

TWEED-BRUNSWICK GROUNDWATER VULNERABILITY MAP

LOCATION

The Tweed Valley catchment area is located approximately 800km north of Sydney in the north-eastern area of New South Wales, and lies between latitude's 153°07' and 153°36', and longitude's 28°11' and 28°34' as shown in Figure 1. The Tweed Valley catchment is primarily drained by the Oxley, Rous, and Tweed Rivers, the upper reaches of which originate in the Ranges surrounding Mount Warning. The catchment has an area of approximately 1300km², and a population of approximately 62 000, with the major centres being Murwillumbah and Tweed Heads.

The Brunswick Valley catchment is located approximately 700km north of Sydney, south-east of the Tweed Valley Catchment, and lies between latitude's 153°26' and 153°39', and longitude's 28°18' and 28°42' as shown in Figure 1. The Brunswick Valley catchment is primarily drained by the Brunswick River, Marshalls and Simpsons Creeks. The catchment has an area of approximately 550km² with the main centres of population located at Brunswick Heads, Mullumbimby and Byron Bay.

CLIMATE

The Tweed and Brunswick Valley catchments lie within the subtropical maritime region of the eastern coast of Australia. This leads to the summer months being predominantly warm and humid, while the winter months are mild.

The average annual rainfall for the area is approximately 1700mm, of which 60% falls during months from January through April. The highest precipitation occurs on the coastal and northern extremities of the catchments. Cyclonic events can cause intense rainfall during the months from December to April, which can result in flooding during the wet season.

The average annual evaporation for the region is 1600mm, with December being the peak month of 189mm and June having the lowest monthly figure of 78mm.

PHYSIOGRAPHY

The topography of the Tweed and Brunswick Valley catchments is quite varied. The majority of the terrain in the catchments can be classed as hilly to mountainous. Land slopes in excess of 8 degrees cover about 60% of the valley, with extensive flood plains being located around the lower reaches of the rivers (Beale, J.G. 1968).

The most predominant physical features within the Tweed Valley catchment have been carved by the major rivers and their tributaries. Over time they have sculptured a large erosional caldera from what was once a shield volcano. Mount Warning is the remnant of the former shield volcano, rising to a present day height of approximately 1150m. The weathering and erosion of the volcano, as well as sea level fluctuations, have created the floodplains of the Tweed River Valley.

Mountainous areas in the Brunswick Valley are located along the central western boundary of the valley in the headwaters of the Brunswick River and Burringbar Creek. The Brunswick River drains a reasonably steep catchment, with elevations of up to 600m, before entering the flat coastal valley near Mullumbimby. The north arm (Marshalls Creek) commences at an elevation of about 450m and initially flows in an easterly direction, finally turning due south,

near the coast, before joining the Brunswick River. The south arm (Simpsons Creek) flows north, parallel to the coast, and drains the predominantly marshy coastal strip between Byron Bay and Brunswick Heads.

VEGETATION

The catchments are both situated in a sub-tropical zone and therefore have a wide diversity of vegetation.

Areas of rainforest and wet sclerophyll forest in the hinterland are particularly significant. These are listed as World Heritage areas and are on the Register of the National Estate.

Wetland vegetation communities, including mangroves, saltmarsh, and seagrass have developed on floodplain soils, within tidal influences, of the major rivers.

SOILS

There are two major soil types within the Tweed and Brunswick Valley catchments. These are:

- basalt derived soils (kraznozems, chocolate basalts) resulting from the erosion of the tertiary volcanic flows from Mount Warning. These soils occur throughout the catchments and are found in plateau areas and on steeper slopes. They are usually well drained.
- sedimentary derived soils (resulting from the erosion of sandstones and claystones, both metamorphosed and in their alluvial form). These occur on the floodplain and along the coastal strip. Their drainage depends on their location.

Floodplain soils are composed of estuarine sediments and alluvium.

Problems arise with the formation of acid sulfate soils. These are defined as soils in which, as part of a development or ripening process involving bacterial action and aeration, sulfuric acid is produced in amounts that have a pronounced effect upon the main soil characteristics.

Acid sulfate soils are primarily derived from the drainage of parent marine and estuarine sediments that are rich in reduced sulfur compounds, mainly pyrite (FeS_2). Pyrite accumulates through geological time in soil that is rich in organic matter and flushed by dissolved sulfate, usually from sea water. When drainage brings oxygen into the previously saturated soils, the pyrite is oxidised to form sulfuric acid. Acid sulfate soils develop where the production of acid exceeds the neutralising capacity of the parent soil material, so that the soil pH falls below 4. In their oxidising acidic state, the soils contain concentrations of aluminium and iron that are toxic to many plants. Acid runoff or seepage waters from these aurally exposed soils may be detrimental to aquatic life in receiving soils.

SOCIO-ECONOMIC DEVELOPMENT

The first European settlement, within the Tweed / Brunswick area, was attributed to the vast number of timber cutters that arrived in search of Red Cedar. The harvesting of Red Cedar trees continued for many years until the trees were decimated and the community turned to agriculture.

The lush green fields that occur as a result of the high rainfall and mild temperatures of the region made the area ideal for dairying. During the 1950's, farmers began to branch out into

other industries, including bananas on areas with steep slopes, and sugar cane on the river flats.

Since then, primary industry in the region has become wide and varied, including:

Sugar Cane	Oysters	Macadamias
Timber	Beef Cattle	Fishing (recreational & commercial)
Dairy Cattle	Tea Tree	Horticulture
Vegetables	Bananas	Crayfish, Perch (aqua culture)
Oil Tree Production	Stone Fruit	Avocados
Prawns	Bush Foods	Pork / Bacon

Residential areas are concentrated at: Tweed Heads, Terranora, Terranora Heights, Fingal, Chinderah, and Banora Point in the Tweed Valley, and, Brunswick Heads, Byron Bay, Mullimbimby, Hastings Point, and Kingscliff in the Brunswick Valley.

Undisturbed or pastoral lands are concentrated at: Cobaki, Broadwater, and west of Terranora in the Tweed Valley, and, west of the coast and Mullumbimby in the Brunswick Valley.

Commercial / Industrial zones are concentrated at: Tweed Heads and areas south of Tweed Heads.

Agricultural lands (non pastoral) are concentrated at: east of the residential area of Terranora, Sugar cane farming occurs mostly on the floodplain upstream of Chinderah and is the regions most important agricultural activity.

Dredging of the Tweed River and broadwaters, for navigation, has occurred since early in the century and more recently for commercial sand and gravel extraction. The coastal dune system was extensively mined for mineral sands during the 1960's and 1970's.

Tourism is also a major industry in the Tweed and Brunswick Valley catchments. With its beautiful beaches and areas of rainforest, many tourists visit the region. More and more visitors are coming for the ecotourism experience, and this segment of the industry is expanding rapidly in response to this specific demand.

SURFACE WATERS

The average yearly discharge of the Tweed River is 418 000 megalitres. It is tidal to Bray Park Weir, while the Rous River is also influenced by the tide to Kynnumboon. The average yearly discharge of the Brunswick River is 52 000 megalitres. Its tidal range is to the west of Mullumbimby.

Runoff as a percentage of rainfall within the Tweed catchment is 23% (Ross, J.B. & McKibbin, D. 1992), which is just above the average for coastal rivers. The Clarrie Hall Dam is the major storage in the catchment. Runoff as a percentage of rainfall within the Brunswick catchment is 29% (Beale, J.G. 1968), which is also above the average for coastal rivers.

The quality of stormwater runoff from a catchment undergoing the transformation from undisturbed / rural to residential / commercial, i.e., an urbanising catchment, is typically of poorer quality than that from the catchment of both the undisturbed and the completely urbanised / established land. This is due to two major attributes, being:

- occurrence within the catchment of considerable areas of exposed and / or disturbed soils.

- frequent over application of fertilisers to encourage vegetation growth.

The main source of sediment inflow into the major rivers is through agricultural runoff. This runoff can occasionally cause non-point source pollution, such as from nitrogen, while point source nitrogen pollution can occur from sewage treatment discharges.

Significant surface runoff also occurs in the development of urban areas that, in turn, affects stream hydrology and morphology. As urbanisation increases, the percentage of catchment surfaces impervious to rainfall also increases leading to a decrease in groundwater recharge rates and therefore groundwater storage is affected. Urban surface runoff is also a source of pollution of the rivers. Typical materials present in urban runoff are: dust and soil, litter, animal wastes, fertilisers, oil and grease, and particles derived from corrosion and abrasion, spillage's to land surfaces, and illegal waste discharges.

This pollution can have a significant impact on the aquatic/riparian environment of the water courses as well as extending to the fisheries industries within the estuaries to beyond river mouth entrances.

GEOLOGY

The following geological summary has been extracted largely from Graham (1990).

During the Late Silurian period (400 million years ago), mud and sand were deposited into a marine trough, eventually forming greywacke sandstone and shale. These rocks were, over time, metamorphosed into what is now known as the Neranleigh-Fernvale Group. This Group forms the basement rocks of the Tweed - Gold Coast region.

During the Mesozoic Era (80 million years ago), giant freshwater lakes formed west of the Mt Warning area into which sediments were deposited from surrounding highlands such as the New England granite area. One of these lakes is now called the Clarence Basin and holds numerous fossiliferous material.

The border between the Neranleigh-Fernvale Group and the two sedimentary basins formed a point of weakness through which, in the Mesozoic Era, there were many volcanic eruptions. These eruptions were composed of rhyolites and other associated volcanic rocks and extended from well south of the Tweed, under the present day Mt Warning and outcropping in the north at Chillingham and Tamborine. These rocks are called the Chillingham Volcanics.

In the Tertiary Period (20 to 60 million years ago), a new series of eruptions started along the line of weakness of the Chillingham volcanics. These eruptions were of low viscosity basaltic lava spreading out relatively flat over vast distances. The main vents were probably in the Mt. Warning area but there must have been many others, perhaps near Point Danger, Cudgen-Fingal, Binna Burra (Qld) and Mullumbimby. These flows formed the base of the growing volcanic complex.

A later Tertiary volcanic phase of less plastic and quicker hardening acidic lavas, such as rhyolite, replaced the basalt. This lava tended to harden in the vents, thus building up the pressure underneath, until eventually, violent explosions released the pressure. This violence at times pulverised the rock into fine ash or larger volcanic bombs or frothed it to pumice. This material, mainly rhyolite, can now be seen as a hard layer resisting erosion in the cliffs of Springbrook and at the edge of the Lamington Plateau and Tweed Range. Due to the fact that the rhyolite is acidic and the water is also acidic, this rock does not weather as rapidly as

the basic lava that came later. As a result, the rhyolite forms a barrier to the downcutting highland streams, producing numerous waterfalls and cataracts.

The next stage of the volcanic complex came with a series of outflows of basalt lava. Like the first phase, this was probably a relatively quiet one, with long lava flows coming from a number of vents, but with the Mt Warning vents being the major ones. These basalt flows can be seen on the tops of the Lamington Plateau, the Tweed Range and the Nightcap Range.

Around 10 million years ago, the volcano began its demise. Immobile and very acidic trachyandesite effectively plugged the vents causing acid intrusives, including syenite and trachyte, to upwell in radial cracks. Under the hardening plug, micro-granite began to form, which can now be seen in the Mt. Nullum area. It is this complex of plug and ring dykes, later revealed by erosion, which makes up the present Mount Warning landscape.

Over time, the high rainfall, and thus surface water drainage, caused considerable erosion branching out in a radial form from Mount Warning. Erosion tends to occur more prominently around planes of weakness, such as fractures formed from the great pressure exerted by the upwelling magma and possible collapse of the caldera. Erosion of the inner part of the shield around the volcanic centre occurred, resulting in the present amphitheatre-like structure. Discontinuous alluvial deposits have built up within the drainage channels, becoming more extensive from Murwillumbah to the coast, where surface relief is minimal.

During the Quaternary period aeolian processes formed the sand dunes extending along the east coast from Point Danger to Cudgen Headland.

Over time, this geological provenance has been sculptured by wind and water, weathering and erosion resulting in the present landforms that we see today, producing recent alluvium, sand, and soil.

The geology of the Tweed and Brunswick Valley catchments can be seen in the Aquifer Media vulnerability component map.

Feature Definition

Depth To Water Table

This is an important feature as it determines the depth of material through which a contaminant must travel before reaching the aquifer. In general, attenuation capacity increases with depth to water increases because deeper water levels imply longer travel times. 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 unconfined or confined.

The Depth to Water Table feature, for Tweed and Brunswick catchments, was calculated by combining actual DTWT data with topography. The groundwater is predominantly defined as a fractured aquifer system, which recharges locally. A Depth to Water Table map was constructed from the Departmental records of standing water levels and hydrogeologic principles, with 5 metre contour intervals.

Recharge

Net Recharge represents the amount of water per unit area of land that penetrates the ground surface and reaches the water table. 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 factors that are incorporated in the recharge map for the Tweed and Brunswick Valley catchments were; Slope, Geology (Aquifer) Type, Geological Infiltration Proportion, Rainfall and Soil Permeability.

Aquifer Media

Aquifer medium governs the route and path length (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 affective surface area of materials with which the contaminant may come in contact within the aquifer. The route that a contaminant will take can be strongly influenced by fracturing or by an interconnected series of solution openings that may provide pathways for easier flow.

For the Tweed and Brunswick Valley catchments, the aquifer media was defined by its geology.

Soil Media

Soil has a significant impact on the amount of recharge that can infiltrate into the ground and hence on the ability of a contaminant to enter into the ground. 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 fairly thick, the attenuation processes of filtration, biodegradation, sorption, and volatilisation may be quite significant. Soil media can be described in terms of its textural classification and ranks it in order of pollution potential.

The soil mapping for the Tweed and Brunswick area was recently completed. A request was made for additional soil permeability and cation exchange capacity (CEC) maps. The permeability maps were used as a combination of both soil media and soil hydraulic conductivity.

Topography

Topography is considered as the slope and slope variability of the land surface. Topography helps control whether a pollutant will run off or remain on the surface in one area long enough to infiltrate. Slopes that provide a greater opportunity for contaminants to infiltrate will be associated with a higher groundwater pollution potential. Topography influences soil development and therefore has an effect on contaminant attenuation. Slope percentages were calculated using the GIS and then used for ranking and rating purposes for topography.

Impact of the Vadose Zone

The vadose zone refers to the zone above the watertable that is unsaturated or discontinuously saturated. The type of vadose zone media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. 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 vadose zone in the Tweed and Brunswick Valley catchments include; Soil Depth, Vadose Zone Type (based on the soils CEC), and Depth to Water Table. A more detailed breakdown of the factors employed, as well as the resulting equation and ratings, is discussed in the range and rating tables devised for the area.

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 bedding planes. For purposes of this Vulnerability Map, hydraulic conductivity has been incorporated into the Soil Media map in the form of soil permeability due to hydraulic conductivity and permeability being related. The Soil Media map was divided into ranges where high hydraulic conductivity (high permeability), is associated with higher pollution potential.

Range and Rating Tables for the Tweed / Brunswick Valley Catchment Study Area

Within the Tweed and Brunswick Valley catchments, the features that were deemed important in the development of a vulnerability map included: Depth to Water Table, 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 1, 2, and 3 respectively.

Table 1 - Ranges and Ratings for Depth to Water

<i>Depth to Water Table (m)</i>	
Range	Rating
< 5	10
5 - 10	9
10 - 15	7
15 - 20	5
20 - 25	3
>25	1
Weight 5	

Table 2 - Ranges and Ratings for Topography

<i>Topography as Slope %</i>	
Range	Rating
< 10%	10
10 - 20%	8
20 - 30%	5
30 - 40%	3
>40%	1
Weight 1	

Table 3 - Ranges and Ratings for Aquifer Media

Aquifer Media

Range (Geology Type)	Rating
Beach sand and dunes	10
Alluvium	8
Basalts	6
Sedimentary	5
Metasediments	4
Plutonic	1
Weight 5	

The derivation of the a) Recharge, b) Vadose Zone Impact, and c) Soil Media maps, are discussed in the following section.

Recharge

This feature was generated as a map that is specific for the study area. It incorporates features into an equation that are believed to be important to the recharge component of the study area. The equation used calculates the ability of an area to act as a recharge zone relative to another area. The factors used to generate the Recharge map include: geology type (aquifer media), geological infiltration proportion, slope, soil permeability, and rainfall.

The following equation was used to generate a **Recharge Value**. This Recharge Value was then grouped into a range of values that were given a rating for use in the final DRASTIC calculation.

$$\text{Recharge Value} = \text{Slope \%} + \text{Rainfall} + \text{Infiltration Proportion of Geological Type} + \text{Soil Permeability}$$

Where:

<i>Infiltration Proportion of Geological Type</i>	
Range	Factor
Beach sand and dunes	5
Basalts	5
Alluvium	4
Sedimentary	4
Metasediments	3
Plutonic	1

<i>Slope %</i>	
Range	Factor
<10%	5
10 - 20%	4
20 - 30%	3
30 - 40%	2
>40%	1

<i>Rainfall (mm)</i>	
Range	Factor
>1875mm	4
1750 - 1875mm	3
1625 - 1750mm	2
<1625mm	1

<i>Soil Permeability</i>	
Range	Factor
0.1-119mm/day (very low)	1
120-1200mm/day (low)	2
1201-4800mm/day (moderate)	3
> 4800mm/day (high)	4
Disturbed terrain	4

The maximum Recharge Value is: 18

The minimum Recharge Value is: 4

The rating table for Recharge is shown in Table 4.

Table 4 - Ranges and Ratings for Recharge

<i>Recharge</i>	
Range	Rating
16-18	10
13-15	9
10-12	5
7-9	3
4-6	1
Weight 4	

Impact of Vadose Zone

As discussed previously this feature attempts to classify that zone of soil and regolith (saprolite) found above the water table, known as the vadose zone, with regard to its ability to allow any potential contaminant to move through this zone towards the aquifer. The Vadose zone feature, for the purposes of this vulnerability map, incorporates Soil Depth, Vadose Zone Type, and DTWT.

An equation was used incorporating these factors believed to be important to the vadose zone for the study area. The equation provides a **Vadose Zone Value** for a particular area defined by these factors and which is relative to another zone within the context of the study area. This **Vadose Zone Value** was then grouped into a range of values that were given a rating for use in the final DRASTIC calculation.

Impact of Vadose Zone = Soil depth + Vadose Zone Type + DTWT

Where:

Soil Depth information was used from digitised soil landscapes maps from the Lismore-Ballina, and Tweed Heads 1:100 000 sheets. Soil landscapes maps of the area indicate that soil depth ranges from absent to >2 m depth.

Vadose Zone Type was based on the digitised CEC index maps that have been developed for the Tweed and Brunswick Valley catchments.

Depth to water table has previously been used, but is factored for its contribution to the vadose zone impact.

<i>Soil Depth (m)</i>	
Range	Factor
absent	4
<0.5	4
0.5-1	3
1-2	2
>2	1

<i>Vadose Zone Type (Ion Exchange Capacity >20cm depth)</i>	
Range	Factor
< 6 me/100g (very low)	5
6-12 me/100g (low)	4
12-25 me/100g (moderate)	3
25-40 me/100g (high)	2
> 40 me/100g (very high)	1
Highly variable areas	4
Disturbed terrain	3

<i>Vadose Zone Type (Ion Exchange Capacity <20cm depth)</i>	
Range	Factor
< 6 me/100g (very low)	5
6-12 me/100g (low)	4
12-25 me/100g (moderate)	3
25-40 me/100g (high)	2
> 40 me/100g (very high)	1
Highly variable areas	4
Disturbed terrain	3

<i>Depth To Water Table (m)</i>	
Range	Factor
<5	5
5 - 10	4
10- 15	3
15- 20	2
20 - 25	2
>25	1

The maximum **Vadose Zone Impact Value** is: 19

The minimum **Vadose Zone Impact Value** is 4

The ratings for **Vadose Zone Impact** are displayed in Table 5.

Table 6 - Ranges and Ratings for Vadose Zone Impact

<i>Vadose Zone Impact</i>	
Range	Rating
17-19	10
14-16	8
10-13	6
7-9	3
4-6	1
Weight 5	

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 impact of the soil media within the Tweed and Brunswick Valley catchments was based solely on the soil permeability as this reflects both grain size and textural characteristics.

The ranges and ratings for soils have been classified as outlined in Table 6.

Table 7 - Ranges and Ratings for Soil Media

<i>Soil Permeability</i>	
Range	Rating
Disturbed terrain	10
> 4800mm/day (high)	10
1201-4800mm/day (moderate)	7
120-1200mm/day (low)	4
0.1-119mm/day (very low)	1
Weight 2	

AQUIFER VULNERABILITY CLASSIFICATION IN THE TWEED AND BRUNSWICK VALLEY CATCHMENTS

Five classes of vulnerability ranking were 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 distinctive colours on the vulnerability map.

“*High*” vulnerability ranked groundwater resources are usually unconfined, shallow, highly permeable, aquifers such as dune sand with minimal soil coverage and low slope. Depth to water table also plays a significant role in groundwater vulnerability. Those areas that have a water table less than 5 metres, combined with shallow soil depth, low slope, high to very high permeability, and low CEC are deemed highly vulnerable. Aquifers within this class require a high level of protection. Such areas are found particularly along the unconsolidated sands of the coastal foreshores as well as in alluvium of the Rous and Brunswick river systems.

“*Moderately High*” vulnerability ranked groundwater resources for the Tweed and Brunswick area refers to a large portion of the area and includes shallow aquifers associated with moderate slopes, higher rainfall and higher recharge. The soils are often moderately to highly permeable, with a moderate to high cation exchange capacity and a depth to water of less than 10 metres.

“*Moderate*” vulnerability ranked groundwater resources refers to areas associated generally with moderate slopes, in hard rock terrain, water tables greater than 10 metres, and moderate recharge.

“*Moderately Low*” vulnerability ranked groundwater resources is the dominant classification for much of the hilly or steeper terrain associated with the central and western areas of the map. These areas generally have moderate soil permeability with the depth to water often

being greater than 15 metres. The dominant aquifer medium for this rating is either basalt or sedimentary.

“Low” vulnerability ranked groundwater resources in the Tweed and Brunswick catchments is found in areas of very high slope, low rainfall, and low to very low permeability. Most of the low vulnerability within the mapped area is associated with the Mt Warning complex.

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 hydrogeological setting that 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 what the current quality of the water is. Potentially groundwater 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.

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 either of the five aquifer vulnerability classes.

Vulnerability Classification	Groundwater Assessment Requirements
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Low	<p><u>Groundwater Contamination Assessment Report</u></p> <p>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.</p>
Moderately Low	<p><u>Site Investigation With Monitoring</u></p> <p>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.</p>
Moderate	<p><u>Detailed Site Investigation and Monitoring</u></p> <p>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.</p>
Moderately High	<p><u>Demonstrated Groundwater Protection System</u></p> <p>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 ongoing monitoring program, as indicated above. In addition, the protection design system incorporating natural attenuation, hydraulic barriers, physical barriers etc, need 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.</p>
High	<p><u>Demonstrated Remedial Action Plan/Prohibition</u></p> <p>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.</p>

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