot reflect a 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 Wagga Wagga 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 herewith.

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 Wagga Wagga groundwater vulnerability map has been produced and limited for use at 1:100,000 scale. Whilst the geology component map was derived from maps produced at 1:100,000 and 1:250,000 scale, the impact on the resulting groundwater vulnerability map from use of the less detailed geological information is not expected to be significant. However a reliability index on the map sheet indicates where the less detailed geological and soils data has been relied upon, indicating a lesser degree of confidence with the map. The Wagga Wagga groundwater vulnerability map can be used, with the confidence limits indicated, to predict areas of relative groundwater vulnerability up to and including the scale of 1:100,000.

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 level of vulnerability, unless site investigations demonstrates otherwise.

Groundwater Interaction with the Environment

Groundwater plays an important role in the environment. It provides baseflow which helps supports 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.

Areas within Wagga Wagga LGA are subject to rising groundwater levels causing waterlogging and localised land salinisation. Waterlogging is associated with groundwater discharge areas or areas where soil permeability is very low and drainage very poor.

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, subject to waterlogging, will have implications for any development which proposes to rely on the sorption capabilities of the soil in its disposal of wastewater onsite. Waterlogging can result in contaminants being transported via shallow subsurface flow or surface flow to other parts of the environment, including streams, rivers, and wetlands.

Whilst the Wagga Wagga groundwater vulnerability map has attempted to identify the potential impact on the environment from areas with shallow watertables prone to waterlogging it is predominantly concerned with the groundwater resources of the area. The map can therefore not be relied upon to consider the impact of those areas which have shallow watertables and which are not specifically a groundwater resource.

Areas of shallow watertables and its potential to impact on the environment will need to be considered during the specific site assessment.

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 on the Wagga Wagga 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, 45 field samples in total to cover the range of environments and landuses found in the Wagga Wagga Local Government Area.

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 a range of vulnerability ratings used. Elevated nitrate levels were found in the low groundwater vulnerability rating as well as the 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.

Table 1: Comparison of Elevated Nitrate Values with Groundwater Vulnerability Rating

Groundwater Vulnerability Rating	% of study area	No. of sample points with nitrate > 5mg/L	% of sample points with nitrate > 5mg/L	Total No. of points with nitrate sampling
High	10%	2	40%	5
Moderate High	11%	0	0%	14
Moderate	2%	0	0%	3
Moderate Low	18%	1	17%	6
Low	59%	1 (2*)	6% (12%*)	17

* One of the samples from this group, is believed to have elevated nitrate levels as a result of direct contamination from animal faeces, seen within the shallow well.

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, ie not necessarily an even spread of data;
- potential for contamination occurring within the bore/well from surface sources as grab samples were taken;
- with a variety of landuses and different nitrogen loadings found within the study area does not allow any conclusive validation of groundwater vulnerability rating using nitrates as an indicator.

Conclusions

The Wagga Wagga groundwater vulnerability map has identified those areas which are more susceptible to groundwater contamination relative to other areas based on the soil permeability, depth to water table, and geology using the Weights Of Evidence (WOE) technique.

The map indicates that the alluvium along the Murrumbidgee and some of its tributaries are the most vulnerable, with those areas further away from the dominant drainage areas being less vulnerable. The 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 can be found herewith.

Level of Assessment Required

Groundwater vulnerability maps do not directly 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 water as well as and groundwater is assessed. It is important to know who uses these resources (beneficial use) and what the current quality of the water is. Potentially polluting 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 to the groundwater system.

The following Table, modified after the Australian Water Resources Council (AWRC), Draft Guidelines for Groundwater Protection, 1992, is a guide to the amount of groundwater assessment required for a development that requires consent in the five aquifer vulnerability classes.

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.

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