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Risk assessment guidelines for groundwater dependent ecosystems

Volume 1 – The conceptual framework

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The NSW Office of Water manages the policy and regulatory frameworks for the state's surface water and groundwater resources, to provide a secure and sustainable water supply for all users. It also supports water utilities in the provision of water and sewerage services throughout New South Wales.

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Other volumes in this set

Volume 1 – Risk assessment guidelines for groundwater dependent ecosystems – The conceptual framework

Volume 2 – Risk assessment guidelines for groundwater dependent ecosystems – Worked examples for seven pilot coastal aquifers in NSW

Volume 3 – Risk assessment guidelines for groundwater dependent ecosystems – Identification of High Probability Groundwater Dependent Ecosystems on the Coastal Plains of NSW and their Ecological Value

Volume 4 – Risk assessment guidelines for groundwater dependent ecosystems – The Ecological Value of Groundwater Sources on the Coastal Plains of NSW and the Risk from Groundwater Extraction

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Prepared for the New South Wales Government as a requirement under the *NSW Water Act* 2000, to assist in reporting for the Groundwater State Target, and for the Australian Government, National Water Commission, as part of the Coastal Groundwater Quality and Groundwater Dependent Ecosystems Project.

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Prepared for the New South Wales Government as a requirement under the *NSW Water Act* 2000, to assist in reporting for the Groundwater State Target, and for the Australian Government, National Water Commission, as part of the Coastal Groundwater Quality and Groundwater Dependent Ecosystems Project.

Executive summary

This document has four volumes:

Volume 1 – *Risk assessment guidelines for groundwater dependent ecosystems – the conceptual framework* has been developed jointly by the NSW Office of Water and the Office of Environment and Heritage (OEH) to:

1. assist agency staff support the requirements of the *Water Management Act* 2000
2. provide methods to identify and value groundwater dependent ecosystems (GDEs) to assist reporting against the state-wide Target for Groundwater that:

   'By 2015 there is an improvement in the ability of groundwater systems to support groundwater dependent ecosystems and designated beneficial uses', NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015.
3. provide a risk assessment framework for GDEs for the National Water Commission Project Coastal Groundwater Quality and Groundwater Dependent Ecosystems (GDE)
4. Volume 1 provides detailed methods for defining, identifying and assessing ecological value and risk through a risk analysis conceptual framework for GDEs, with supporting background information. The conceptual framework allows potential and actual impacts of proposed activities on GDEs to be assessed in accordance with the *Water Management Act* 2000 (Chapter 1.3 of the Act) and other relevant legislation (see Section 4).

Specifically, this document, Volume 1:

- defines GDE types (Section 3 and Appendix 2)
- provides a method for determining the ecological value of an aquifer and associated GDEs (Section 5)
- provides a method to determine the risk of an activity to the ecological value of an aquifer and associated GDEs (Section 7)
- provides a method for developing management strategies for aquifers and identified GDEs using the Risk Matrix Approach (Section 8).
- in addition, the following background information is also provided in the Appendices to provide context to the above
- a method to identify the type and location of GDEs within an aquifer or defined area (Appendix 4)
- a method for inferring the groundwater dependency of identified ecosystems (Appendix 4)
- a description of surface and subsurface activities that threaten aquifers and associated GDEs (Appendix 5).

Volume 2 – *Risk assessment guidelines for groundwater dependent ecosystems. Worked examples for seven pilot coastal aquifer* in NSW is a report on the outcomes of applying the risk analysis framework process described in Volume 1. The assessment of ecological value and risk for an aquifer and its associated GDEs was refined through application of the methodology to pilot sites. The pilot sites provide practical worked examples of how to apply the risk analysis framework to GDEs under the risk of potential and actual impacts from groundwater extraction and climate change scenarios.

Specifically, this document, Volume 2:

- provides a rationale for the pilot site selection
- describes other project components
- provides outcomes of the framework assessment for the seven pilot sites that includes:

- o Woy Woy Sandbeds – Appendix 1
- o Tomago Sandbeds – Appendix 2
- o Tea Gardens Sandbeds – Appendix 3
- o Nabiac Sandbeds – Appendix 4
- o Manning Floodplain Alluvium – Appendix 5
- o Macleay Sandbeds – Appendix 6
- o Stuarts Point Sandbeds – Appendix 7.

Volume 3 – *Identification of High Probability Groundwater Dependent Ecosystems on the Coastal Plains of NSW and their Ecological Value* is a report identifying the location of individual High Probability GDE communities for all the NSW coastal aquifers investigated as part of this study. In addition, this report also identifies which of these High Probability (HP) GDEs are located within a defined conservation value area such as National Parks estate, or similarly have protective status as defined by other forms of legal instruments such as a local government environmental planning policy. These HP-GDEs that occur within a defined conservation area are termed "High Ecological Value (HEV) GDEs". Collectively both the HP and HEV GDEs are put forward to the NSW Government for consideration when defining 'High Priority' GDEs to be listed within the relevant water sharing plans.

Volume 4 – *The Ecological Value of Groundwater Sources on the Coastal Plains of NSW and the Risk from groundwater extraction* is a report identifying the overall ecological risk on a water source scale from groundwater extraction including maps identifying the location of HEV-GDEs relative to licensed extraction. This report will assist the NSW Government in identifying priority water sources for future investigations and where potential local impact areas within each water source may already exist.

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1. Introduction

Volume 1 *Risk assessment guidelines for groundwater dependent ecosystems* has been developed by the NSW Office of Water and the Office of Environment and Heritage, Department of Premier and Cabinet (OEH) to assist agency staff and support the requirements of the *Water Management Act* 2000, the *NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015*, and the Australian Government National Water Commission as part of the Coastal Groundwater Quality and Groundwater Dependent Ecosystems Project. These guidelines have also been incorporated as part of '*The approach for groundwater sharing plans. Report to assist community consultation,* NSW Office of Water, 2010'.

Volume 1 details the risk analysis framework, providing procedures to assess the risk of potential and actual impacts of proposed activities on GDEs in accordance with relevant legislation (refer Section 4.1) and the *Water Management Act* 2000 (Chapter 1.3 of the Act) so as to:

Provide for the sustainable and integrated management of the water sources of the State for the benefit of both present and future generations and, in particular to:

a. apply the principles of ecologically sustainable development
b. protect, enhance and restore water sources, their associated ecosystems, ecological processes, biological diversity and their water quality
c. recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including:
   i. benefits to the environment.
d. to integrate the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna.

The NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002 implements the above Act by providing guidance on the protection and management of GDEs. It sets out management objectives and principles to:

- ensure that the most vulnerable and valuable ecosystems are protected
- manage groundwater extraction within defined limits thereby providing flow sufficient to sustain ecological processes and maintain biodiversity
- ensure that sufficient groundwater of suitable quality is available to ecosystems when needed
- ensure that the precautionary principle is applied to protect groundwater dependent ecosystems, particularly the dynamics of flow and availability and the species reliant on these attributes
- ensure that land use activities aim to minimise adverse impacts on groundwater dependent ecosystems.

Many land and water use activities within a catchment have the potential to affect GDE function and viability by altering surface and subsurface conditions that are outside the physiological tolerance ranges or dispersal capabilities of groundwater reliant communities. There are a growing number of examples of catastrophic crashes in groundwater ecosystems due to water chemistry alteration such as the activation of acid sulfate soil or saline intrusions, Ergil, 2000, and water level fluctuations caused by over-extraction. Further, contaminants such as heavy metals and other pollutants are rendering groundwater toxic to the environment and millions of humans, Nickson et al, 1998 cited in Boulton, 2005.

Accordingly, land and water use activities which impact on GDEs are required to be managed within a regulatory and licensing framework. The *Water Management Act* 2000, *Water Act* 1912 and water sharing plans are fundamental components of this regulatory and licensing framework.

The *Water Management Act* 2000 is the key piece of legislation for the management of water in New South Wales (NSW). Water sharing plans are the main tool under the The *Water Management Act* 2000 for managing the State's water resources. Water sharing plans set out the rules for the sharing of water in a particular water source between the environment and water users. Water sharing plans also provide rules for the protection of GDE's such as set back distances and no drawdown rules for water supply works from high priority GDEs, ie. those GDE's of High Ecological Value (HEV) that have been selected by an interagency expert panel to be listed within water sharing plans. The provisions within Water sharing plans therefore protects both high ecological / conservation value GDEs from development and extraction as well as providing water for all (non high value) GDEs in general. For further details on ether High Ecological Value or High Priority GDEs refer to Section 5.2.

These Guidelines have been developed to operate within the regulatory and licensing framework provided by the *Water Management Act* 2000 and water sharing plans. The guidelines are based on an assessment of various ecological and risk factors that are important to decisions on allowing a proposed activity or development. Specifically, Volume 1 will:

- define GDE types – Section 3 and Appendix 2
- provide a method for determining the ecological value of an aquifer and associated GDEs – Section 5
- provide a method to determine the risk of an activity to the ecological value of an aquifer and associated GDEs – Section 7
- provide a method for developing management strategies for aquifers and identified GDEs using the Risk Matrix Approach – Section 8

In addition, the following background information is also provided in the appendices to provide context to the above:

- A method to identify the type and location of GDEs within an aquifer or defined area v Appendix 4.
- A method for inferring the groundwater dependency of identified ecosystems – Appendix 4.
- A description of surface and subsurface activities that threaten aquifers and associated GDEs – Appendix 5.

2. Definitions

2.1. What are groundwater dependent ecosystems?

Groundwater dependent ecosystems or GDEs represent a vital and significant component of the natural environment, ARMCANZ 1996; ANZECC, 1996. However, the understanding of what constitutes a GDE varies across the general public, government agencies and scientific community. In order to provide consistency, this document uses the definition as outlined in the *Water Management Act* 2000 amendment *Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources,* 2008, Order Schedule 1, Dictionary, Department of Water and Energy as:

> *'Ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater.'*

This definition is similar to The National Water Commission (NWC) definition of GDEs as ecosystems that are dependent on groundwater for their existence and health http://dictionary.nsw.gov.au/water_dictionary/ . Therefore, based on these definitions, GDEs explicitly **include any ecosystem** that uses groundwater at any time or for any duration in order to maintain its composition and condition.

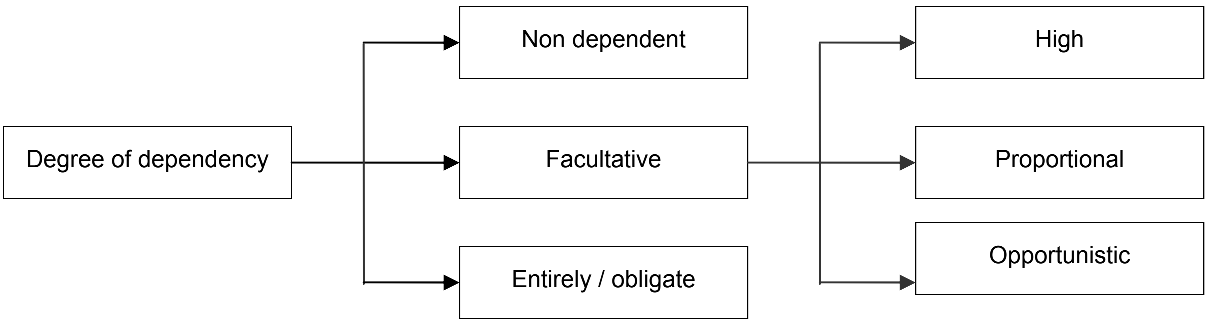
GDEs include a broad range of environments from highly specialised species and ecosystems that possess unique biotic and abiotic characteristics that 'separate' them from other ecosystems that do not rely on groundwater to survive to more general terrestrial and aquatic ecosystems that have an opportunistic dependence on groundwater or rely on it during times of drought.

The dependence on groundwater has resulted in many plant and animal communities being able to:

- survive major climatic changes
- retain phylogenetic and distributional relictual species and communities
- develop or retain narrow range habitat requirements; ie. narrow range endemic species. To survive, these species and communities continue to rely on the continuance of certain groundwater levels/pressure and water chemistry
- develop specialised morphological and/or physiological adaptations to survive in groundwater environments.

GDEs can rely on groundwater for the maintenance of some or all of their ecological functions (Clifton et al, 2007). This dependence on groundwater can be variable, ranging from partial and infrequent dependence, ie. seasonal or episodic, to total (entire / obligate), continual dependence (Figure 1). It is often difficult however to determine the nature of this dependence (Parsons, 2009; Dillion et al, 2009).

Figure 1. Degrees of groundwater dependence (adapted from Sigonyela, 2006)



Non dependent ecosystems are the ecosystems that occur mostly in recharge areas and have no connection with groundwater. Ecosystems or species are entirely (obligate) groundwater dependent if they are restricted to locations of groundwater discharge; eg. mound springs of the Great Artesian Basin, or within aquifers; eg. subterranean cave and stygofauna communities. Changes to the groundwater regime; eg. groundwater discharge or water table levels, can result in significant changes to species distribution and composition of ecosystems highly dependent on groundwater; eg. many wetlands, Hatton and Evans, 1998.

Facultative GDEs require groundwater in some locations but not in others, particularly where an alternative source of water can be accessed to maintain ecological function, Clifton *et al,* 2007; O'Grady *et al*, 2007. Dependence on groundwater for facultative GDEs can range from opportunistic to being highly dependent. Ecosystems with a proportional dependence on groundwater do not generally exhibit the threshold type response of the more dependent ecosystems. As a change occurs in a groundwater attribute; eg. level, a proportional response generally occurs within the ecosystem, Hatton and Evans, 1998. Opportunistic dependency occurs when ecosystems use groundwater as required. For example, this may occur when surface water / soil moisture is unavailable, such as at the end of a dry period. Minor changes to the groundwater regime may not have any adverse impacts but these ecosystems can die if a lack of access to groundwater is prolonged. It is however difficult to distinguish between proportional and opportunistic dependency.

A GDE's sensitivity to change is therefore dependent in part on their reliance on or access to groundwater as well as their ability to disperse or relocate should the groundwater regime change. The communities within these environments can be impacted by a range of factors that alter groundwater levels, water pressure, water chemistry and aquifer structure.

The relationship of GDE and groundwater is further described in Appendix 1.

2.2. What is groundwater?

The core water resource for any GDE is of course groundwater. It is the access and use of this water source that separates these ecosystems from solely surface water (rainfall, rivers) ecosystems. It is therefore necessary to define groundwater. The definition of groundwater, however, is not as straight forward as it may seem and, as with the term GDE, varies between public perception, scientific disciplines and government agencies.

Groundwater is, as the term implies, water that occurs under the ground. Under natural conditions, rainfall, stream flow in losing systems or lateral through flow between water sources flows through the geological medium, including soil and rock. Where this water encounters an impermeable layer and accumulates it forms a saturated zone, which can vary in scale from large regional reservoirs or regional aquifers, to small perched aquifers or temporary flow through systems. The water within the saturated zone will always move from higher to lower elevations, flowing through pore spaces, small and large voids (cavities, cracks and caves) until it eventually discharges as springs, seeps or directly into rivers or the ocean.

The definition of what constitutes groundwater varies in specifics depending on whether the definition is aimed at the management of a large regional aquifer or the management of ecosystems that require subsurface water in a range of forms from total immersion in a saturated zone or drawing water from the unsaturated zone that sits above the saturated zone of a watertable.

The definition of Groundwater within the relevant State and Commonwealth legislation is listed below and demonstrates the wide differences in perceptions. It is clear that there is discrepancy between State and Federal policies which does have a major influence on what groundwater systems and, therefore, GDEs are recognised.

NSW State Policy

***Water Act* 1912, NSW**

The meaning of both groundwater and aquifer is not defined in this Act.

The NSW Groundwater Quality Protection Policy (Department of Land and Water Conservation, 1998)

Groundwater is defined as:

> *'Groundwater, in a broad sense, is all water which occurs below the land surface in aquifer.'*

***Water Management Act*, 2000 (refer to 2008 amendment)**

Groundwater and GDE is not defined. Aquifer is defined to mean:

> *'A geological structure or formation, or an artificial landfill that is permeated with water or is capable of being permeated with water.'*

***Guidelines for the Assessment and Management of Groundwater Contamination*, Department of Environment and Conservation, 2007**

Aquifer is defined as:

> *'A geological unit capable of storing and transmitting useful quantities of groundwater.'*

Groundwater is defined as:

> *'All waters occurring below the land surface.'*

***Water sharing plan for the NSW Great Artesian Basin Groundwater Sources 2008 Order under the Water Management Act 2000*, schedule 1 Dictionary**

State definitions were amended in this Act to include the following:

- Groundwater is defined as:

  'Water that occurs beneath the surface of the ground in the saturated zone.'

Commonwealth Policy

Water Act, 2007

Aquifer is not defined. Groundwater is spelt 'ground water'. Note the separation into two words.

Ground water is defined to mean:

a. *'Water occurring naturally below ground level (whether in an aquifer or otherwise)* or
b. *Water occurring at a place below ground that has been pumped, diverted or released to that place for the purpose of being stored there; but does not include water held in underground tanks, pipes or other works.'*

Water resource is defined to mean:

a. *'Surface water or ground water* or
b. *A watercourse, lake, wetland or aquifer (whether or not it currently has water in it); and includes all aspects of the water resource (including water, organisms and other components and ecosystems that contribute to the physical state and environmental value of the water resource).'*

***Atlas of Groundwater Dependent Ecosystems, Phase 1 Scoping Study*, National Water Commission, 2010.**

States that the definition of groundwater is:

a. *'Water occurring naturally below ground level (whether in an aquifer or otherwise)* or

b. *Water occurring at a place below ground that has been pumped, diverted or released to that place for the purpose of being stored there; but does not include water held in underground tanks, pipes or other works.'* (Source: *Water Act* 2007).
Note that this definition includes the capillary zone, which is an important source of water for many GDEs. It also includes recently infiltrated rainwater in the soil profile, however, which should be excluded as it is a component of rainfall rather than groundwater.

In the context of these definitions, groundwater from the perspective of GDEs that have formed and evolved under natural conditions as a result of the presence of that groundwater, must have in its definition four components, these being, it:

a. is water below the ground

b. is there because of natural processes ie. it cannot be artificial, pumped or placed there or stored in underground tanks, pipes or other works

c. forms a saturated zone, without any implication of permanency or duration

d. includes the unsaturated / capillary / vadose zone above the saturated zone that is required by terrestrial vegetation communities as well as being an ecosystem in its own right.

Therefore, for the purposes of this document Groundwater is defined as:

> *'Water occurring naturally below ground level (whether in an aquifer or otherwise), including the saturated zone and the unsaturated vadose zone.'*

This definition includes regional groundwater aquifers and small, often transient, shallow through-flow down hill slopes, riverine alluvials and perched aquifers. It includes both the saturated (phreatic) and the unsaturated (vadose) zone and takes into account the capillary zone (that zone that is immediately above the water table where water is drawn upwards by capillary tension as defined in http://dictionary.nsw.gov.au/water_dictionary/ which is an important source of water for many GDEs, in particular terrestrial vegetation.

2.3 What are High Priority GDEs

The term **'High Priority GDE'** is a specific legislative management term used within The *Water Management Act* 2000 which has been developed and refined through the process of developing Water Sharing Plans. It was initially defined in the water sharing plan for the NSW Great Artesian Basin Groundwater Sources, 2008, Order Schedule 1, Dictionary as:

> *'Ecosystems which are considered high priority for management action.'.*

This definition was further refined within the *Greater Metropolitan Region Groundwater Source Water Sharing Plan* (NOW, 2010d, p 31) by the addition of a number of provisions that were designed to protect environmental assets such as GDEs. These provisions include equating high priority with high conservation value (high ecological value) groundwater dependent ecosystems. Therefore, a High Priority GDE is one which has high ecological value (HEV). However, as mentioned earlier a HEV GDE is not considered a High Priority Ecosystem from the management perspective, until it has been assessed through an interagency expert panel which includes groundwater and ecology experts.

3. GDE types and classification

Ecosystems dependent on groundwater were first recognised and classified in Australia by Hatton and Evans, 1998, and subsequently acknowledged in NSW within the within the NSW Groundwater Dependent Ecosystem Policy, Department of Land and Water Conservation, 2002. In the period since, the number of recognised types and smaller subunits of GDEs have increased to the point where they are NSW Office of Water, to occur in almost every environment across the landscape including terrestrial dry land, freshwater, marine and subterranean environments. This heterogeneity of ecosystems using groundwater in a variety of ways has caused a significant amount of difficulty with grouping such a diverse range of ecosystems in a logical and meaningful manner. There have been a number of broad classification schemes developed; eg. Hatton and Evans, 1998; Evans and Clifton, 2001; Eamus *et al,* 2006; Foster *et al*, 2006, that attempt to separate GDEs based on a variety of attributes. However, the separation is either too broad, does not allow for the finer separation of ecosystems into ecological subunits, does not account for the major contributing factors that separate ecological communities or does not encompass the full range of potential GDE environments.

There are also a number of general; eg. RAMSAR and specific; eg. DIWA, aquatic ecosystem classification schemes currently available or being developed; eg. *Draft Australian National Aquatic Ecosystem Classification scheme*, Aquatic Ecosystem Task Group, 2010, which include components of GDEs. They, however, do not highlight the relevant aquifers of each ecosystem or include non aquatic ecosystems such as terrestrial vegetation communities and, therefore, do not adequately accommodate all types of GDEs.

The classification scheme presented here includes all ecosystems that are supported by groundwater (see Groundwater Dependent Ecosystem Classification Table – Appendix 2). This classification scheme assumes that all GDEs can be classified under seven ecosystem types (described in detail in Appendix 2). These are:

Subsurface ecosystems – Underground ecosystems

1. Karst and caves.
2. Subsurface phreatic aquifer ecosystems.
3. Baseflow stream (hyporheic or subsurface water ecosystems).

Note that subsurface ecosystems can include some estuarine and near shore marine ecosystems such as submarine springs, interstitial habitat in sand, shingle, pebble beaches as well as intertidal sand and mudflats.

Surface ecosystems – Above ground ecosystems

1. Groundwater dependent wetlands.
2. Baseflow streams (surface water ecosystems).
3. Estuarine and near shore marine ecosystems.
4. Phreatophytes – Groundwater dependent terrestrial ecosystems.

The classification of GDEs into the seven broad types is based upon ecological, geomorphic and water chemistry criteria. Ecosystems are classified based on the decision tree in Figure 2.

It must be emphasised that the seven ecosystem types are the broadest category and that each type can and has been further subdivided into subtypes, in order to include and describe more specialised GDE environments (see Groundwater dependent ecosystem classification table – Appendix 2). Most previous classifications are based solely on broad scale separation of an ecosystem and do not allow for the finer separation of these ecosystem types into smaller community units or subtypes that are an essential management requirement. As mentioned above, the presented classification scheme separates GDEs from broad scale types through to finer level subtypes based on a hierarchical series of attribute filters. Each GDE type represents a distinct ecological community that has no overlap with the other types, although there is some overlap between subtypes, particularly for groundwater dependent wetlands/terrestrial vegetation and the surface and subsurface components of baseflow rivers.

It is acknowledged that as this field of study is still in its infancy, the list provided is by no means complete or inclusive. The authors expect that, as the science progresses, new GDEs will be added. This classification scheme is therefore dynamic and flexible in structure and provides a framework into which newly recognised GDEs can be included. It is also designed to be used both retrospectively with currently listed aquatic ecosystem classifications; eg. DIWA, as well as support or be integrated into processes; eg. within the HCVAE or MDBA processes for identifying conservation value.

Why do we need to classify GDEs at all?

A classification system for GDEs was necessary in order to fulfil the requirements of the *Water Managmement Act* 2000. The Act stipulated that the State's natural environment needed to be managed sustainably through the provision of a suitable supply of water (for both quantity and quality) and rules for the protection of high value water dependent ecosystems. In order to know what a high value system was and what it was not, it was essential to be able to rank and, therefore, prioritise the numerous ecosystems. In order to rank the natural environment, it is first necessary to divide the landscape into discrete management / ecosystem units (ecosystem types and subtypes) and to evaluate each unit based on a list of attributes. These attributes included:

a. defining the ecosystem / unit
b. outlining where the ecosystem/unit is located (surface, subsurface, topographic and geomorphic setting)
c. describing the ecosystem/unit's water requirements (groundwater dependency and water chemistry)
d. determining the ecological value of the ecosystem / unit
e. determining the size of the ecosystem/unit (percentage area of catchment / aquifer).

The base unit to which GDEs are separated is the 'Ecosystem'.

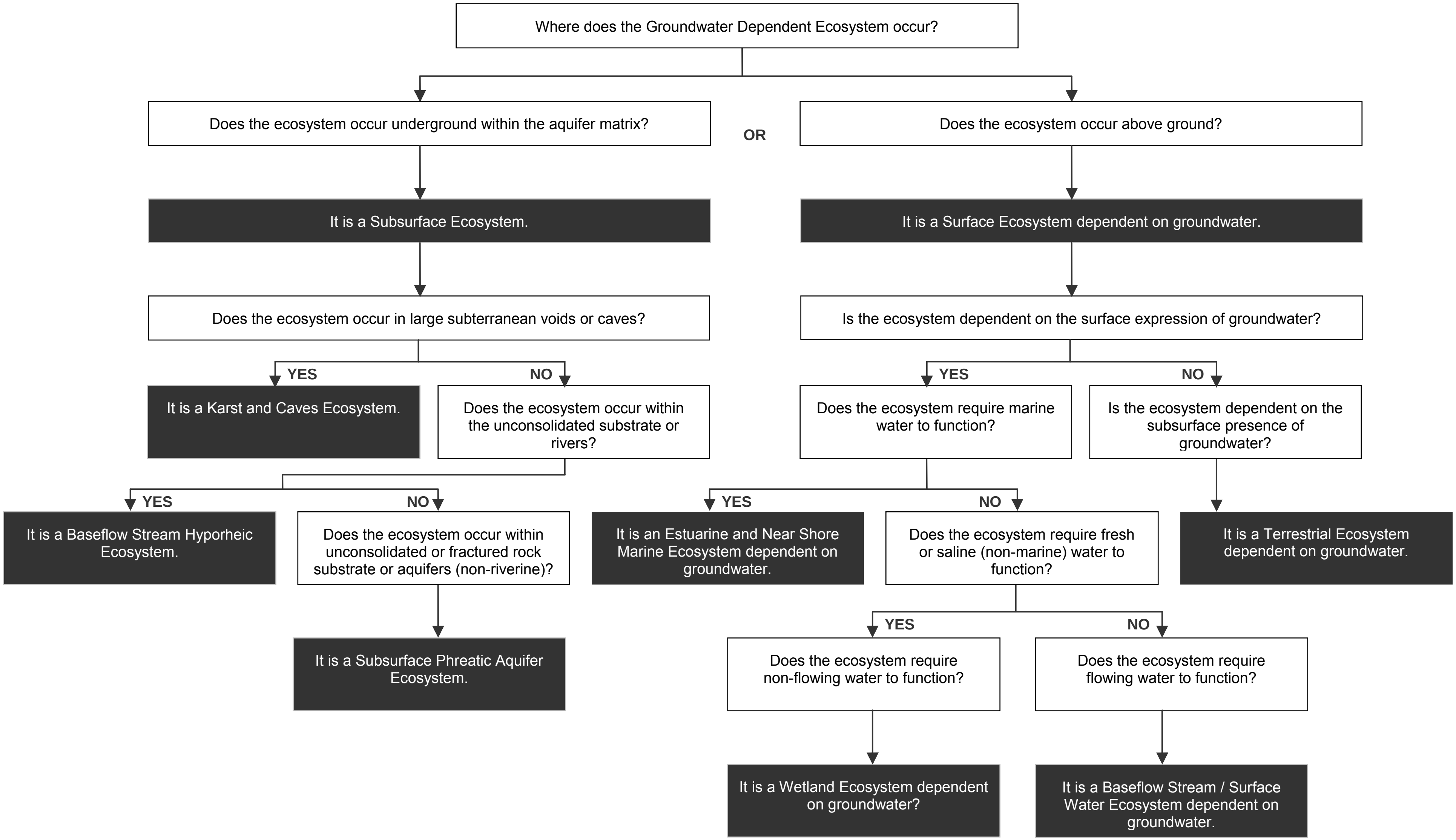
An ecosystem is defined as:

> *'A functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area, and all the non-living physical and chemical factors of their environment, linked together through nutrient cycling and energy flow',* Province of British Columbia, 1995.

Each GDE type is, therefore, a broad but distinct group of organisms that are defined by a combination of geology; geomorphic features; and physico-chemical ranges. These attributes dictate the habitats and the species / community composition of the ecosystem. Therefore, each ecosystem is a finite areal (a defined mappable area) unit of species that are controlled by specific abiotic factors that can be delineated on a landscape. This finite unit can therefore have a defined relationship with the water source (in this case an aquifer) that can be managed partly by managing the water source.

The above attributes provide a framework for measuring and comparing both area and value of an ecosystem unit against other ecosystem units of the same type. Once an ecosystem unit has been ranked it can be compared with others in a defined area. It can then be given a ranking; ie. high, medium or low, and managed appropriately.

Figure 2. GDE Classification decision tree



4. Policy and legislative framework

Groundwater ecosystem dependence is an increasingly important component of surface and groundwater initiatives in NSW and has been incorporated within Groundwater Management Plans under the Water Reform Agenda.

Australia has signed a number of international agreements that are relevant to the management of ecosystems that depend on groundwater. The principles in these agreements have been applied at the national and state government level through a number of policies. These policies cover aspects of management of the quantity and quality of groundwater as well as the physical expression of the ecosystem.

Initial recognition by the Australian Government for the need to manage groundwater resources in a manner that would not threaten the environment occurred within the *1992 National Strategy for Ecologically Sustainable Development* http://www.environment.gov.au/ .*The National Strategy for the Conservation of Australia's Biological Diversity*, Department of the Environment, Sport and Territories, 1996, aimed at ensuring the effective identification, conservation and ecologically sustainable use of Australia's biodiversity. In 1994, the Council of Australian Governments (CoAG) agreed that the environment was a legitimate user of water. In 1996, the *National Principles for Provision of Water for Ecosystems,* Agriculture and Resource Management Council of Australia and New Zealand and Australian and New Zealand Environment and Conservation Council, 1996, were adopted by all Australian governments. Twelve principles were aimed at sustaining, and, where necessary, restoring ecological processes and biodiversity of water dependent ecosystems. A *National Framework for Improved Groundwater Management*, Agriculture and Resource Management Council of Australia and New Zealand Standing Committee on Agriculture and Resource Management, 1996, recommended that groundwater management plans be developed. The NSW Government introduced its major Water Reform Program in 1997 which lead to the release of the State Groundwater Policy Framework Document, Department of Land and Water Conservation, 1997, and The NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002. Following this, in 2004, CoAG agreed to the NWI, which is a comprehensive strategy driven by the Australian Government to improve water management across the country.

The following policies are relevant to the protection and management of GDEs in NSW and are discussed in more detail in Appendix 3:

- *NSW State Groundwater Policy Framework Document*, Department of Land and Water Conservation, 1997. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW Groundwater Quality Protection Policy, Department of Land and Water Conservation, 1998. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW Quantity Management Policy.
- NSW Wetlands Management Policy, Department of Environment, Climate Change and Water, 2010a.
- State Environmental Planning Policy No. 14 – Coastal Wetlands, SEPP 14. http://www.austlii.edu.au/au/legis/nsw/consol_reg/seppn14w543/ , under the *Environmental Planning and Assessment Act* 1979.

- NSW State Rivers and Estuaries Policy – NSW Water Resources Council NSW Government, 1993. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW Sand and Gravel Extraction Policy for Non-Tidal Rivers, NSW Government, 1992. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- Water Compliance Policy (NSW Office of Water, 2010a. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW Water Extraction Monitoring Policy. http://www.water.nsw.gov.au/Water-licensing/Metering/default.aspx
- Draft Floodplain Harvesting Policy, NSW Office of Water, 2010b. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx
- NSW Weirs Policy, NSW Government. http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx

These Guidelines have considered the above policies.

4.1. Legislation

4.1.1. *Water Management Act* 2000

The *Water Management Act* 2000 is the key piece of legislation for the management of water in NSW. The *Water Management Act* 2000 aims to provide for the sustainable and integrated management of the water sources of NSW for the benefit of both present and future generations. The following objects of the *Water Management Act* 2000 are relevant to the management of GDEs to:

a. apply principles of ecologically sustainable development

b. protect, enhance and restore water sources, their associated ecosystem, ecological processes and biological diversity and their water quality

c. recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including:

   i. benefits to the environment

d. integrate the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna.

The *Water Management Act* 2000 also provides water management principles and the following general principles are relevant to the management of GDEs:

b. Water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded.

b. Habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored.

b. The quality of all water sources should be protected and, wherever possible, enhanced.

b. The cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised.

b. The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirement.

The *Water Management Act* 2000 also provides specific water management principles which are relevant to the management of GDEs. In particular, the sharing of water from a water source (through water sharing plans) must protect the water source and its dependent ecosystems. Further, in relation to water use, drainage management, floodplain management, controlled activities and aquifer interference activities, these activities should avoid or minimise land degradation, including soil erosion, compaction, geomorphic instability, contamination, acidity, water-logging, decline of native vegetation or, where appropriate, salinity and, where possible, land should be rehabilitated.

These Guidelines promote the above objects and water management principles of the *Water Management Act* 2000, particularly in relation to the protection of GDEs through rules in water sharing plans (see Appendix 3 for further details).

4.1.2. *Water Act* 1912

The *Water Management Act* 2000 is gradually being phased in to replace the *Water Act* 1912 as water sharing plans commence. Applications for licences under the *Water Act* 1912 are assessed in accordance with the objects and water management principles of the *Water Management Act* 2000. Accordingly, the promotion of the objects and water management principles of the *Water Management Act* 2000 by these Guidelines is equally relevant for water sharing plan areas and non water sharing plan areas.

4.1.3 Water sharing plans

Water sharing plans are the main tool under the *Water Management Act* 2000 for managing the State's water resources. Water sharing plans promote the objects and water management principles of the *Water Management Act* 2000 in providing rules for the sharing of water between the environment and water users, and between different types of water users. There are six main types of rules which operate to protect GDEs in the water sharing plans. These are distance and drawn down rules, casing rules, cease to pump rules, dealing (trading rules) and local impact rules. These rules are discussed in detail in Appendix 3.

4.1.4. Other relevant NSW legislation

The following legislation is also relevant to the protection and management of GDEs in NSW:

- ***Threatened Species Conservation Act* 1995**. This Act and its listings are used in the determination of the ecological value of a GDE, ie. if a GDE contains a threatened species as listed under this Act, the GDE is taken to have higher ecological value.
- ***Native Vegetation Act* 2003**. This Act is relevant to the protection of vegetation which may be or form part of a GDE community.
- ***Fisheries Management Act* 1994**. This Act is relevant to the determination of the ecological value of a GDE (ie. if the GDE contains a threatened species as listed under this Act, the GDE is taken to have higher ecological value).
- *Draft New South Wales Biodiversity Strategy*, Department of Environment, Climate Change and Water NSW and Industry and Investment NSW, 2010. The Strategy is directly relevant as its objectives include the:
    - smarter biodiversity investment and improved partnerships
    - whole of landscape planning
    - effectively managing threats
    - sustainable production environments.
- *NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010-2015*.

4.1.5. Relevant Commonwealth legislation

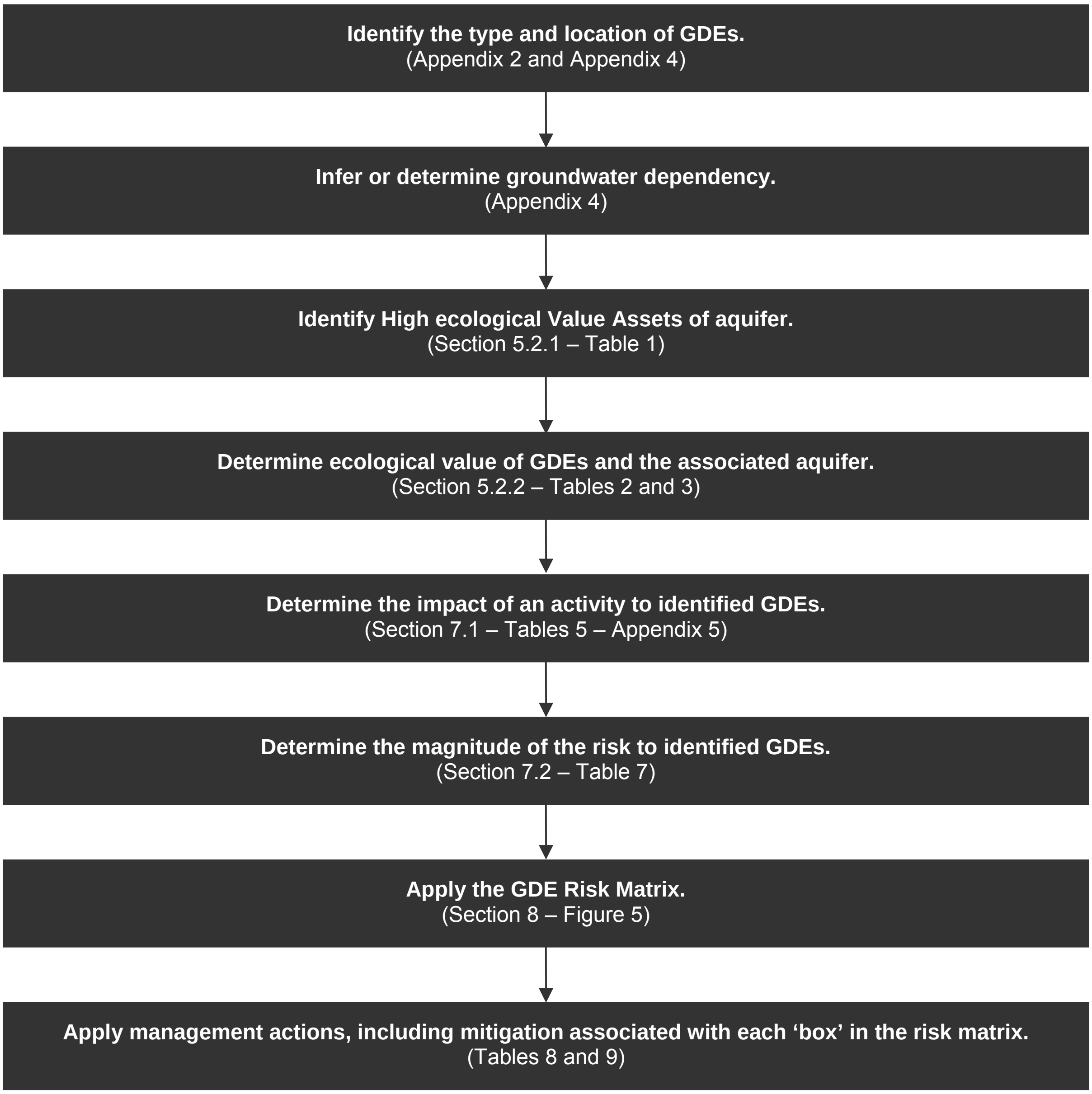
The *Environmental Protection and Biodiversity Conservation Act* 1999, is relevant to the determination of the ecological value of a GDE; ie. if the GDE contains a threatened species as listed under this Act, the GDE is taken to have higher ecological value.

5. Ecological valuation and risk assessment process

5.1. Navigation of ecological valuation and risk assessment process

This section describes the ecological valuation and risk assessment process for identified GDEs. In summary, GDEs are first identified and classified and the level of dependency on groundwater for individual GDEs inferred. Once the current ecological value of individual aquifers has been determined, the ecological value of the GDEs associated with that aquifer must then be assessed. The individual value of each GDE within the aquifer can also be assessed as a stand alone unit. Following an assessment of the aquifer and associated GDEs current value, the potential future impact of a proposed activity on the aquifer and associated GDEs must then be determined. The magnitude of risk from that activity to the ecological value of the GDE(s) and aquifer is then determined. Finally, the Risk Matrix is applied to determine the most appropriate management response for a given environmental value. This process is depicted in Figure 3.

Figure 3. Ecological valuation and risk assessment process



5.2. Ecological valuation

Once the GDEs have been identified within the aquifer and the dependency of the potential or known GDEs has been inferred (via the desktop analysis – Appendix 4) or confirmed (through field assessment and / or appropriate verification methods), an assessment of the ecological value of the aquifer and its associated GDEs is required. The assignment of ecological value at the aquifer and individual GDE scale is essential in determining management actions and priorities such as ranking an aquifer or GDE. The location and ecological value of identified GDEs, including those identified as high priority is stored with the NSW Office of Water / OEH Corporate Database. This dataset was developed to assist groundwater resource management and the implementation of 'The NSW State Groundwater Dependent Ecosystems Policy, Department of Land and Water Conservation, 2002, and *Water Management Act* 2000.

The ecological value of a GDE or aquifer is determined using the process described below and is based upon the procedure contained within the *Groundwater Dependent Ecosystems Assessment, Registration and Scheduling of High Priority Manual*, Department of Natural Resources, 2006.

The value of a GDE is taken in its broadest sense to include the biota, ecosystem processes, both physical and biological, and the roles that these ecosystems play in sustaining other systems such as wetlands, estuaries and terrestrial communities. The approach adopted for this document is based on the assumption that all GDEs have an intrinsic biodiversity and ecosystem function value and that a variation in environmental parameters, as a result of a development proposal for instance, has the potential to alter or modify these values. Therefore, in order to determine the significance of this change, it is important to first understand the existing values of the ecosystem to be altered, and then assess the degree of change likely to occur. The level of expected or actual impact is then a comparison of the degree of change relative to the values being affected. Once the ecological value is determined it remains a constant while management actions will vary depending on the level of value and the risk from a potential or actual impact.

The determination of the ecological value of an aquifer and its associated GDEs is divided into two major stages:

Stage 1 – General aquifer ecological valuation and identification of high ecological value assets

This stage is the initial desk top approach that inventories the currently known GDEs of high ecological value and establishes the aquifer as having an ecological value by sustaining these ecosystems. This process is also used as the initial process for listing of High Priority GDEs within the water sharing plan Process. The listing includes:

1. Areas of known or potential GDEs that have been identified to have high conservation value under legislative/other assessment programs (see Table 1).
2. Obligate or entirely dependent ecosystems and species. This is the current Stage 1 identification of High Priority GDEs.

Stage 2 – Detailed ecological valuation of an aquifer and GDE

This stage is a detailed ecologcal assessment of identified GDEs which is conducted as a two step process:

The steps are:

Step 1. Identification of the ecologiccal value of individual GDEs within an aquifer.

Step 2. Identification of the ecological value of the aquifer.

This second mandatory stage provides the framework to value those GDEs that have either not previously been assessed and acknowleged under existing environmental protection legislation or acknowledged by a State or National Environmental agency. This stage provides the process for listing newly identifed GDEs as High Ecological Value GDEs that may then be considered for listing as High Priority GDE's for inclusion into the water sharing plan schedules.

Stage 2 is based on criteria adapted from Dunn (2000) that includes:

- GDE environment (surface and subsurface environment).
- Rarity of the dependent biota or physical features.
- Diversity.
- Special features.

5.2.1. Stage 1 – General aquifer ecological valuation and identification of high ecological value assets

Stage 1 is a rapid identification of high ecological value assets and is a broad scale assessment that aims to identify if an aquifer has any environmental assets that have been previously identified as having important conservation significance, ie. have high ecological value, through other legislated conservation processes or programs. This allows for the initial protection of GDEs of known high conservation value via the protection of the water source though the assignment of High Priority status within the water sharing plans process (see Section 2.3). This is the initial process for listing High Priority GDEs within the water sharing plans process.

Stage 1 involves a desktop exercise assembling all known records of communities / species / areas of high ecological value within an aquifer. It includes interrogating known data bases, GIS records and other studies.

Identification of high ecological value GDEs within the aquifer

High ecological value for an ecosystem is defined as an ecosystem which is in a natural or near-natural condition, or that fulfills any of the below criteria. They include:

a. Groundwater dependent communities where a slight to moderate change in groundwater discharge or water tables would result in a substantial change in their distribution, species composition and/or health. This includes all ecosystems that are identified and acknowledged as being entirely (or obligate) dependent on groundwater for their survival. These ecosystems included all Karst, springs, mound springs, subterranean aquifer ecosystems and some wetlands including hanging swamps. Obligate groundwater dependent ecosystems are included in this listing as they are recognised throughout the literature to contain many values, including the following:
    - A high proportion of either phylogenetic or distributional relicts as well as short range endemic species.
    - They are extremely sensitive to the environmental characteristics of the water they inhabit and, thus, potentially are useful indicators of groundwater health.
    - Some are rare or unique.
    - The ecosystems surviving in aquifers, caves and springs are amongst the oldest surviving on earth.
    - They have water quality benefits, biodiversity value and add to the ecological diversity in a region.

b. Those ecosystems that have already been identified as important by other environmental agencies or within existing legislation or international agreements; ie. those GDEs that are partly or wholly located within a State or Federal Reserve System; eg. National Park/ Reserve; or are a recognised high conservation area, such as a sub-catchment identified as high conservation value; eg. stressed rivers; high value vegetation, SEPP wetlands, DIWA wetland etc.

c. Any natural groundwater dependent system that is habitat for any endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under the *NSW Threatened Species Act* 1995, *NSW Fisheries Management Act* 1994 or the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 or identified by an acknowledged expert taxonomist / ecologist.

Acknowledging the presence of these high value ecological assets is the first step in assigning both an ecological value to an aquifer and individual GDEs. This initial prioritisation assists in developing an appropriate management strategy. Bioregional and catchment scale issues, such as reservation status or if there are recognised and listed rare and threatened species or communities are also important. The area and number of GDE subtypes and the relative condition of those ecosystems in the landscape and bioregion give a regional context to the degree of threat to that biota. Consideration of these issues can assist in determining the role that the aquifer plays in relation to the maintenance and protection of biodiversity within any legislated assets and within the region as a whole. In addition, there may be particular species or features present that are considered to make an additional contribution to an aquifer's biodiversity value.

Table 1 – General aquifer ecological valuation allows for the rapid identification of assets of ecological value using prior assessments. A list of three questions is provided in the table below, to which a 'yes' or 'no' answer must be given. If a 'yes' answer in any question applies to any of the identifed GDEs they are assigned a High Ecological Value. The aquifer as a whole is therefore considered to have ecological value. In order to determine the final aquifer ecological value, proceed to Stage 2.

Table 1.General aquifer ecolgical valuation

	Yes	No	List/Comments
Does the aquifer or portion of it occur within a state reserve or support any GDEs within a sub-catchment identified as High Conservation Value; eg. Stressed Rivers; high value vegetation, SEPP wetlands, DIWA wetland etc?			
Does the aquifer support obligate/entirely dependent GDEs including: karsts, springs, mound springs, subterranean aquifer ecosystems and some wetlands such as hanging swamps.			
Does the aquifer support GDEs that have any endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under the *NSW Threatened Species Act* 1995, *NSW Fisheries Management Act* 1994 or the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 or identified by an acknowledged expert taxonomist / regional ecologist as being important?			

5.2.2. Stage 2 – Detailed aquifer and GDE ecological valuation

The Stage 2 ecological valuation process assesses those potential or known GDEs as well as their associated aquifers using a detailed ecological assessment. This assessment utilises the data collected in Stage 1 and additional data based on criteria that includes a combination of biotic; eg. Biodiversity and abiotic; eg. landform diversity and physicochemical) surrogates. A core set of criteria are used to provide a standard data set across the state and are listed below. These four criteria are derived and adapted from Dunn, 2000 and Bennett *et al*, 2002. The criteria are:

a. GDE environment (surface and subsurface environment).

b. Rarity of dependent biota or physical features within catchment and/or hydrological unit (as appropriate).

c. Diversity within catchment and/or hydrological unit (as appropriate).

d. Special features.

The optimum ecological value assessment is achieved by following both steps in the process as the identification and valuation of all individual GDEs within an aquifer allow for a greater confidence in the final result as well as providing the ability to set individual GDE management plans rather than general aquifer.water source rules. This Stage 2 process, however, is also flexible in that it can be taylored to the requirements of a particular investigation i.e. it can be applied at the local scale for individual GDE assessment (use Table 2) or at a regional scale for assessing an aquifers ecological value (use Table 3). The assessment of both steps provides the opportunity to add to and refine the initial assessment in Stage 1 as well as expanding the listing of additional GDEs and confirming the ecological value of an aquifer. It also highlights the detailed data used and provides transparency for the decisions made in determining the final ecological value. In either case, the final ecological value result is used in the Risk Assessment Matrix (Figure 5.).

To fill in the tables identifying the ecological value of the individual GDE and aquifer:

1. Provide a rank (high, moderate or low) against each question under all criteria.
2. To assign a rank, refer to the threshold information attached to each criterion. If unsure of the appropriate rank for any of the questions and criteria, consult with the local regional ecologist or hydrogeologist.
3. Upon completion, tally the number of high, moderate or low scores. The overall value for the GDE or aquifer is the category of value (H, M, L) that has the most attributes assigned to it. If the number of highs is greater than the moderate or lows then the value is high.

For GDEs and aquifers that are ranked as moderate or low value but have been identified as having high ecological value assets listed under the rarity / special feature criteria, apply the protection and mitigation actions as outlined in Table 6. Aquifer and GDE risk assessment guide (pre mitigation measures).

The four criteria used in the ecological valuation are:

1. **GDE environment (surface and subsurface landscape) condition – as described above in Stage 1**

   A landscape context is essential in the assessment of the ecological value of a GDE not only because the value of a GDE is determined by the condition of the aquifer (see above) but also the value of an aquifer is determined by the condition of the surrounding landscape and recharge areas. The type of GDE and their condition will also have strong influences on the range and composition of species that persist.

2. **Rarity within catchment and / or hydrological unit**

   Rarity can be defined as natural features that have intrinsic value; eg. rare/threatened species), regardless of whether they support other values in a catchment, Bennett *et al*, 2002. A catchment may contain single, many or a combination of rare or threatened features. In NSW, legislation is a key driver for the management of threatened species and communities. Limited distribution at the extreme of the known range and endemism may also influence a species rarity. For the macro water sharing plans, rarity is defined as threatened or endangered water dependent species, populations or communities as listed under the *NSW Threatened Species and Conservation Act* 1995 or the *NSW Fisheries Management Act* 1994, or the only one of its kind in a catchment.

GDE communities are often fragmented within a water source. The ecological value of these patches can be assessed individually. It should be noted that individual species within a community type have minimum patch size or range requirements (patch size therefore has an impact on biodiversity). Smaller patches generally contain fewer species than larger patches, Debinski and Holt, 2000. It can therefore be assumed that larger patches have greater biodiversity and ecological value. It is difficult however, to know 'How much habitat is enough' as different species use different kinds of habitat, and require different amounts of habitat for persistence. Fahrig, 2003. The patch size rank of the GDE type/subtype relative to other patches of the same GDE type / subtype can be determined as follows. All patches of the same GDE type / subtype are ranked in size from 1 to 100 where the smallest patch is 1 and the largest is 100. The ranked patches are then assigned a patch value of high, moderate, low value where high value is 50 to 100; moderate value is 49-30 and low value is < 30.

The percentage of GDE type / subtype remaining relative to original/historical/pre-European coverage estimates can be determined using reconstructed vegetation/wetland mapping.

3. **Diversity within catchment and / or hydrological unit as appropriate**

   Diversity operates at micro and macro scales and applies at genetic, species, community and regional levels, Bennett *et al*, 2002. For the macro water sharing plans, diversity includes the variety of stream dependent flora and fauna species and riparian habitats. Diversity can be influenced by disturbance to natural riverine features and the presence of exotic species.

4. **Special features within catchment and / or hydrological unit as appropriate**

   In the macro water sharing plans special features include riverine features within the landscape that are uncommon; eg. a wild and scenic river, important ecosystems or species (keystone or flagship), or important for river functions; eg. drought refuge and connectivity – refuge pools which will support species and population during periods of low flow, Dunn, 2000. The special features listed in Table 2 – GDE ecological valuation guide, are only examples of what could be used.

If additional information is available it can be used to fine tune evaluation and priorisation of identified GDEs. For example:

- Proximity and connectivity; ie. prioritising sites that are connected or in close proximity to other high conservation value sites, such as EECs, SEPP 14, SEPP 26.
- Patch site vulnerability (to selected activities such as extraction). Vulnerability to activities can influenced by the type of ecosystem (natural resilience) or by the patch size of the GDE.

Table 2. Identification of the ecological value of individual GDEs within an aquifer

	High	Moderate	Low	Unknown	Comments
GDE environment					
GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 etc.	Yes	NA	No		
Presence of exotic flora or fauna within GDE.	None exist.	Exotic species in small numbers.	Exotic species in large populations of one or more species.		
Removal or alteration of GDE type or subtype.	No detectable change in physical structure, species composition or size in GDE type or subtype.	Minor change or alteration in physical structure, species composition, or size resulting in a temporary change in GDE type or subtype.	Major change/alternation in physical structure, species composition, or size resulting in a permanent change in GDE type or subtype.		
Aquifer					
Water quantity parameters					
Alteration of the frequency and / or magnitude and/or timing of watertable level fluctuations.	No detectable change from natural seasonal variation.	Fluctuation in groundwater levels resulting in temporary change to part of any dependent habitat type.*	Fluctuation in groundwater levels resulting in permanent loss of any dependent habitat type.*		
Alteration of groundwater pressure.	No detectable change from natural seasonal variation.	Fluctuation in groundwater pressure resulting in temporary change to part of any dependent habitat type.	Fluctuation in groundwater pressure resulting in permanent loss of any dependent habitat type.		
Alteration to direction of hydraulic gradients.	No detectable change from natural seasonal variation.	Temporary changes resulting in short-term alterations to habitat conditions.	Permanent reversals in hydraulic gradients resulting in changes to any dependent habitat type.		
Alteration of base flow conditions.	No detectable change from natural seasonal variation.	Temporary reduction in baseflow conditions exceeding seasonal variation.	Permanent loss or reversal of base flow conditions.		

	High	Moderate	Low	Unknown	Comments
Water quality parameters					
Degree of acid runoff or acidification of aquifer.	No detectable change from natural seasonal variation.	Temporary exposure of acid sulfate soils with likely runoff into dependent ecosystems.	Permanent exposure of acid sulfate soils with likely runoff into dependent ecosystems.		
Degree of nutrient load.	No detectable change from natural seasonal variation.	Temporary increase in nutrient load to dependent ecosystems.	Permanent increase in nutrient load to dependent ecosystems.		
Degree of groundwater salinity.	No detectable change from natural seasonal variation.	Temporary increase in salinity to dependent ecosystem.	Permanent increase in salinity to dependent ecosystem.		
Degree of bioaccumulation; ie. heavy metal contamination.	No detectable change from natural seasonal variation.	Temporary exposure of dependent ecosystems to heavy metals and/or toxins.	Permanent exposure of dependent ecosystem to heavy metal and/or toxins.		
Aquifer structure					
Degree of alteration of aquifer structure; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc.	No detectable change in aquifer structure	Minor change/alteration of aquifer structure resulting in a temporary change in GDE habitat. **	Major change/alternation of aquifer structure resulting in a permanent change in GDE habitat.**		
Biodiversity					
Rarity within catchment / aquifer					
Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community within GDE.	Yes	NA	No		
Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE.***	Yes	NA	No		
Patch size rank of GDE relative to other patches of the same GDE type/subtype (as appropriate).	> 50	49 to 30	< 30		
Patch size percentage of GDE relative to original / historic extent.	> 50%	49 to 30%	< 30%		

	High	Moderate	Low	Unknown	Comments
Diversity within catchment / aquifer					
Diversity of groundwater dependent native flora and fauna species within a GDE.	Presence of five or more species or >80% number of species relative to a reference site.	Presence of two to four species or 80-50% of species relative to reference sites.	Presence of one species or less than 50 percent of species relative to reference sites.		
Special features within catchment / aquifer					
Provides drought refuge for terrestrial or aquatic species.	The only water source within a radius of >10km.	The only water source within a radius of 1-9km and no access to multiple water sources.	Access to multiple water sources.		
Presence of rare physical/physico-chemical features or environments; eg. karsts, mound springs, natural saline wetlands, peat swamps etc.	Occurs only within the aquifer.	Occurs only within the catchment.	Occurs only within the state.		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification / denitrification, biodegradation through aquifer connectivity.	Unconfined aquifer with connection to terrestrial and aquatic ecosystems.	Semi confined aquifer with limited (spatial and or temporal) connectivity to terrestrial and aquatic ecosystems.	Confined aquifer has very limited or no connection to terrestrial and aquatic ecosystems.		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification / denitrification, biodegradation relating to aquifer structure and porosity.	Unconsolidated aquifer with connection to terrestrial and aquatic ecosystems.	Fractured Rock/semi-consolidated aquifer connected to terrestrial and aquatic ecosystems.	Consolidated aquifer connected to terrestrial and aquatic ecosystems.		
Total number of attributes					
Overall value					
Comments					

* Note: Methods to determine magnitude (e.g. temporary or permanent) of change or alteration will depend on the criteria and habitat type being monitored. A discussion on these methods is outside the scope of this document.

** Minor and/or major changes to aquifer structure depend on the aquifer type and its location. Determination of what is minor or major is outside the scope of this document.

*** Species or communities are deemed significant if they occur within a fauna corridor or identified as a key habitat under the NSW National Parks and Wildlife Service programs (Key Habitat and Fauna Corridor Mapping Project of Northern NSW), Identified Critical Habitats, or identified within biiodiversity strategies or regional/local biodiversity assessments.

Table 3. Identification of the ecological value of the aquifer

	High	Moderate	Low	Unknown	Comments
GDE environment					
Percentage of aquifer area covered by native GDE vegetation.	> 50%	50 to 30%	< 30%		
Percentage of GDE area reserved in National Estates, listed wetlands, SEPP 26 etc.	> 50%	50 to 10%	< 10%		
Presence of exotic flora or fauna.	None exist.	Exotic species in small numbers.	Exotic species in large populations of one or more species.		
Removal or alteration of a GDE type or subtype.	No detectable change in physical structure, species composition or size in GDE type or subtype.	Minor change or alteration in physical structure, species composition, or size resulting in a temporary change in GDE type or subtype.	Major change/alternation in physical structure, species composition, or size resulting in a permanent change in GDE type or subtype.		
Aquifer					
Water quantity parameters					
Alteration of the frequency and/or magnitude and/or timing of watertable level fluctuations.	No detectable change from natural seasonal variation.	Fluctuation in groundwater levels resulting in temporary change to part of any dependent habitat type.	Fluctuation in groundwater levels resulting in permanent loss of any dependent habitat type. *		
Alteration of groundwater pressure.	No detectable change from natural seasonal variation.	Fluctuation in groundwater pressure resulting in temporary change to part of any dependent habitat type.	Fluctuation in groundwater pressure resulting in permanent loss of any dependent habitat type.		
Alteration to direction of hydraulic gradients.	No detectable change from natural seasonal variation.	Temporary changes resulting in short-term alterations to habitat conditions.	Permanent reversals in hydraulic gradients resulting in changes to any dependent habitat type.		
Alteration of base flow conditions.	No detectable change from natural seasonal variation.	Temporary reduction in baseflow conditions exceeding seasonal variation.	Permanent loss or reversal of base flow conditions.		

	High	Moderate	Low	Unknown	Comments
Water quality parameters					
Degree of Acid runoff or acidification of aquifer.	No detectable change from natural seasonal variation.	Temporary exposure of acid sulfate soils with likely runoff into dependent ecosystems.	Permanent exposure of acid sulfate soils with likely runoff into.dependent ecosystems.		
Degree of nutrient load.	No detectable change from natural seasonal variation.	Temporary increase in nutrient load to dependent ecosystems.	Permanent increase in nutrient load to dependent ecosystems.		
Degree of groundwater salinity.	No detectable change from natural seasonal variation.	Temporary increase in salinity to dependent ecosystem.	Permanent increase in salinity to dependent ecosystem.		
Degree of bioaccumulation; ie. Heavy metal contamination.	No detectable change from natural seasonal variation.	Temporary exposure of dependent ecosystems to heavy metals and/or toxins.	Permanent exposure of dependent ecosystem to heavy metal and/or toxins.		
Aquifer structure					
Degree of alteration of aquifer structure; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction, compaction of aquifer, etc.	No detectable change in aquifer structure	Minor change/alteration of aquifer structure resulting in a temporary change in GDE habitat.**	Major change/alternation of aquifer structure resulting in a permanent change in GDE habitat.**		
Biodiversity					
Rarity within catchment/aquifer					
Presence of Threatened, Rare, Vulnerable or Endangered species, population or ecological community.	Yes	NA	No		
Presence of indicator, keystone, flagship, endemic or significant species, populations or communities.***	Yes	NA	No		

	High	Moderate	Low	Unknown	Comments
Diversity within catchment / aquifer					
Diversity of GDE type. Refer to GDE Classification table.	Presence of greater than four GDE types.	Presence of three to four GDE types.	Presence of less than three GDE subtypes.		
Diversity of GDE subtypes. Refer to GDE Classification table.	Presence of five or more subtypes.	Presence of two to four subtypes.	Presence of one subtype.		
Special features within catchment / groundwater					
Maintains ecosystems by providing water	Provides water to ecosystems of high conservation value	Provides water to identified GDEs.	Provides water to low conservation value GDEs.		
Presence of rare physical / physico-chemical features or environments; eg. karsts, mound springs, natural saline wetlands, peat swamps etc.	Occurs only within the aquifer.	Occurs within the catchment.	Occurs within the state.		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification / denitrification, biodegradation through aquifer connectivity.	Unconfined aquifer with connection to terrestrial and aquatic ecosystems.	Semi confined aquifer with limited (spatial and or temporal) connectivity to terrestrial and aquatic ecosystems.	Confined aquifer has very limited or no connection to terrestrial and aquatic ecosystems.		
Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification / denitrification, biodegradation relatiing to aquifer structure and porousity.	Unconsolidated aquifer with connection to terrestrial and aquatic ecosystems.	Fractured rock / semiconsolidated aquifer connected to terrestrial and aquatic ecosystems.	Consolidated aquifer connected to terrestrial and aquatic ecosystems.		
Total number of attributes					
Overall value					
Comments					

*Note: Methods to determine magnitude; eg. temporary or permanent) of change or alteration will depend on the criteria and habitat type being monitored. A discussion on these methods is outside the scope of this document.

** Minor and / or major changes to aquifer structure depend on the aquifer type and its location. Determination of what is minor or major is outside the scope of this document.

*** Species or communities are deemed significant if they occur within a fauna corridor or identified as a key habitat under the NSW National Parks and Wildlife Service programs (Key Habitat and Fauna Corridor Mapping Project of Northern NSW), Identified Critical Habitats, or identified within biodiversity strategies or regional/local biodiversity assessments.

6. Surface and subsurface activities that threaten aquifers and / or associated GDEs

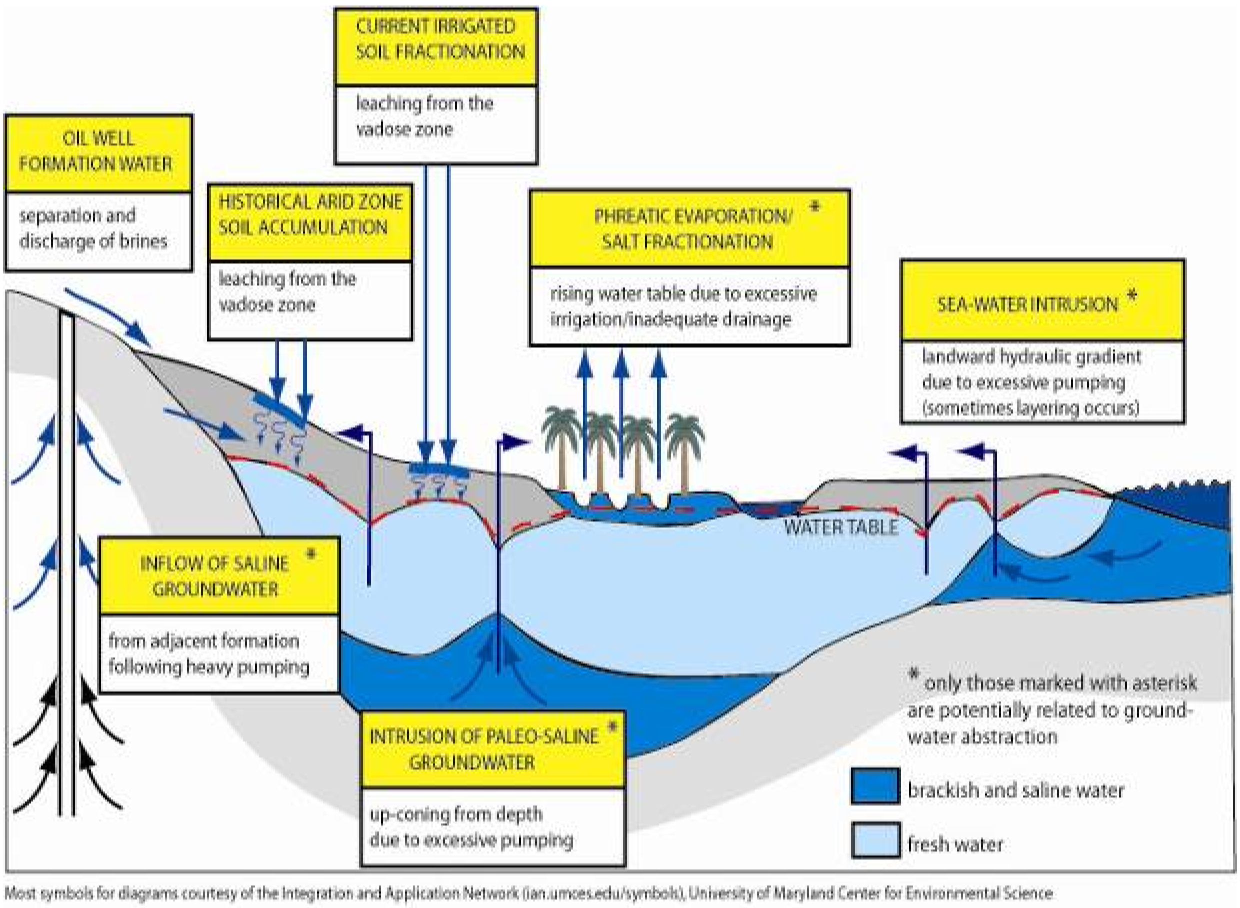
There are many activities that affect the health and condition of an aquifer and associated GDEs. These activities can cause changes to water quantity, water quality and interfere with aquifer structure. In many cases, one impact has a domino effect. For example, a decrease in groundwater levels in a coastal sandbed aquifer with acid sulfate soils has the following effects:

1. Removal of a aquifer from dependent surface species.
2. Exposure of the acid sulfate soils horizon resulting in acidification of the groundwater which can mobilise heavy metals which can then move into and contaminate the surrounding groundwater and surface systems (rivers, wetlands and estuaries).

This one localised impact can therefore affect many hydraulically linked environments and can have a wide, long lasting effect on ecosystems a significant distance downstream.

When bores and wells are constructed, or quarries or mines intercept the groundwater flow path, water is removed from the system resulting in a shift in the water balance. In certain circumstances this interception of groundwater may be quite detrimental to the ecosystems reliant upon that water as less water or poorer quality water is available (Figure 4).

Figure 4. Conceptual model of impacts on flow regime from extraction



Source: Foster et al, 2006

The three main categories of change to an aquifer that can impact on GDEs are:

1. Water quantity
2. Water quality
3. Aquifer structure

Further information on the impact of changes to the above on GDEs is provided in Appendix 5: Surface and subsurface activities that threaten aquifers and / or associated GDEs.

Listed in Table 4 (Surface and subsurface activities that may threaten an aquifer and / or associated GDEs) are a number of surface and subsurface activities that have the potential to detrimentally affect GDEs through single or multiple impacts. This list is by no means complete and should only be used as an indicator of the activities that can impact on a GDE. Each site will still need to be assessed on a case by case basis.

Table 4. Examples of surface and subsurface activities that may threaten an aquifer and / or its associated GDEs

Water quantity
Water extraction of groundwater. • River bed / wetland water extraction. • Extraction adjacent to wetland and terrestrial groundwater dependent communities.
Water extraction of surface water in loosing water bodies.
River regulation.
Drainage of swamps.
Water extraction from dewatering (eg. mining) or injection.
Aquifer and river flow direction alteration (eg. open cut mining in a highly connective alluvium / floodplain harvesting).
Water Quality
Nutrient enrichment – Variety of sources.
Turbidity – Variety of sources.
Salinity – Dry land salinity. • Saline Wedges within aquifers. • Saline Wedges within tidal pools. • Salinisation of groundwater and rising saline groundwater.
Pesticide and fertilizer use from agricultural Industries.
Effluent discharge.
Contaminated sites – Nutrients, heavy metals, hydrocarbons.
Irrigation and mining tail-water.
Exposure of acid sulfate soils.
Aquifer structure
Compaction of aquifer by dewatering; eg. mining.
Subsidence, fracturing and bedrock/stream bed cracking; eg. mining.

Land Use
Erosion and sedimentation – Variety of sources.
Sealing of land surface by urban developments in highly porous recharge zones.
Sand and gravel extraction from alluviums and rivers.
Grazing – Habitat removal, nutrient enrichment of surface and groundwater.
Lakebed cropping – Removal of surface biodiversity.
Changes in land drainage.
Modification of water course structure.
Afforestation or deforestation.
Fire – Alteration of terrestrial vegetation community and nutrient enrichment of surface and groundwater.
Excavation for developments – Aquifer interference and water level alterations.

7. A method to determine the risk of an activity to the ecological value of an aquifer and its associated GDEs

An important consideration when assessing the risk of an activity to an aquifer and/or its associated GDEs is an awareness of the interconnected nature of the landscape. Groundwater is recharged through the lands surface, connected rivers, streams and lakes and discharged onto the land surface, and into rivers, lakes, estuaries and marine environments. Surface activities can have an impact on groundwater quality, levels and pressure. These, in turn, can impact surface environments down slope / stream; ie. in the discharge areas.

This assessment identifies risks to the four main aquifer assets according to several attributes as follows:

Water quantity assets

- Risk of a change in groundwater levels / pressures on GDEs.
- Risk of a change in the timing and or magnitude of groundwater level fluctuations on GDEs.
- Risk of changing base flow conditions on GDEs.
- Risk of changing aquifer flow paths.
- Risk of disrupting ecological processes that deliver ecosystem services.

Water quality assets

- Risk of changing the chemical conditions of the aquifer.
- Risk on the aquifer by a change in the freshwater / salt water interface.
- Likelihood of a change in beneficial use of the aquifer.

Aquifer integrity assets

Risk of damage to aquifer geological structure; eg. substrate, fracturing, compaction, bed cracking.

Biological integrity assets

- Risk of alteration to the number of native species within the groundwater dependent communities (fauna and flora)
- Risk of alteration to the species composition of the groundwater dependent communities (fauna and flora)
- Risk of exotic flora or fauna being introduced
- Risk of removal or alteration of a GDE type / subtype habitat; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction

The approach adopted is based on the assumptions that:

- GDEs have intrinsic values that include a biodiversity and ecosystem function
- a surface and groundwater activity that alters the environmental parameters of the GDE outside of any known natural range will have an adverse impact on the ecosystem and its value
- the attributes listed in the Aquifer and GDE Risk Assessment Sheets are directed at all GDEs

- the higher the risk the greater the potential loss of ecological value of the GDE
- the impact of water level fluctuations will vary according to degree of groundwater dependency.

The approach presented in this document has been developed to fulfil the following three requirements:

1. Development applications must be assessed quickly. The assessment procedure must therefore be simple, transparent and able to be applied easily across large and small areas as well as across different landscapes.
2. Priorities should be based on assessment of important natural values and the range of threats to the GDE.
3. These assessments do not need to be detailed, but can be broad and relative, provided they are sufficient to delineate how groundwater ecosystems may be impacted in order to protect these valuable natural assets.

The risk assessment process is described below and involves:

1. The identification of the GDEs types and subtypes (refer to Appendix 2) and their inferred dependency on groundwater (refer to Appendix 4) within each aquifer.
2. The determination of ecological value of the aquifer and its associated GDEs.
3. The determination of the impact of an activity to the aquifer and/or identified GDE.
4. The determination of the level of potential risk from an activity.
5. Development of management action strategies through Figure 5 – Risk matrix approach.

7.1. Determining the impact of an activity to an aquifer and / or associated GDEs

Before undertaking a risk assessment it is important to consider the impact of existing disturbances on the ecosystems being assessed. For example, in assessing the risk of extraction from new licences, it is important to consider the impact of current licences, if any.

To determine the significance of a change, the existing values and disturbance tolerances / sensitivities of the ecosystem being affected must be understood. This includes the dispersal capabilities / opportunities of the associated biota. The level of anticipated impact is a comparison of the degree of change relative to the ecological values being affected. In ecosystems that are totally dependent on groundwater, and which have limited dispersal capabilities / opportunities are disturbance intolerant or sensitive to change. For example, only a small change in water level or water quality can cause a significant and rapid detrimental change for invertebrate / vertebrate species within karsts and mound springs. In ecosystems that only rely on groundwater during extreme climatic conditions (droughts) such as terrestrial vegetation communities, there may have to be a large change to warrant a response or the response may have a significant time lag from the disturbance event. Different elements of an ecosystem will have different reaction times and responses to a particular impact. It is therefore essential that the rapid response elements; ie. those GDE that are most vulnerable to changes in the groundwater regime, are identified at an early stage of any investigation.

Caution – if disturbance tolerant indicators are chosen as flagship indicators then the entire ecosystem could collapse before a response is detected.

The decision of how much change and, therefore, impact that is acceptable, is a subjective economic and social value decision and is not a consideration of this document.

To determine the impact of a current or proposed activity to a GDE within and adjacent to the area of investigation, answer ‘likely’, ‘unlikely’ or ‘insufficient data’ to the questions listed in the impact checklist (Table 5 – GDE / Aquifer impact checklist of proposed activity). Any ‘insufficient data’ record will highlight information gaps that may need to be examined in greater detail.

Table 5. Aquifer / GDE impact checklist for a proposed activity

	Likely	Unlikely	Insufficient data
Groundwater management area / zone:			
Activity to be assessed:			
Water quantity impacts			
Will there be an alteration to the watertable levels (rising or dropping water tables)?			
Will there be any alteration to the aquifer flow paths?			
Will there be any alteration of aquifer discharge volume to off site GDEs?			
Will there be an alteration of the frequency/timing of water table level fluctuations?			
Will there be any alteration of river base flow in the karst / cave?			
Will there be an alteration of surface river base flow?			
Will there a reduction in artesian/spring water pressure?			
Water quality impacts			
Will there be an alteration to the natural groundwater chemistry and / or chemical gradients?			
Will acid sulfate soils be exposed, resulting in the acidification of aquifer and acid runoff?			
Will there be an alteration in nutrient loads?			
Will there be an alteration in sediment loads?			
Will there be an alteration in groundwater salinity levels?			
Will there be an alteration in groundwater temperatures?			
Will there be any bioaccumulation of heavy metals?			
Aquifer Integrity impacts			
Will there be any substrate alteration compaction; eg. aquifer, river gravel bed compaction by heavy machinery or over extraction of water?			
Will there be any cracking or fracturing of the bedrock?			
Biological integrity impacts			
Will there be an alteration to the number of native species within the groundwater dependent communities (fauna and flora)?			
Will there be an alteration to the species composition of the groundwater dependent communities (fauna and flora)?			
Will exotic flora or fauna be introduced?			
Will there be any removal or alteration of a GDE type / subtype habitat; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction?			
Total			
Impact			

7.2. Determining the magnitude of potential risk from an activity

To assist in the risk assessment, a suggested list of information requirements is provided in Table 6.

Table 6. Information requirements

Description of proposed activity from application
List of GDE subtype / habitats.
Area of GDE subtype.
Area and current condition of all habitat and / or GDE subtype listed above.
Habitat groundwater dependency.
Natural water table level fluctuations.
Water level requirements for each identified habitat type.
Groundwater table level (average).
Groundwater depth (thickness).
Current species list of native species within the groundwater dependent communities (fauna andfFlora). Include list of threatened, rare, endangered or vulnerable species.
List of exotic species.

If a risk from an activity to an aquifer and/or associated GDEs has been identified, the magnitude of the risk can be determined using Table 7 – Aquifer and GDE Risk Assessment Guide (pre-mitigation measures). This assessment allows a more detailed examination of the impacts and allows the impacts to be ranked based on a high, medium or low rating. The overall risk is the highest value attained by any asset. It must be stressed that such rankings are only indicative and are a means of reaching a final descriptive rating. They do not necessarily represent real quantities and should not be used in any other context than this method.

Some aquifers / GDE has little or no data available, whereas others have reliable data. The Aquifer and GDE risk assessment guide (see over) allows for the input of as much or as little information as is available. Where information is limited about an aquifer / GDE, experts should use their local knowledge and professional technical expertise.

Table 7. Aquifer and GDE risk assessment

Aquifer Name:

Risk factors

	High	**Moderate**	**Low**	**Insufficient data or unknown**
Water quantity asset				
What will be the risk of a change in groundwater levels/pressure on GDEs?	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in permanent loss or alteration of defined habitat type.	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in temporary loss or alteration of defined habitat type.	No change to aquifer water levels or pressure.	
What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?	Fluctuation in groundwater level(s) or piezometric pressure beyond established seasonal variation, resulting in permanent loss or alteration of defined habitat type.	Fluctuation in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in temporary loss or alteration of defined habitat type.	No change in timing of water level fluctuations.	
What will be the risk of changing base flow conditions on GDEs?	Permanent reversal of base flow conditions.	Temporary reversal of base flow conditions exceeding seasonal variation.	No change in direction of flow.	
Water quality asset				
What is the risk of changing the chemical conditions of the aquifer?	Permanent change; eg. in pH, DO, nutrients, temperature and / or turbidity.	Temporary change; eg. in pH, DO, nutrients, temperature and / or turbidity.	Negligible change (<5%).	
What is the risk on the aquifer by a change in the freshwater/salt water interface?	Permanent change in location or gradient of salt / freshwater interface.	Temporary change in location or gradient of salt / freshwater interface.	No change or not applicable	
What is the likelihood of a change in beneficial use (BU) of the aquifer?	Reduction in water quality beyond designated BU category (for identified trigger parameters).	Reduction in water quality within designated BU category (for identified trigger parameters).	Negligible change for identified triggers (<5%).	

Aquifer Name:				
Risk factors				
	High	**Moderate**	**Low**	**Insufficient data or unknown**
Aquifer integrity asset				
What is the risk of damage to the geologic structure?	Permanent destruction of the aquifer matrix. Major cracking/fracturing of the bedrock/stream bed leading complete dewatering of the GDE.	Temporary adjustment to the aquifer matrix. Minor cracking/fracturing of the bedrock/stream bed leading to partial dewatering of the GDE.	No change	
Biological integrity asset				
What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?	> 10% reduction in No. of species.	10 to 5% reduction in No. of species.	No reduction in No. of species.	
What is the risk of alterations to the species composition of the groundwater dependent communities (fauna and flora)?	> 10% change in species composition.	10 to 5% change in species composition.	No change in species composition.	
What is the risk of increasing the presence of exotic flora or fauna?	Large populations of one or more species.	Species in small numbers.	None exist.	
What is the risk of removing or altering a GDE subtype habitat; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction?	> 20% removal or alteration of habitat area.	10 to 20% removal or alteration of habitat.	No removal or alteration of habitat.	
Risk valuation				
Risk				

Exception rule: If the number of **unknowns** exceed 50 percent of questions, the risk is considered to be high until proven otherwise.

*Note: Methods to determine magnitude or degree of alteration will depend on the criteria and habitat type being monitored. A discussion on these methods is outside the scope of this document.

8. The risk matrix

The Risk matrix (Figure 5) was built on the concept developed for the macro water sharing plan process. It is a method of outlining the most appropriate management response for a given environmental value under a particular activity. The risk matrix is a component of adaptive management and is designed to:

1. recommend the most appropriate management strategies for each given scenario at the outset
2. test the effectiveness of the management strategies over a time period by combining a monitoring program with an effective framework for adaptive management; ie. responding to the monitoring outcomes.

The aim of the management strategies is to:

1. maintain and / or improve the ecological value of a aquifer and its associated GDEs
2. to reduce the level of risk to that aquifer and associated GDEs.

The management strategies for an aquifer and its associated GDEs or for indivdual GDEs are based on the comparison of the ecological value of the aquifer and it's associated GDEs against the risk to them by the proposed or current activity. The risk is a combination of the likelihood that an altered groundwater regime or water quality will impact adversely on the ability of the asset to access sufficient groundwater or sufficeint quality to meet its requirements and the degree of threat posed to the groundwater by the proposed or current activity.

The application of the risk matrix can be applied to either an aquifer ecological evaluation using Table 3 or an individual GDE ecological valuation using Table 2.

The matrix consists of two axes, the vertical axis plots the level of ecological value and the horizontal axis plots the level of risk of an activity does or may impose on the aquifer and its associated GDEs. For the purpose of matrix function and structure, the ranking of both ecological values and risk is divided into a three category system of High, Medium and Low values. The attributes for each ecological value category are in Section 8.1. These categories and associated management actions apply to both aquifers and their associated GDEs.

Figure 5. Risk matrix

Category 1 High Ecological Value (HEV) Sensitive Environmental Area (SEA)	A	B	C
Category 2 Moderate Ecological Value (MEV) Sensitive Environmental Area (SEA)	D	E	F
Category 3 Low Ecological Value (LEV)	G	H	I
	Category 1. Low Risk	**Category 2. Moderate Risk**	**Category 3. High Risk**

The risk matrix identifies both the level of management action required and the time frame in which this action needs to be implemented (action priority). Each component aligns with each of the axes. The management action is **aligned with ecological value and does not vary with changes in risk**;

ie. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low. **However, the timing of the management action is aligned and determined by the level of risk.** For example, if an ecosystem or aquifer has been identified as of high ecological value and the risk assessment process has identified a proposal or current activity that poses a high risk, the management strategy would require immediate action before the impact occurs, or undertaken with significant protection measures if the activity is unavoidable. If the impact is a current activity, the strategy would be to either immediately stop the activity or commence mitigation works in a short time frame to limit damage to the identified ecological values.

The management strategies for aquifers and GDEs are largely vested in the legislative controls of the *Water Management Act* 2000. A requirement of the water sharing plans is to monitor plan performance using a standard set of Performance Indicators. For the purpose of Section 35 (1) (b) of the *Water Management Act* 2000, the following broad indicator categories are to be used to determine the performance of each plan against its objectives:

a. Change in ecological condition and value of these aquifers and their dependent ecosystems. This includes changes in species / community numbers and composition.

b. Change in groundwater extraction relative to the extraction limit.

c. Change in climate adjusted water levels.

d. Change in water quality.

8.1. Attributes for ecological value categories

The attributes for each ecological value category are described below. These categories apply to both aquifers and their associated GDEs.

Category 1 – High Ecological Value (HEV) – Sensitive environmental areas

All of the GDEs and aquifers that are assessed as being of high ecological value (HEV) will be of high conservation value. HEV can include:

- GDE communities (including stygofauna) where only slight changes in key groundwater attributes below or above a threshold would result in their loss; ie. entirely dependent ecosystems).
- GDEs or aquifers that are partly or wholly located within a State or Federal Reserve System; eg. National Park / Reserve, or a ‘high conservation area’.
- Any GDE or aquifer that is relatively unaltered and in good condition.
- Any natural GDE that is habitat for any endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under the *NSW Threatened Species Act* 1995, *NSW Fisheries Management Act* 1994 or the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 or identified as above by an acknowledged expert taxonomist / ecologist.

Category 2 – Moderate Ecological Value (MEV) – Sensitive environmental area

- GDE communities where moderate change in groundwater discharge or water tables is required to cause change in their distribution, composition and / or health (the value is based on the potential vulnerability / sensitivity to change).
- Any natural GDE system that is habitat for any vulnerable or threatened biota (fauna or flora), populations or communities as listed under the *NSW Threatened Species Act* 1995, *NSW*

Fisheries Management Act 1994 or the *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999.

- Any GDE or aquifer that provides ecological services to other ecosystems such as river, wetlands and estuaries.
- GDE communities that exhibit either a threshold or proportional response to changes in groundwater attributes. Moderate systems can include highly dependent systems which can exhibit a threshold response.
- Any GDE or aquifer that is regarded as in moderate to good condition from its natural state but not covered by state or federal legislation.
- MEV can also include ecosystems where groundwater appears only to play a minor role in the water balance of such ecosystems such as at the end of a dry season or during extreme drought.

Category 3 – Low ecological value

- Any aquifer or GDE type that is highly modified from that of its natural state. Note: It is acknowledged that although these GDEs and / or aquifer may be highly impacted they may still contain a functioning ecosystem with high value species; ie. listed threatened or rare species, as well providing important habitat for elements of the biodiversity. These can include high value attributes such rare, threatened or unique species or unique abiotic features. These are referred as identified assets within Table 8 – Management requirement and actions associated with ecological value and risk. It is essential that these elements are identified and managed appropriately to retain, sustain and improve the ecosystem conditions.
- Involves a high cost to rehabilitate, if possible at all, and there are other similar GDE types in moderate to good condition; ie. have little need of rehabilitation, existing within the catchment / aquifer.
- Management actions associated with each box within Figure 5 – Risk matrix are described in Table 8 – Risk matrix management actions and Table 9 – Management requirement and actions associated with ecological value and risk.

Table 8. Risk matrix management actions for each matrix box

Risk matrix box	Descriptor	Management action short term	Management action mid term	Management action long term **
A	**High value / low risk**	Protection measures for aquifer and GDEs.	Continue protection measures for aquifers and GDEs.	Adaptive management. Continue monitoring.
		Baseline risk monitoring.	Periodic monitoring and assessment.	
B	**High value / moderate Risk**	Protection measures for aquifer and GDEs.	Protection measures for aquifer and GDEs.	Adaptive management. Continue monitoring.
		Baseline risk monitoring. Mitigation action.	Monitoring and periodic assessment of mitigation.	
C	**High value / high risk**	Protection measures for aquifer and GDEs.	Protection measures for aquifer and GDEs.	Adaptive management. Continue monitoring.
		Baseline risk monitoring. Mitigation.	Monitoring and annual *assessment of mitigation.	
D	**Moderate value / low risk**	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline risk monitoring.	Baseline Risk monitoring.	
E	**Moderate Value/Moderate Risk**	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring.	Monitoring and periodic assessment of mitigation.	
		Mitigation action.		
F	**Moderate Value/High Risk**	Protection of hotspots.	Protection of hotspots.	Adaptive management. Continue monitoring.
		Baseline Risk monitoring. Mitigation Action.	Monitoring and annual *assessment of mitigation.	
G	**Low value/Low risk**	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.
		Baseline Risk monitoring.	Baseline Risk monitoring.	
H	**Low Value/Moderate Risk**	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.
		Baseline Risk monitoring. Mitigation action.	Monitoring and periodic assessment of mitigation.	
I	**Low Value/High Risk**	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.

* Annual assessment of mitigation or as deemed necessary based on GDE type.

** It is anticipated that that the monitoring actions and management will change in light of observed GDE responses. The triggers for management responses will vary depending on GDE type and WSP. Therefore, this is outside the scope of this document.

8.2. Management strategies for risk categories

For the type of change associated with high, moderate and low risk refer to the *Aquifer and GDE Risk Assessment Guide* (Table 7).

Category 1 – Low risk

Minor to no discernable impact resulting in no change or minor change to the aquifer and/or associated GDEs.

Category 2 – Moderate risk

Moderate Risk to the aquifer and/or associated GDEs has been identified through the risk assessment process or has triggered threshold levels of indicators that moderate impact will result or / has resulted in a temporary change to the ecosystem.

Category 3 – High risk

High risk has been identified through the risk assessment process or has triggered threshold levels of the indicators that significant to major impact will result or has resulted in a permanent change to the aquifer and/or associated GDEs.

Management requirements and actions associated with ecological value and risk within Figure 5 – Risk matrix are described in Table 9 – Management requirement and actions associated with ecological value and risk below.

Table 9. Management requirements and actions associated with each level of ecological value and risk

Criteria	Assumptions	Management requirement	Management action	Results of management action (arrows indicate desired directions of outcomes)
HEV	All of ecosystem is of high value. Ecosystem in good condition.	Protection of aquifer and GDE catchment / subcatchments.	Management actions (water sharing plan rules).	Status Quo
		Monitoring to ensure no change to risk.	No further action required.	
			Protection of entire aquifer and catchment.	
MEV	Elements of ecosystem has value.	Protect valued assets including aquifer and GDE vicinity.	Management actions (water sharing plan rules).	▲
	Ecosystem in good to fair condition.	Mitigation to improve impacted assets.	Mitigation actions.	
			Protection of identified assets.	
			Rehabilitation where necessary.	

Criteria	Assumptions	Management requirement	Management action	Results of management action (arrows indicate desired directions of outcomes)
LEV	Low ecological value and highly impacted.	Rehabilitate both aquifer water levels and surrounding catchment (where appropriate).	Management actions (water sharing plan rules).	▲
			Mitigation actions.	
			Protect of identified assets.	
			Rehabilitation where necessary.	
High Risk	Risk is substantial / permanent, occurring now, or imminent.	Immediate action.	Mitigate impact and apply water sharing plan rules.	▼
			Monitor effectiveness of mitigation strategy using appropriate indicators.	
Moderate Risk	Risk is likely/moderate, temporary or sporadic, seasonal.	Immediate action.	Mitigate impact and apply water sharing plan rules.	▼
			Monitor effectiveness of mitigation strategy using appropriate indicators.	
Low risk	Risk is unlikely, minor.	No mitigation action.	Continue to monitor selected indicator(s).	Status quo
		Monitoring to ensure no change of risk.		

8.3. Adaptive management

The risk matrix builds on the adaptive management strategy incorporated into the macro water sharing plans. The term refers to the practice of changing the management regime in response to new information, either from monitoring or some other improvement in understanding. Adaptive management is a requirement of both the *Water Management Act* 2000 (section 5 (h)) and the National Water Initiative (clause 25 (iv)). This strategy provides a vital feedback mechanism that allows for testing of the rules that are put into place in order to ensure maximum effectiveness. The goal of adaptive management though an ongoing monitoring program is to ensure that the ecological values identified are retained and/or improved by mitigating the risk.

In some aquifers, particularly those that are not highly committed, there is insufficient information to develop adequate plan rules to manage the environmental or socio-economic risks. In these cases, further analysis or data collection may be required during the life of the plan. The macro water sharing plans does include provisions which make allowance for this additional work. Where any aspects of the plan may change as a result of this new information, this will be stated in the plan to give certainty and to ensure that it is clear to water users that certain rules may be varied during the life of the plan.

The risk matrix also operates under the precautionary principle. The precautionary principle is applied where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (principle adopted at the 1992 United Nations Conference in Rio on Environment and Development).

There are two strategies for managing the risk of an activity to each aquifer (or water source) and GDE. These are:

1. **Management actions**

   Management actions are the generic management strategies and rules listed within the water sharing plans for the protection of GDEs through the protection of the aquifer. These actions use the precautionary principle and are intended as preventative measures. The rules are listed below.

2. **Mitigation actions**

   Mitigation actions differ from management actions in that they are generally additional measures for managing short term or localised impacts. Mitigation actions are likely to be needed when an activity has already had an impact and would require immediate action. Additional funding and resourcing will often be required to ensure their implementation. An example of mitigation measures would be the activation of 'cease to pump' rules where a detectable drawdown was recorded at the boundary of a high ecological value GDE (sensitive environmental area).

The Process for assigning either management action or mitigation action is determined by the level of change / risk / impact and the triggering of threshold levels (indicator levels outside of natural variations – these levels will need to be determined on a case by case basis).

8.4. Monitoring program design

The macro-water sharing plan process developed for NSW provides for a value and risk assessment based approach to determine the type of rules. Initial management for most will be based on maintaining extraction below the sustainable yield.

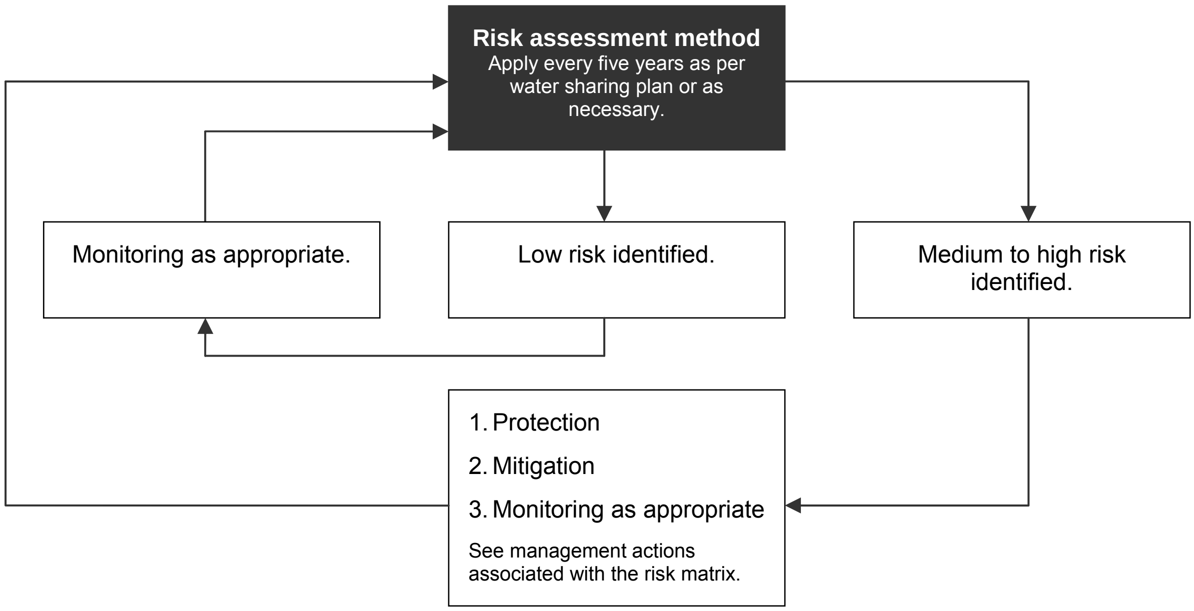
The risk assessment approach (Figure 5) should trigger a review of the ecological value and level of risk to an aquifer and associated GDEs in over allocated systems. For aquifer and/or associated GDEs that are considered to be at 'high or moderate risk', a monitoring program should be implemented to collect appropriate indicators. The data should be used in developing WSP management rules that mitigate / alleviate impacts when a threshold is exceeded or triggered, thereby reducing the risk to a lower category.

Figure 6 – Risk assessment flow chart involves determining:

- the ecological value of an aquifer and associated GDEs
- the environmental risk associated with extraction (or activity)
- management action as stipulated by the risk matrix (Figure 5).

As outlined in Figure 6 – Risk assessment flow chart, the first step is to complete an initial review of the aquifer / GDE using Figure 5 – Risk matrix to categorise the aquifer ecosystem as being either 'high' 'moderate' or 'low' risk. For aquifer and associated GDEs identified as being at high or moderate risk, appropriate protection and mitigation should be implemented as required.

Figure 6. Risk assessment flow chart



8.4.1. Monitoring

The type of monitoring required will depend on the type of risk identified in the risk matrix, the type of aquifer, its uses, and the types of associated GDEs. It is therefore difficult to advocate any single performance indicator that could be used to monitor the success, or otherwise, of management programs, without being general in the approach. This document does not propose any detailed monitoring method for aquifers or associated GDEs. It is anticipated that that the monitoring actions and management will change in light of observed aquifer / GDE responses. The triggers for management responses will vary depending on aquifer / GDE type and water sharing plan. Therefore, this is outside the scope of this document.

The current controls to manage GDEs are largely vested in the legislative controls of the *Water Management Act* 2000. A requirement of the water sharing plans is to monitor plan performance using a standard set of performance indicators as set out by *Water Management Act* 2000. For the purpose of Section 35 (1) (b) of *the Water Management Act* 2000, the following indicators relevant to GDEs are to be used to determine the performance of each plan against its objectives:

a. Change in groundwater extraction relative to the extraction limit.

b. Change in climate adjusted water levels.

c. Change in ecological condition of these aquifers and their dependent ecosystems.

d. Change in water quality.

It is proposed that the risk matrix be used to identify the type of risk or potential impact to an aquifer and associated GDEs and to prioritise the appropriate indicators for monitoring that risk.

8.5. Management actions

The management strategies/rules associated with the risk matrix are those outlined within the relevant macro water sharing plans. Each plan will state the vision, objectives, strategies and performance indicators for the Plan. Recharge estimates and the planned environmental water will be specified for each aquifer. Total volumes of licensed entitlement and an estimate of the total volume needed to meet basic landholders' rights needs will also be stated for each aquifer.

In general, as the level of competition between risk (of not undertaking or continuing the activity) and ecological values increases, the level of management also increases to reduce the risk to the aquifer from extraction or other activities. The management strategies described in the water sharing plans are specifically related to managing water levels and are applicable to High Priority GDEs which are individual GDEs with high ecological values.

It should also be noted that a key objective of the National Water Initiative http://www.nwc.gov.au/www/html/117-national-water-initiative.asp is the recognition of the connectivity between surface and groundwater resources and (that) connected systems (should be) managed as a single resource. In aquifers defined as 'highly connected' to a river system, a combined surface water / groundwater plan can be developed, or other tools such as the linking of access rules can be used.

The WSP rules for protecting High Priority GDEs are detailed in Appendix 3.

8.5.1. Risk mitigation actions

The outcomes of the risk matrix are considered, with weighting given to the ecological value assessment; ie. the maintenance and protection of the identified values. Mitigation measures, applied through rules in the water sharing plan, can reduce the impact of extraction (or an activity) on a aquifer. For example, an aquifer which is at high environmental risk may have its risk reduced to moderate or low if the effect of extraction on the aquifer / GDE can be successfully mitigated. This step involves identifying actions that could be implemented to mitigate the risk to the aquifer from extraction. This does not change the overall environmental risk from extraction, but provides a strategy for ensuring extraction is brought back to or kept within natural variations. Mitigating actions will be expressed as rules in the macro groundwater sharing plans to ensure their effectiveness. Mitigation is primarily applied to managing the impact to the aquifer from extraction. Examples are:

- Limiting or excluding extraction from within buffer zones around GDEs.
- Monitoring whether groundwater quality changes over time.
- Checking whether the groundwater regime alters over time.
- Setting trigger levels for water level / quality monitoring, such as cease to pump rules.
- Setting volume restrictions on extraction – Temporary water restrictions (see text box overleaf).

Temporary water restrictions for a water source

Water Management Act 2000 – Sect 324

If (the Minister is) satisfied that it is necessary to do so in the public interest (such as to cope with a water shortage or threat to public health or safety), the Minister may, by order in writing, direct that, for a specified period, the taking of water from a specified water source is prohibited, or is subject to specified restrictions, as the case requires. If (the Minister is) satisfied that it is necessary to do so to:

1. maintain or protect water levels in an aquifer
2. maintain, protect or improve the quality of water in an aquifer
3. prevent land subsidence or compaction in an aquifer
4. protect groundwater-dependent ecosystems
5. maintain pressure, or to ensure pressure recovery, in an aquifer.

9. Application of the process

The assessment of ecological value and risk of aquifer and/or associated GDEs has been refined through application of the methodology to several pilot studies and are discussed in Volume 2.

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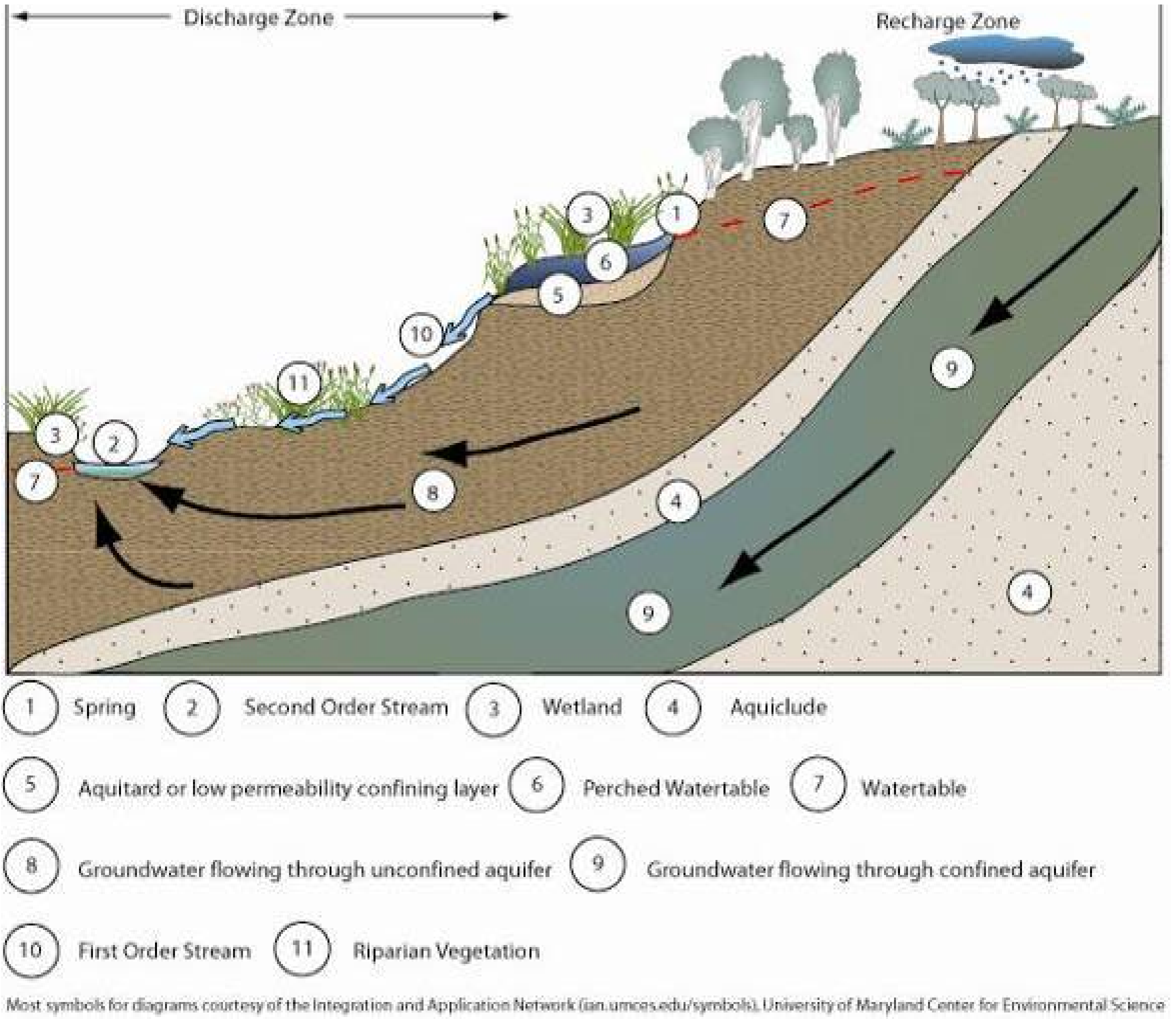
Appendix 1

Groundwater and its relationship to GDES

1. Introduction

Under natural conditions, all aquifers are recharged by rainfall, stream flow or lateral though flow. Groundwater flows through the geological medium from higher to lower elevations, flowing through pore species, small and large voids (cavities, cracks and caves) until it eventually discharges as springs, seeps or directly into rivers or the ocean. Where the water table is close to the surface, some of this groundwater may be intercepted by vegetation and wetlands. These processes are illustrated in Appendix 1 – Figure 1.

Appendix 1 – Figure 1. Groundwater conceptual model



1.1. Types of aquifers

Aquifers have been divided into five geological aquifer units as per the macro water sharing plans. Additional aquifer types not currently covered by the macro water sharing plans are also listed below and include shallow perched aquifers and palaeovalley alluvial sediments. These are recognised aquifer types that support a wide variety of GDEs.

Alluvial aquifers

1. Riverine alluvial sediments

Includes the sands, clays and gravels associated with inland rivers and streams; eg. Macquarie River Floodplain and alluvium.

2. Palaeovalley alluvial sediments.

Palaeovalley alluvials and palaeochannels represent remnants of river channels that are associated with prehistoric drainage basins. They are typically composed of unconsolidated material including fine to course grains sediments. Palaeovalley aquifers are limited by their shallow depth (typically < 50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of a palaeovalley, Magee and Geo-science Australia, 2009.

Coastal sand bed aquifers

Includes the sands, shells and clays along the coast of NSW, eg. Botany sands.

Fractured rock aquifers

includes large tectonic fold belts (consisting of metamorphic and igneous rocks), basalt caps and calcareous formations; eg. Alstonville Basalts, New England Fold Belt, Lachlan Fold Belt.

Porous sedimentary rock aquifers

Includes the large sedimentary basins of sandstone with inter-bedded siltstone, shale and coal and the ‘consolidated’ sands with dual porosity characteristics; eg. Hawkesbury / Nepean Sandstone, Western Murray, Oxley Basin and Gunnedah Basin.

Additional aquifer types not currently covered by the macro water sharing plans include shallow perched aquifers and palaeovalley alluvial sediments. These are recognised aquifer types that support a wide variety of GDEs.

Shallow perched aquifers

Perched aquifers are spatially limited, often small shallow aquifers formed when water percolation is interrupted by another confining layer (clays or rock) thus forming a saturated zone (aquifer) above the main regional water table; eg. Blue Mountain Hanging Swamps. They are typically composed of unconsolidated material including fine to course grains sediments and organic deposits such as humus or peat.

Palaeovalley alluvial sediments

Palaeovalley alluvials represent remnants of river channels that are associated with prehistoric drainage basins. They are typically composed of unconsolidated material including fine to course grains sediments. Palaeovalley aquifers are limited by their shallow depth (typically < 50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of a palaeovalley (Magee and Geo-science Australia, 2009).

1.2. GDEs associated with aquifer type

Each aquifer may contain a number of different GDE types and subtypes as described in Appendix 1 – Table 1 – GDE Aquifer Type Quick Reference Guide. Table 1 is an indicative guide to the common GDEs associated with each aquifer type. Each aquifer type has a range of GDEs associated with it that include a subset of GDE types that are aquifer type specific. There is also considerable overlap of GDEs across aquifer types, particularly in the broad Type 1 category (see Appendix 2 for classification of GDE types).

Appendix 1 – Table 1. GDE Aquifer type quick reference guide

Aquifer type	GDE type
Unconsolidated alluvial aquifers	**Groundwater dependent wetlands** Freshwater floodplain swamps Freshwater lakes and lagoons Freshwater springs Waterholes Subsurface hyporheic ecosystems within wetlands
	Base flow stream hyporheic ecosystems Subsurface hyporheic ecosystems
	Subsurface phreatic aquifer ecosystem Palaeovalley alluvial sediment Palaeochannels
	Baseflow stream (surface ecosystems) Surface water riverine ecosystems (perennial and intermittent rivers and streams)
	Estuarine and near shore marine ecosystems Tidal wetland / inter-tidal mud flats
	Phreatophytes – Groundwater dependent terrestrial vegetation
Unconsolidated coastal sandbed aquifers	**Groundwater dependent wetlands** Coastal freshwater wetlands Coastal lakes and lagoons Springs Subsurface hyporheic ecosystems within wetlands
	Subsurface phreatic aquifer ecosystem
	Baseflow stream (hyporheic ecosystems) Subsurface hyporheic ecosystems
	Baseflow streams (surface ecosystem) Surface water riverine ecosystems (perennial and intermittent rivers and streams
	Estuarine and near shore marine ecosystems Mangrove wetlands swamps and forests Saltmarsh Seagrass beds and meadows Intertidal sands and mudflats Interstitial habitat in sand, shingle or pebble beaches Macro and micro algal communities Submarine springs – Wonky holes
	Phreatophytes – Groundwater dependent terrestrial vegetation

Aquifer type	GDE type
Consolidated fractured rock aquifer	**Karst / limestone caves** Freshwater limestone caves Anchialine (marine) limestone caves Evaporite caves Non carbonate caves in pseudokarsts
	Groundwater dependent wetlands Springs and seeps Rockpools and waterholes Geothermal wetlands Karst wetlands
	Subsurface phreatic aquifer ecosystem
	Baseflow stream (surface ecosystems) Surface water riverine ecosystems
	Baseflow stream (hyporheic ecosystems) Subsurface hyporheic ecosystems
	Phreatophytes – Groundwater dependent terrestrial vegetation
Consolidated porous sandstone aquifer	**Karst / caves ecosystems** Non carbonate caves in pseudokarst
	Subsurface phreatic aquifer eocystems
	Groundwater dependent wetlands Freshwater lakes and lagoons Springs and seeps Rockpools and waterholes Upland swamps
	Baseflow stream (surface ecosystems) Surface water riverine ecosystems
	Baseflow stream (hyporheic ecosystems Subsurface hyporheic ecosystems
	Phreatophytes – Groundwater dependent terrestrial vegetation
Unconsolidated perched aquifers	**Groundwater dependent wetlands** Springs and seeps Upland swamps Freshwater wetlands Arid zone wetlands Freshwater lakes and lagoons Subsurface hyporheic ecosystems within wetlands
	Subsurface phreatic aquifer ecosystem
	Baseflow stream (surface ecosystems) Surface water riverine ecosystems
	Baseflow stream (hyporheic ecosystems Subsurface hyporheic ecosystems
	Phreatophytes – Groundwater dependent terrestrial vegetation

Appendix 2

GDE types and classification

1. Introduction

The seven types of GDEs used within the classification are summarised below and shown in Appendix 2 –Table 1 – Groundwater dependent ecosystems classification guide. The table is designed to be read from left to right, ie. when classifying a GDE it is broadly grouped into a general or broad classification first and then separated into finer scale groups in each column to the right. For example, the broad GDE type, groundwater dependent wetlands, can be found under both subsurface and surface ecosystems. Under surface ecosystems it occurs in three different types of environments (inland, upland and coastal). Within each environment, groundwater dependent wetlands are divided into three subtypes, the number of wetland types under each subtype differs according to available information. Although only three subtype levels have been shown, with most subtype three units remaining undetermined, the table was developed so that additional subtypes could be added indefinitely as more information becomes available to separate the communities. This classification provides the basic structure for that to occur.

1.2 Subsurface ecosystems – Underground ecosystems

1. Karst and caves.
2. Subsurface phreatic aquifer ecosystems.
3. Baseflow stream (hyporheic or subsurface water ecosystems).

Note that subsurface ecosystems can include some groundwater dependent wetlands (hyporheic Ecosystems) and estuarine and near shore marine ecosystems (submarine springs, interstitial habitat in sand, shingle, pebble beaches as well as intertidal sand and mudflats).

1.3 Surface ecosystems – Above ground ecosystems

1. Groundwater dependent wetlands.
2. Baseflow streams (surface water ecosystems).
3. Estuarine and near shore marine ecosystems.
4. Phreatophytes – Groundwater dependent terrestrial ecosystems.

A brief description of the ecosystem types are provided below.

2. Subsurface ecosystems

Aquifers contain not only water that can be pumped but also a diverse subsurface community of fauna and bacteria that inhabit the pore spaces and voids of groundwater environments. The recognition of these ecosystems has led to groundwater ecology becoming a major discipline of scientific endeavor (Gibert *et al,* 1994), particularly in the Northern Hemisphere and increasingly within Australia. Aquifers contain a broad range of organisms which include 'macro' invertebrates and vertebrates that can be seen with the naked eye, 'micro' organisms termed 'meiofauna' (invertebrates that can only be seen with a microscope) and bacteria (biofilm) communities. The general term for all animals that occur in subsurface waters is 'stygofauna' (Ward *et al,* 2000), although this term is more specifically related to the macro invertebrate communities. In terms of global composition, crustaceans dominate the larger stygofauna. There is a paucity of vertebrates and insects, while oligocheates (worms) and gastropods (snails) are regionally significant, Botosaneanu, 1986; Culver and Sket, 2000; Sket 1999a. The diversity of these groundwater ecosystems was recently highlighted by the identification of stygofauna 'hotspots' in North America and Europe, Culver and Sket, 2000.

Despite considerable continental aridity and a paucity of cave and karst areas by world standards, Australia has been identified as a regional centre of stygofauna diversity, Guzik *et al,* 2010; Holsinger, 1988; Williams, 1980. This is supported by research in Western Australia, Humphreys 2002; Jasinska and Knott, 1991. The two richest sites in the world for stygal amphipods are the Ethel Gorge calcrete and Barrow Island, both in northwestern Australia, Humphreys, 2001; Bradbury and Williams 1997. There are also more *stygal dytyscid* (water) beetles in the Yilgarrn region than in the remainder of the world combined, Humphreys, 2001. Until recently, less attention has been given to the stygofauna of Eastern Australia. However, surveys suggest that this area, and in particular NSW is, at least, as diverse as the regions previously mentioned and are also an important region of stygofauna diversity (Eberhard *et al,* 1991, Eberhard and Spate, 1995; Thurgate *et al*, 2001; Tomlinson *et al,* 2007; Tomlinson and Boulton 2008, Tomlinson and Boulton, 2010.

The most significant and potentially sensitive groundwater dependent organisms are those that occur in aquifers and cave ecosystems. These organisms depend totally dependent on groundwater and are adapted to these environments.

Aquifer and cave ecosystems and organisms have many values, including the following:

- Some are rare or unique.
- The ecosystems surviving in aquifers and caves are amongst the oldest surviving on earth.
- They have water quality benefits, biodiversity value and add to the ecological diversity in a region.

Australia is biogeographically distinct in its groundwater fauna (Guzik *et al,* 2011; Humphreys, 2002) and the subterranean fauna of NSW is biogeographically distinct from other Australian 'hotspots', Eberhard and Spate, 1995; Thurgate *et al,* 2001. In addition to the diversity aspect, our ecological perspective of groundwater has broadened to consider the subsurface system as having a complex and interactive boundary with surface ecosystems at a range of scales. Most groundwater fauna (Appendix 2 – Photograph 1. a and b), are extremely sensitive to the environmental characteristics of the water they inhabit and, thus, potentially are useful indicators of groundwater health. Without knowledge of the amount of diversity present in the natural populations in each aquifer it is not possible to predict the effect of management actions. The value of identifying species delineations and distributions, beside the critical role of correct identification in medical and economic fields, is that good taxonomy and systematics; ie. understanding the natural relationships among species, is fundamental to good biology.

Appendix 2 – Photograph 1. 1A and 1b – Examples of stygofauna

The gradients in environmental conditions between epigean (surface) and hypogean (subsurface) habitats create the microhabitat complexity that promotes coexistence of taxa, enhancing local biodiversity and ecosystem function. At an evolutionary scale, natural disruption of linkages such as tectonic activity may promote biodiversity by severing genetic exchange and leading to allopatric speciation. As the Australian stygofaunal assemblages contain numerous short-range endemics and occur in systems of potential or actual resource development, they represent a real challenge for innovative environmental management, Watts and Humphries, 2000; Malard *et al,* 1996. Resource development in many parts of Australia relies on water and promises tempting short-term economic benefits. It is far more difficult to attach an economic value to stygofaunal biodiversity, especially when information on potential ‘ecosystem services’ provided by such fauna is lacking.

At present we have little understanding of the tolerances or environmental requirements of stygofauna. Their presence in groundwater systems will be very useful indicators of groundwater health in the future as well as being strong indicators in surface water environments of groundwater discharge areas. An increasing concern in NSW (and Australia) is:

1. The lack of knowledge of biodiversity, distribution and ecology of our groundwater faunas.
2. The ever increasing over-use and pollution of Australia’s groundwater reserves.

The recent discovery of not only new species but new families of Crustacea (Syncarida) in NSW highlights how little we know of these ecosystems.

The importance of aquifer ecosystems is that groundwater environments within unconsolidated alluvial and fractured rock aquifers (as well as karstic aquifers) harbour a dynamic and diverse range of invertebrate communities that are composed of most of the major taxonomic groups found in the surface water habitats. There is a marked bias towards the crustacean and oligochaete groups, Marmonier *et al,* 1993; Rouch and Danielopol, 1997; Sket 1999b; Danielopol *et al,* 2000. There are also several groups that have no surface water relatives. Botosaneanu, 1986, listed approximately 7,000 aquatic subterranean species worldwide, whereas, Culver *et al*, 1992, suggested there may be as many as 50,000 to 100,000 terrestrial and aquatic species world-wide.

In NSW there are currently more than 360 taxa that have been collected from approximately 60 percent of the known cavernous karst systems. In 1994 / 95, Eberhard and Spate, 1995, completed a major survey of cave macroinvertebrate fauna from over 130 caves. The results of this survey significantly increased the number of known subterranean fauna in NSW. Compared with the state of knowledge published prior to 1993, the number of orders was almost doubled (from 21 to 39), and the number of families recorded increased by almost two-thirds (from 61 to 161). Before 1993, 11 troglobitic species had been recorded, and this has since increased to 40 to 52 species, Thurgate *et al,* 2001. Most of these species are new to science.

Groundwater biodiversity, in general, exhibits several peculiarities including:

- A low number of lineages which are able to pass through the darkness barrier.
- A high proportion of either phylogenetic or distributional relicts as well as endemic species.
- Truncated food webs lacking primary producers, herbivores and obligate predators; ie. a general trend towards omnivory, Gibert and Deharveng, 2002.

Obligate or solely groundwater animals also have three major morphological characteristics that are compensation for anophthalmy; ie. lack of eyes, hypertrophy; ie. excessive development, of sensory organs and the presence of highly developed chemical and mechanical receptors, Gibert *et al,* 1994.

The relatively new field of phreatobiology; ie. the study of subterranean ecosystems, has its own unique terminology and classification. Groundwater faunal communities consist of species with varying degrees of adaptation to the subterranean environment.

Information available on the distribution of stygofauna within NSW aquifers is both sparse and scattered. The particular aquifer types that need to be surveyed are alluvial, fractured rock, including Limestone karst units, across the state. Further work needs to be conducted, particularly in the shallow unconsolidated aquifers.

2.1. Karst and caves

Caves and karsts are natural cavities in rock, which acts as a conduit for water flow between input points, such as stream sinks, and output points, such as springs or seeps, White, 1984, see Appendix 2 – Figure 1.

Karst is a specialised form of cave terrain with distinct landforms and drainage characteristics. Caves are referred to as 'Karsts' where they are formed by the greater solubility of certain rocks in natural waters than is common, Gillieson, 1996. Most karsts form commonly in limestone and other carbonates such as dolomite, however also include evaporites such as gypsum and halite, silicates such as sandstone and quartzites, and in some basalts and granites, Gillieson, 1996. 'Caves', in general, can form in many other rock types, and by many other processes other than solution, such as weathering, hydraulic action, tectonic movements, melt water and the evacuation of molten rock (lava), where they are referred to as 'pseudokarsts', Gillieson, 1996, Jennings, 1985.

The karsts of Eastern Australia are not uniformly distributed across the landscape. Instead they form a series of scattered outcrops that are concentrated in the southeast of Eastern Australia. Most of the Eastern Australian Karsts are of small size with limited surface expression. Small tower karsts are present in the North Coast region. These were developed in the Cretaceous, Osborne and Branagan, 1988. This region is the transition zone between the tropical karsts of Northern Australia in areas such as the Einasleigh Uplands and the Mitchell Grass Downs Region, and the temperate karsts of South-East Australia. There are approximately 90 small karst area widely scattered in the south Western Slopes, South East Highlands and the Australian Alps Regions of NSW. Often these are ancient karsts, some of which developed in the Permian, Osborne and Branagan, 1988. These are impounded karst areas, that is, they are surrounded by higher lying non-carbonated terrains so the groundwater systems are generally small and discontinuous.

Karst and cave ecosystems include aquatic ecosystems that occur within voids and cavities within limestone deposits as well as the terrestrial ecosystems that occur in the dry (high humidity) parts of caves. The aquatic ecosystems contain a specialised fauna that are adapted to live in perpetual darkness and are totally dependent on groundwater. The ecosystem / organisms are: often highly specialised in their morphology and physiology; highly endemic; and often of ancient lineage. Hollingsworth *et al*, 2008, divide karst and cave environments into four subtypes as outlined below:

Freshwater limestone / carbonate karst

In most cases, carbonate karst is produced by chemical dissolution by slightly acidic water on a soluble layer of bedrock, notably limestone or dolomite. Carbonate karst is a terrain with distinctive hydrology and landforms arising from the combination of high rock solubility and well-developed secondary porosity. Groundwater flow velocities typically are much faster here than they are in porous media, contaminant attenuation mechanisms typically are much less effective, and flow tends to be anisotropic and heterogeneous, Hollingsworth *et al*, 2008.

Evaporite karst

Evaporite karst is similar to Carbonate karst in that dissolution is the dominant process, but unlike Carbonate karst, the very high solubility of evaporite minerals produces highly-mineralized ground water. Environments and ecosystems in rvaporite karsts would be expected to contain organisms that are more tolerant of dissolved solutes. The most common of these lithologies include gypsum, anhydrite, and halite, Hollingsworth *et al,* 2008.

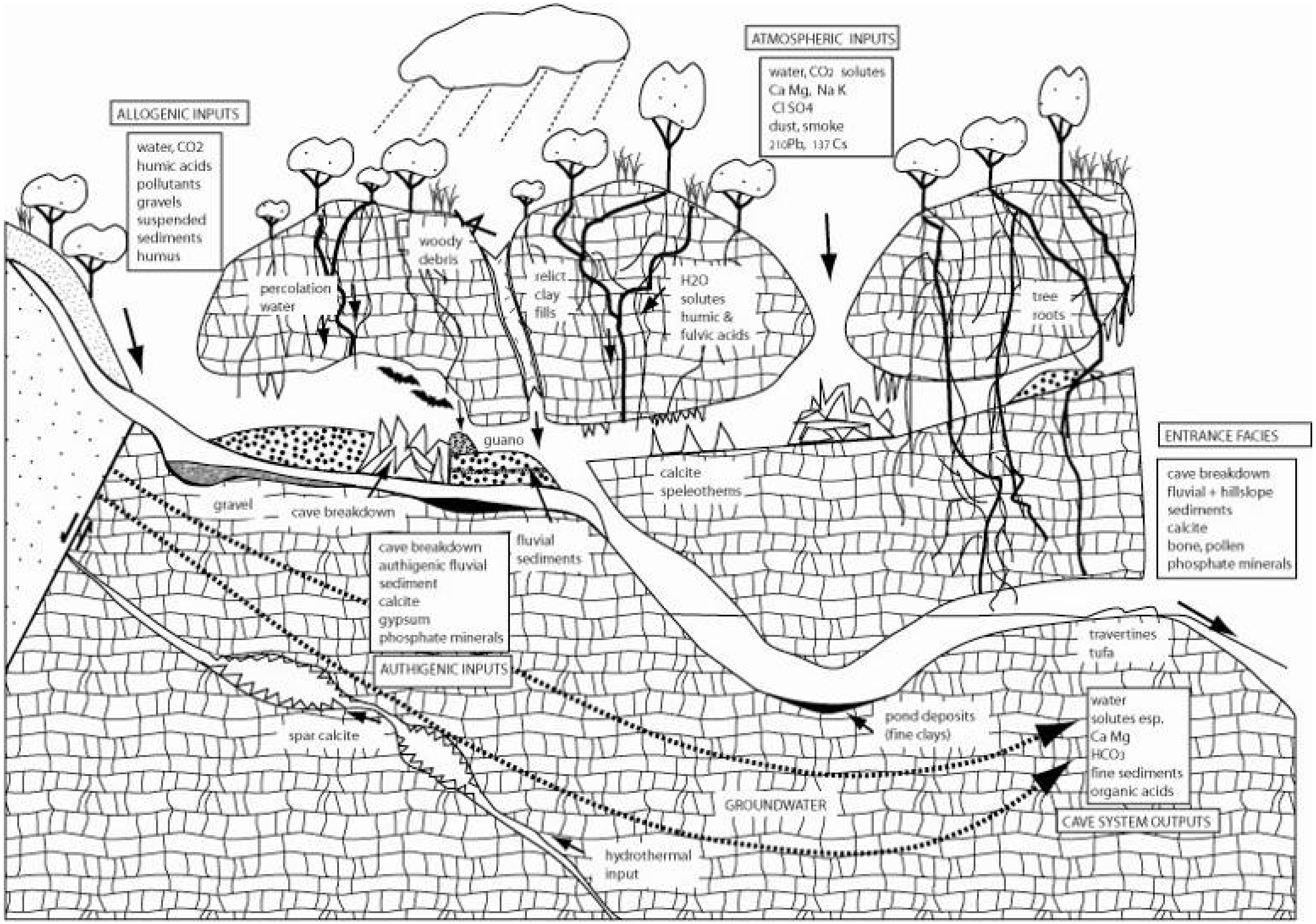
Anchialine (marine) caves

Anchialine caves consist of haline waters, usually with a restricted exposure to the open air, and always with more or less extensive connections to the sea and showing noticeable marine as well as terrestrial influences. Anchialine waters are usually polyhaline or euhaline, but can also be mesohaline or hyperhaline, Stock *et.al,* 1986.

Non-carbonate caves in pseudokarsts

Pseudokarst is an environment or setting that resembles karst, but where solution is not a critical formative process to produce cavities, isolated voids or connected passages or tubes, such as lava tubes. The subsurface environment in these areas is similar in many ways to other types of caves, but because they were formed by processes other than dissolution, groundwater flow, water quality, and environmental factors typically are distinct, Hollingsworth *et al,* 2008.

Appendix 2 – Figure 1. Cave System



Source: Gillieson, 1996.

2.2. Subsurface phreatic aquifer ecosystems

An aquifer is an underground layer of permeable (porous) rock, sediment (usually sand or gravel), or soil that contains a saturated zone of water. The pore spaces in aquifers are filled with water and are interconnected so that water flows through them. Sandstones, unconsolidated sediments such as gravels, and porous (fractured rocks and solution voids) lime stones make the best aquifers. They can range from a few square kilometers to thousands of square kilometers in size.

The ecosystems associated with aquifers consist of invertebrate, microbial and (rarely) vertebrate species and communities and are characterised as being: generally highly specialised in their morphology physiology; highly endemic; and often of ancient lineage. This category comprises the aquatic ecosystems that can be found in free water within aquifers and can support a large biodiversity. Hypogean life exists in a continuum through different types of karstic, cave, porous and fissured aquifers. Some ecosystems; eg. in riverine plains, exist along a continuum between fully aquatic (surface water) communities and fully aquifer (subsurface water) communities. Aquifer ecosystems are not necessarily confined to near surface environments. Stygofauna (animals occupying cave or aquifer habitats) have been identified at depths of up to 600 m. Many aquifer ecosystems have developed in very stable environments. Subtle changes in groundwater quality due to contamination by agricultural chemicals or septic tank effluent may result in changes in ecosystem function.

There is five broad types of groundwater aquifer systems in NSW, each have associated dependent ecosystems, Department of Land and Water Conservation, 2002.

Unconsolidated alluvial groundwater systems

Groundwater that occurs in unconsolidated sediments associated with rivers. These groundwater systems occur under the floodplains of rivers west and east of the Great Dividing Range. Groundwater in these systems can be very shallow and can occur within a few metres below the ground surface and extend to over 100 m. These groundwater systems are often in direct connection with surface water bodies such as rivers and wetlands. Groundwater within these systems can support terrestrial vegetation, wetlands, hypogean ecosystems as well as base flow river systems and riverine hyporheic ecosystems (the zone within the river bed).

GDEs are found also in palaeovalleys. Palaeovalley alluvials represent remnants of river channels that are associated with prehistoric drainage basins. Although surface water no longer flows in most palaeovalleys, the sediment which has filled these old river channels still retain recharge and storage capacity. These aquifers are capable of storing significant quantities of groundwater which can support a variety of GDEs. Palaeovalley aquifers are limited by their shallow depth (typically < 50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of the palaeovalley, Magee and Geoscience Australia, 2009.

Unconsolidated coastal sand bed groundwater systems

There are significant coastal sand bed groundwater systems along the coast of NSW. These systems are highly permeable and easily recharged through rainfall. The groundwater within these systems supports wetlands; eg. back dune and window wetlands, terrestrial vegetation, baseflow streams and hypogean ecosystems.

Consolidated fractured rock groundwater systems

In NSW, all outcropping and sub-cropping rocks contain a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater.

Known as fractured rock groundwater systems, they support base flows to rivers, wetlands, caves, terrestrial vegetation and hypogean ecosystems.

Consolidated porous sedimentary rock groundwater systems

Groundwater that is stored within porous sedimentary rock such as sandstone. Sedimentary rock aquifers support springs and soaks, hanging swamps, terrestrial vegetation, microbial hypogean ecosystems, and out flow riverine hyporheic zones and base flows.

Unconsolidated perched groundwater systems

Perched aquifers are spatially limited, small, shallow aquifers formed when the water percolation is interrupted by another confining layer (clays or rock) thus forming a saturated zone (aquifer) above the main regional water table. They are typically composed of unconsolidated material including fine to course grains sediments and organic deposits such as humus or peat. These systems are highly permeable and easily recharged through rainfall and seepage from porous or fractured rock aquifers. The groundwater within these systems supports wetlands; eg. upland headwater and valley fill swamps, hanging swamps, terrestrial vegetation, baseflow streams and hypogean ecosystems. Groundwater contained in these systems moves slowly downslope towards the downstream exit where it emanates as seepage and baseflow into the receiving drainage system, Planning Assessment Commission, 2009. Also included under perched aquifers are Palaeovalley alluvial sediments (see below).

Palaeovalley alluvial sediments

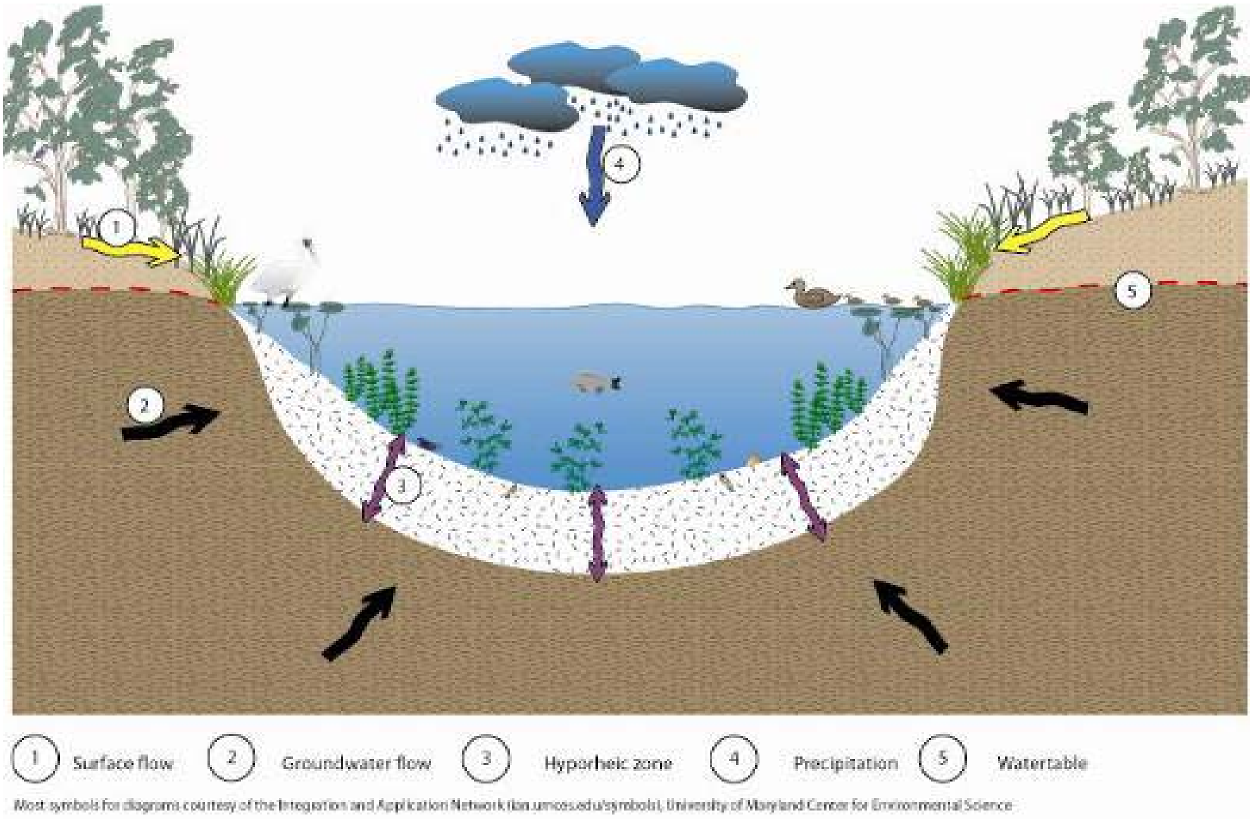
GDEs are found also in palaeovalleys. Palaeovalley alluvials represent remnants of river channels that are associated with prehistoric drainage basins. Although surface water no longer flows in most palaeovalleys, the sediment which has filled these old river channels still retain recharge and storage capacity. These aquifers are capable of storing significant quantities of groundwater which can support a variety of GDEs. Palaeovalley aquifers are limited by their shallow depth (typically < 50 m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of the palaeovalley, Magee and Geoscience Australia, 2009.

2.3. Baseflow streams (hyporheic ecosystems)

Streams can originate from a variety of sources including snow melt, overland runoff from precipitation, shallow subsurface flow through the unsaturated zone and from groundwater discharge. Of these processes, groundwater discharge usually is the least variable source of water to streams. The volume and sustainability of stream flow from headwaters and alluvial aquifers to downstream reaches commonly depend on contributions from groundwater. Even the groundwater contribution to streams can be variable depending on the hydrogeological and climatic settings of a stream. The determining factors that control the percentage of the groundwater contributions to a stream and the stability / variability of the groundwater input include the size of the groundwater reservoir or aquifer and its permeability. Streams that begin in extensive permeable aquifers generally have a stable point of origin and sustainable discharge from their headwaters and throughout the aquifer. In contrast, streams that begin as discharge from low permeable rock or sediments and rely on rainfall have a point of origin that moves up and down the catchment seasonally, have a highly variable discharge and commonly go dry. Nearly all streams need to have some contribution from groundwater in order to provide reliable habitat for aquatic ecosystems. Understanding the interactions between groundwater and surface water is fundamental to understanding and managing the chemical and biological characteristics of streams throughout their lengths.

River base flow ecosystems include a combination of subsurface and surface ecosystems depending on the structure of the river bed sediments. Groundwater base flow in sand-bed and gravel-bed rivers (Appendix 2 – Photograph 2) support both riparian vegetation and in-stream macrophyte communities, surface water aquatic invertebrate communities, and a specialised community of invertebrates (termed hyporheos) that exist below the river bed / substrate surface in the hyporheic zone (Appendix 2 – Figure 2).

Appendix 2 – Figure 2. Hyporheic zone within a streambed

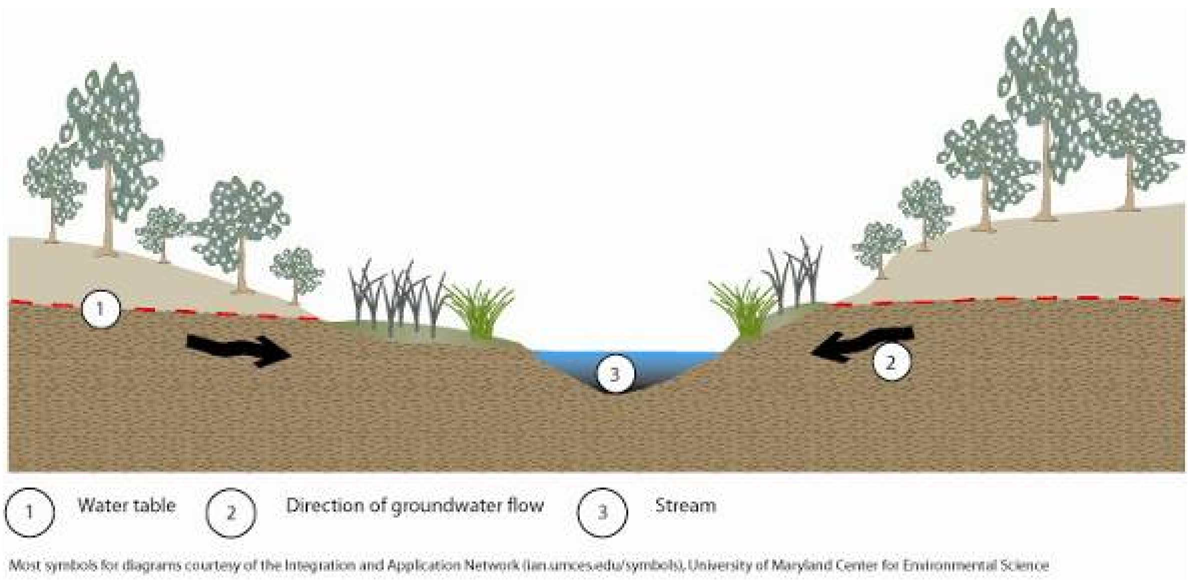


Most streams that drain the eastern and western margins of the Great Dividing Range originate as spring or seepage fed watercourses and has a significant groundwater baseflow component downstream. As with aquifers, only sparse and scattered information is currently available on the distribution of baseflow systems within NSW.

Appendix 2 – Photograph 2. Gravel bed river supported by baseflow

Base flow, by definition, is stream flow that is supported entirely by groundwater discharge, Wilson and Moore, 1998. Strong interactions between streams or rivers and the groundwater system are usually associated with shallow aquifers. If the water table or groundwater level in an aquifer is higher than the running level in a stream, groundwater will flow or discharge to the stream. In this case, the stream is defined as a 'gaining stream', and the groundwater discharge is called 'baseflow' (Appendix 2 – Figure 3).

Appendix 2 – Figure 3. Gaining stream



If the water table is lower than the running level in a stream, water will flow from the stream and recharge the groundwater. In this case the stream is defined as a ‘losing stream’, and the recharge to the groundwater is called ‘stream leakage’ and there is, therefore no baseflow component to the stream. Some parts of a stream may be gaining streams and others may be losing streams, and this may change over time, Evans, 2007.

In many cases, the majority of natural gains to stream flow during low-flow periods are derived from releases from groundwater storage. This occurs where stream channels intersect the main phreatic surface in a draining aquifer. For low flows to be sustainable the:

- draining aquifer must be recharged seasonally with adequate amounts of moisture
- water table must be shallow enough to be intersected by the stream
- aquifers size and hydraulic properties must be sufficient to maintain flows throughout the dry season.

River base flow GDEs occur in both intermittent and permanent flowing streams that have seasonal or continuous groundwater contribution to their water regimes, SKM, 2007. A stream can be either ‘disconnected’ from or ‘connected’ to the aquifer. The stream and the aquifer are considered to be ‘connected’ if there is no zone of unsaturated material between the stream and the water table. A ‘connected’ stream occurs when the water table level intersects the surface water body. Under these conditions the surface water body can be affected by changes in the water table level and/or the groundwater level in the aquifer, Evans, 2007.

The stream and the aquifer are considered to be ‘disconnected’ if:

- the water table level is below the base of the surface water body; ie. the water table level does not intersect the surface water body
- a zone of unsaturated material exists between the surface water body and the water table, Evans, 2007.

In this case, any changes in the water table level and/or the groundwater level in the aquifer will have little or no effect on the surface water body where the water table and water body are disconnected, Evans 2007.

The three type of stream flow regimes are outlined below.

1. **Perennial** – Flows are continuous because of recharge from groundwater or in areas of regular surface runoff regardless of weather conditions. During hydrological drought conditions, flow may be impaired. This is a characteristic of humid areas.
2. **Intermittent or seasonal** – Flows only at certain times of the year when water is received from springs or from some surface source such as melting snow in mountainous areas.
3. **Ephemeral** – Flows only in direct response to precipitation, and whose channel is at all times above the water table. Within the drier areas of NSW, the majority of rivers are ephemeral, most flow events occur in direct response to major rainfall and are frequently of short duration **and do not support GDEs**.

River flows can be maintained by groundwater which provides base flows long after a rainfall event. Baseflow typically emerges as springs or as diffuse flow from saturated sediments or rock underlying the stream and banks and may be crucial for instream and near stream ecosystems. For example, in river environments where sand and gravel beds predominate, the area where water exchange between the surface and groundwater aquifers occurs can be an important habitat for many invertebrates. Groundwater base flow in sand and gravel bed rivers can support riparian vegetation (Appendix 2 – Photograph 3). as well as instream macrophyte communities. Other ecosystems supported by baseflow systems can include surface water aquatic invertebrate and vertebrate communities and specialised communities of invertebrates (termed hyporheos) which occur below the substrate surface (hyporheic zone).

Many surface aquatic macroinvertebrates and aquatic vertebrate species rely on base flows for a variety of functions such as:

- reproduction by utilising the stable flow either within the surface substrate or through the hyporheic zone to lay eggs
- a crèche environment for larvae / juvenile stages of macroinvertebrates
- a refuge zone during periods of extreme flows (both low and high flows)
- a supply of nutrients from upwelling zones.

Appendix 2 – Photograph 3. Base flow fed stream (Blue Mountains)

The role of groundwater in supporting flora and fauna will vary spatially along watercourses according to local aquifer recharge and discharge processes.

Sparse and scattered information is currently available on the distribution of base flow systems within NSW. Many rivers and streams on both the eastern and western sides of the Great Dividing Range along south-eastern Australia are maintained by base flow throughout the year and support riparian forests, scrub, sedgelands, grasslands and wetlands as well as in-stream biota and floating and emergent herbfields, Hatton and Evans, 1998. Riparian and aquatic ecosystems in base flow dependent streams would be, to a greater or lesser extent, groundwater dependent themselves. It also contributes significantly to chemical and nutrient processing within the subsurface downwelling and upwelling zones.

3. Surface groundwater dependent ecosystems

3.1. Groundwater dependent wetlands

As an ecosystem, wetlands can be difficult to define. This complexity is reflected in the large number of wetland definitions and classification schemes.

Wetlands have seasonally or perennially saturated soil profiles. The saturation may be caused by ponding of surface flows or flooding, or by groundwater discharge (Le Maitre et al, 1999). Wetlands that depend on groundwater can be ephemeral or permanent systems that have a continuous or seasonal connection with groundwater, Howes *et al,* 2007.

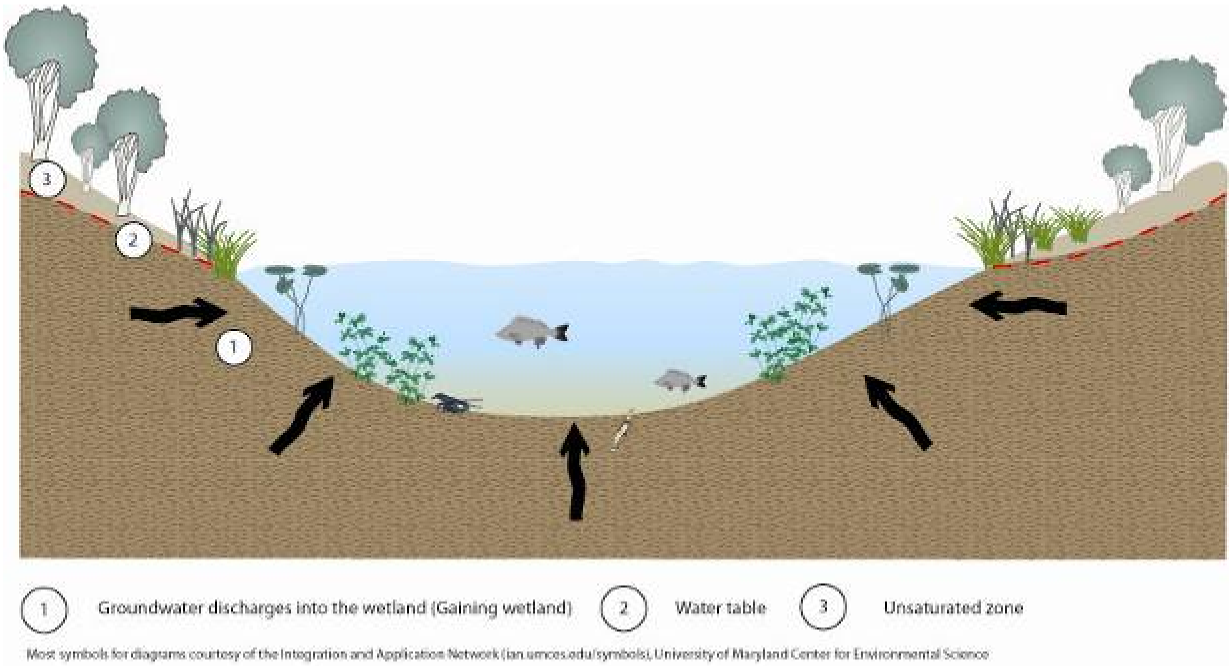
Groundwater dependent wetlands are defined within this document after Paijmans et al, (1985) as land permanently or temporarily under water or waterlogged with a known or likely component of groundwater discharge in their hydrologic cycle. Temporary groundwater dependent wetlands are defined after Marshall *et al*, 2006, as wetlands that have groundwater derived surface water and is waterlogged (with that water) with sufficient frequency and / or duration to affect the biota (within that wetland).

If the presence of groundwater is essential to the biota of a wetland and their ecological processes, then that wetland is groundwater dependent, Parsons, 2009. Even small amounts of groundwater can have important ecological implications, with small seepages supporting unique plant and animal communities. The discharge of nutrient rich groundwater can determine the type and abundance of macrophytes, although the specific chemical or physical processes determining macrophyte distribution are uncertain, Hayashi and Rosenberry, 2002.

Groundwater dependent wetlands exist at the boundary between surface and groundwater systems. They facilitate the flow of water between the groundwater system and the surface-water system. Groundwater interactions with wetlands can be grouped into three categories that focus on the gains and losses of water between the two systems. These categories are:

- **Losing or recharge systems**
  - Water seeps from a wetland into the groundwater.
- **Gaining or discharge systems**
  - Water leaves the groundwater system and enters the surface waters of a wetland (Appendix 2 – Figure 4).
- **Flow-through systems**
  - Water seeps through the upslope side and base of the wetland, and seeps back to the groundwater from the down slope side of the wetland.

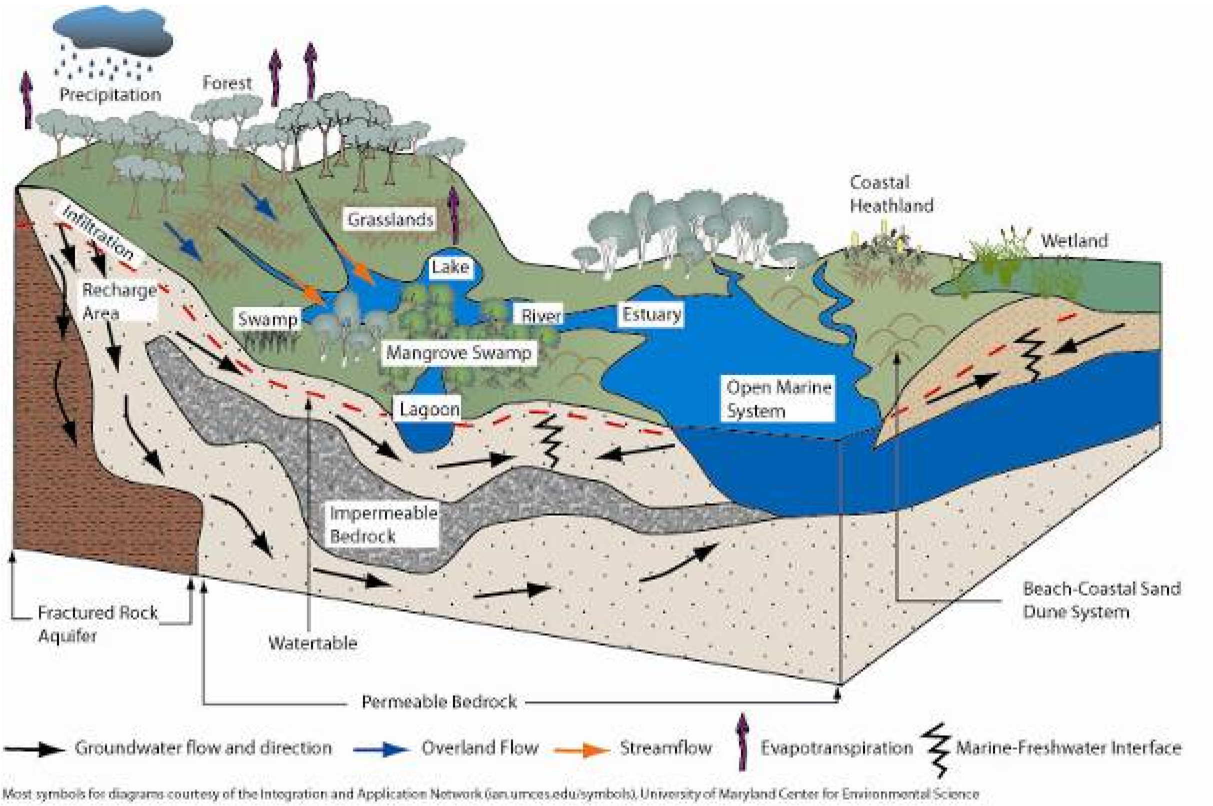
Appendix 2 – Figure 4. Gaining regime



Adapted from McEwan *et al,* 2006; Jolly et al, 2008.

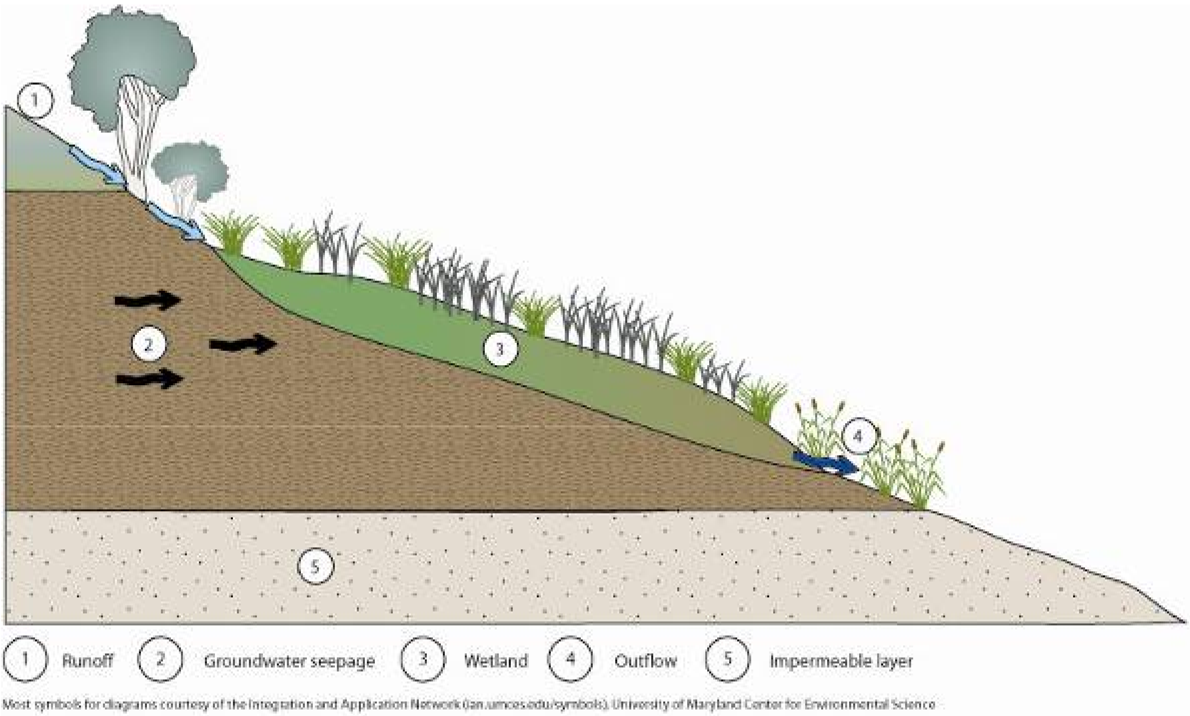
Groundwater dependent wetlands occupy positions in the landscape where factors such as topography, geology and landform allow groundwater discharge to concentrate, Cole *et al*, 1997, see Appendix 2 – Figure 5.

Appendix 2 – Figure 5. Wetlands occupying various topographic positions in the landscape



Groundwater dependent wetlands can be found in the mountains, on the plateaus and high plains, in river valleys and in coastal lowlands. Topographic depressions, slope breaks (Appendix 2 – Figure 6), areas of stratigraphic change, geological faulting, floodplains and other low land landscape areas are all examples of major hydrogeological settings that favour wetland formation, Dear and Svensson, 2007.

Appendix 2 – Figure 6. Slope westland



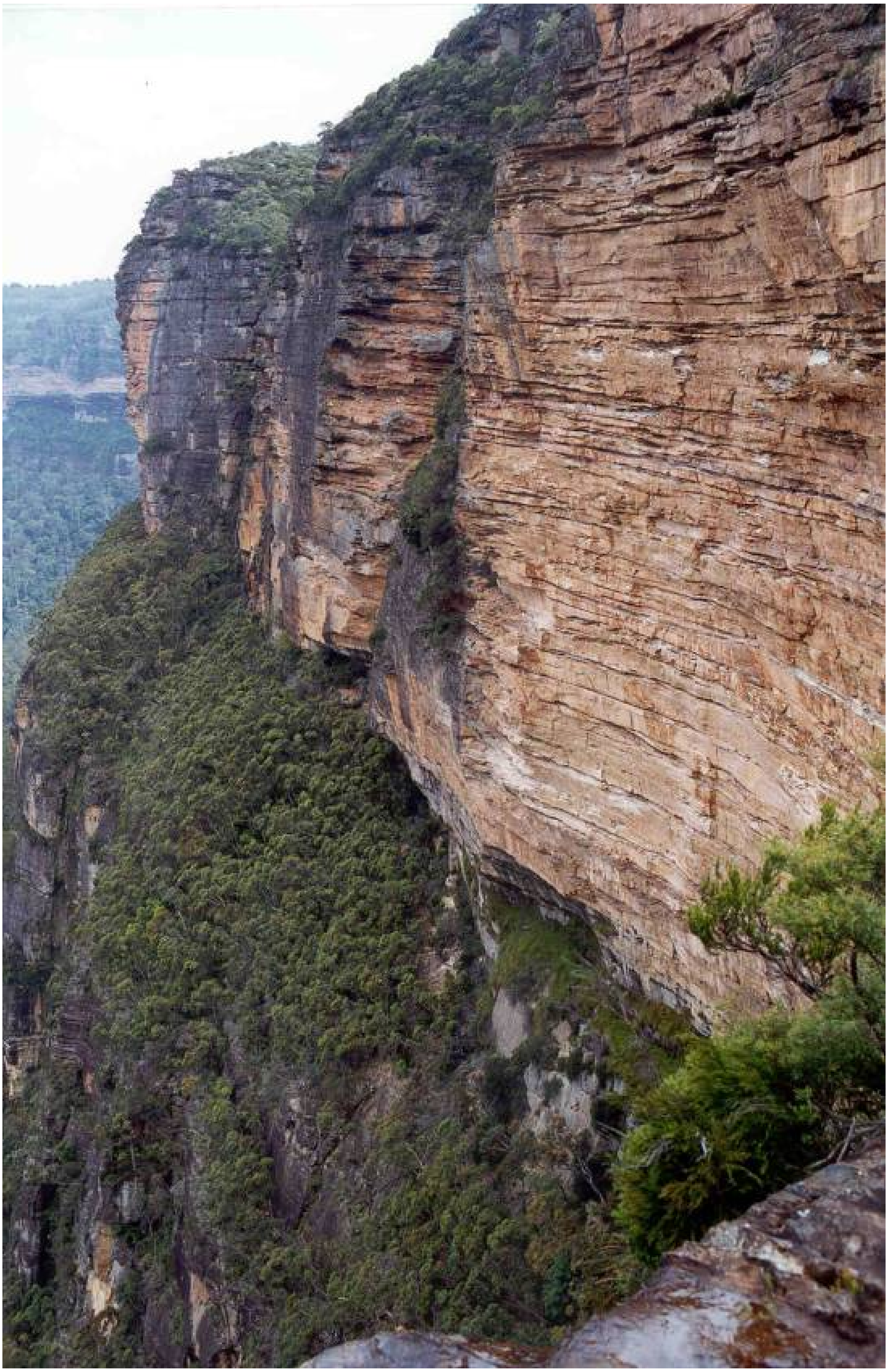
Adapted from Brinson 1993.

Hatton and Evans, 1998, consider wetlands to be the most extensive and diverse set of potentially dependent ecosystems in Australia. Examples of groundwater dependant wetland ecosystems include paperbark swamp forests and woodlands (found on coastal dunes and coastal and river floodplains), swamp sclerophyll forests and woodlands (along riparian corridors of ephemeral or base flow dependent streams), swamp scrubs and heaths (coastal dunes and swampy areas) and swamp shrub lands, sedge lands (coastal, floodplain and valley floor environments, SKM, 2001; Hatton and Evans, 1998. Other wetlands such as springs and cave and karst wetlands are groundwater fed while rock pools and water holes and some arid zone wetlands are surface and groundwater fed.

Many inland wetlands exhibit occasional or seasonal dependency on groundwater. In the context of this document, potential types of groundwater dependent wetlands within inland environments include marshes and wet meadows dominated by herbaceous plants, swamps dominated by shrubs, and wooded swamps dominated by trees as well as lakes, billabongs, wetlands and waterholes. These wetlands are most common on the floodplains along rivers and streams (riparian wetlands), in isolated depressions surrounded by dry land, along the margins of lakes and ponds, and in other low-lying areas where groundwater may intercept the soil surface or where precipitation sufficiently saturates the soil. Although many of these inland wetlands rely on frequent and complex flooding across the floodplain, groundwater can be accessed as an alternative water source.

Groundwater dependent wetlands within upland environments can include shallow marshes, sedge swamps, hanging swamps (Appendix 2 – Photograph 4) wet heaths, peat swamps, seeps and soaks. These wetlands are commonly known as upland swamps.

Appendix 2 – Photograph 4. Seeps and hanging swamps – Blue Mountains



An upland wetland or swamp is a vegetated freshwater area occurring in shallow basins or depressions (Appendix 2 – Photograph 5) located in low hills or mountainous regions, usually adjacent to the tablelands, Department of Environment, Climate Change and Water, 2010b. They include any vegetated wetland on the coastal or inland plains (apart from arid wetlands) that fill through a local catchment, from groundwater or rainfall (that is, they are not subject to flooding from a river, DECCW, 2010b. These wetlands can hold water permanently or fill and drain on a seasonal basis, Bell *et al,* 2008. Water moves through these wetlands as groundwater, in narrow deep channels or across the surface in wide shallow channels floored by depressions. The oxidised humic peat at depth can have low hydraulic conductivity. This can result in the water being 'perched' or disconnected from the general water table, Hope *et al,* 2009. Discharge regimes within this wetland type are common, the groundwater system recharged in the upper reaches of a catchment and discharged to wetlands located in topographical lows. Flow through regimes can dominate in areas where swamps have developed on sloping and elevated areas, Bish and Gates, 1997.

Appendix 2 – Photograph 5. Upland swamps, Bendemeer

Coastal wetlands can be subdivided into non-tidal and tidal wetlands, many of which depend on groundwater or a combination of surface and groundwater. These wetlands can include forested wetlands (Appendix 2 – Photograph 6), some floodplain wetlands, freshwater lagoons, sedgelands and heath/shrub swamps, salt marsh, mangroves and sea grass beds.

Appendix 2 – Photograph 6. Forested wetlands on a coastal plain

3.2. Baseflow streams (surface ecosystems)

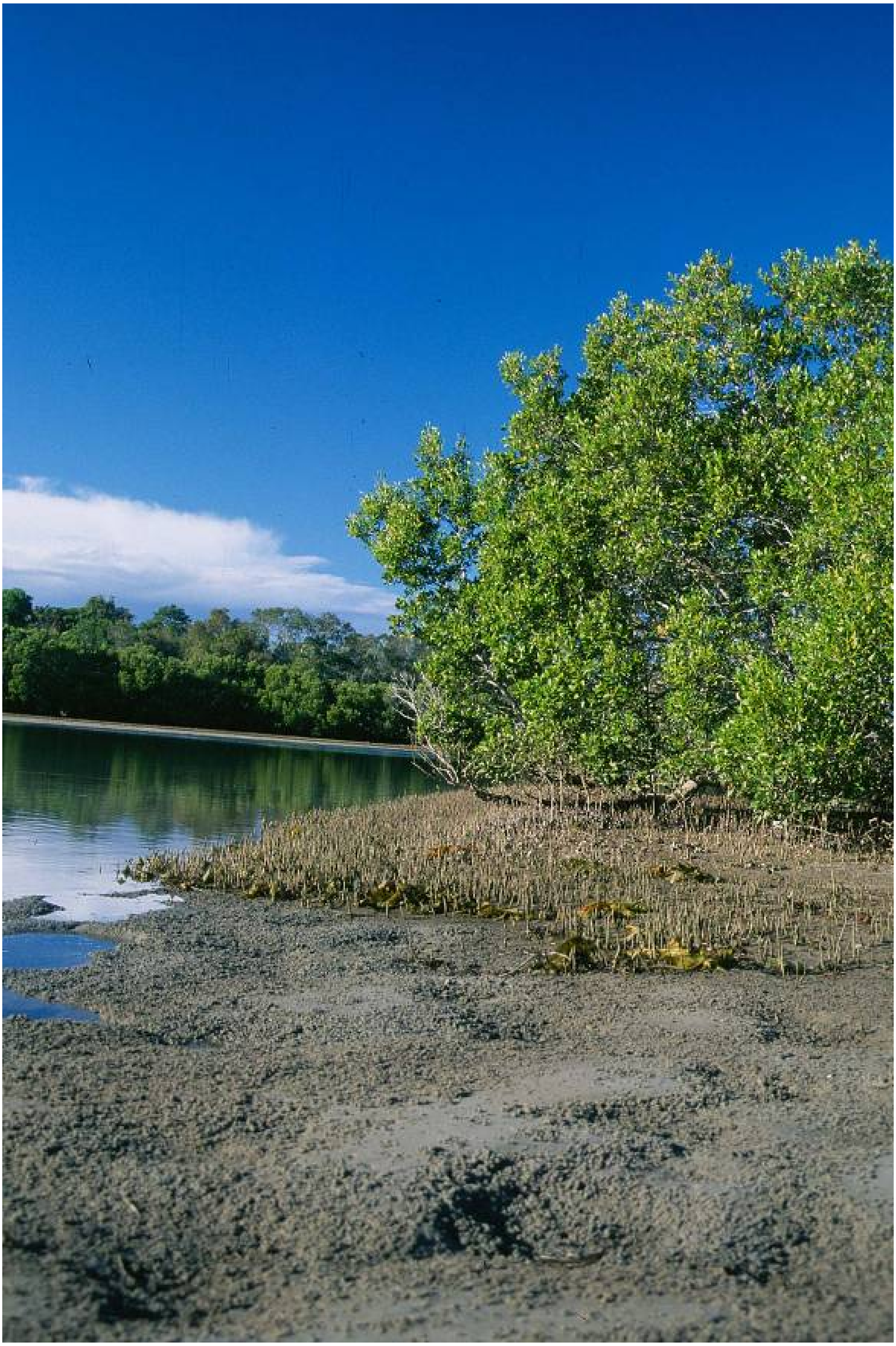
Baseflow crosses the groundwater / surface water ecotone boundary. It supports surface and subsurface riverine ecosystems by providing a permanent water source as either surface flow, flow within the sub-surface, or permanent 'refugia' pools that provide refuge in times of low flow, particularly during summer and in arid and semi-arid areas. This enables a far greater diversity of biota to exist (both within surface water bodies, macrophytes as well as terrestrial /riparian vegetation). It is for this reason that this ecosystem type has been included twice in the GDE classification scheme (Appendix 2).

Baseflow typically emerges as springs or as diffuse flow from saturated sediments or rock underlying the stream and banks and are crucial for maintaining instream and near stream ecosystems. The coastal rivers of south-eastern Australia maintain base flow throughout the year and support riparian forests, scrub, sedgelands and grasslands, as well as in-stream biota and floating and emergent herbfields, Hatton and Evans, 1998. Riparian and aquatic ecosystems in base flow dependent streams will be, to a greater or lesser extent, groundwater dependent themselves.

3.3. Estuarine and near shore marine ecosystems

Estuarine and marine environments often contain an extensive range of GDEs (see Appendix 2 – Figure 5), the result of these ecosystems being situated at the end of drainage systems and the discharge area for aquifers. They can be separated from coastal wetlands by the reliance on seawater and tidal influences and can include coastal mangroves (Appendix 2 – Photograph 7) and salt marshes, coastal lakes, sea grass beds and marine animals.

Appendix 2 – Photograph 7. Mangrove ecosystems

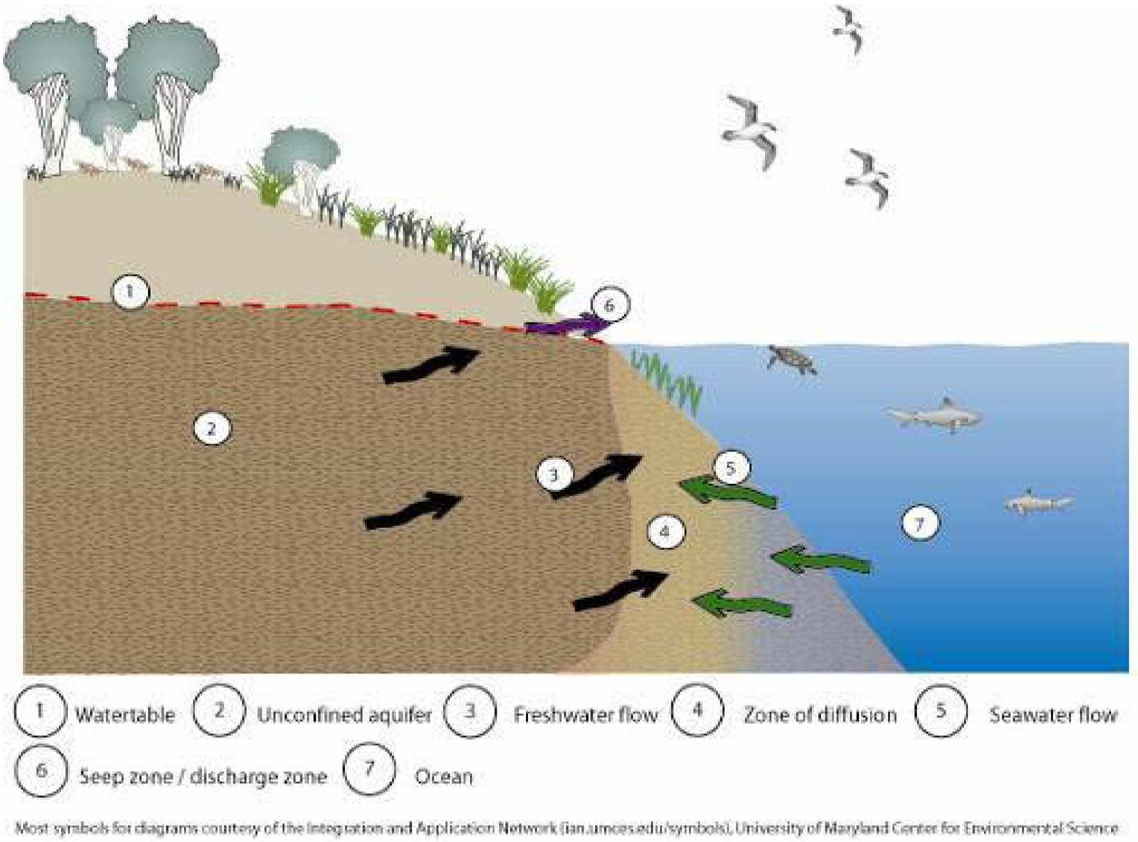


Groundwater reaches coastal environments either by direct discharge or as baseflow in the streams and rivers that drain coastal areas. The inter-tidal and near-shore sub-tidal zones are zones of maximal groundwater discharge, Reilly and Goodman, 1985. Given this, it is logical to assume that many of the habitats located within these zones could potentially be dependent on groundwater for survival.

Estuaries, the location of many estuarine and near shore marine GDEs, are the recipients of almost all of the runoff and groundwater flow yielded by a catchment. Very little surface or groundwater flow enters the ocean directly via the coast. It is the rivers that act as the primary drainage system of a catchment, and, as the rivers enter the coastal zone, they become estuaries. During periods of high rainfall, groundwater systems are recharged from the rivers or by surface percolation and, during periods of low river flow, the same groundwater systems discharge to the rivers.

Coastal aquifers consist of two distinct groundwater zones: an upper fresh water zone and a lower saltwater zone. The fresh and salty groundwater is typically separated by a transition zone where non saline and saline groundwater mix, Pell *et al,* 2004. Groundwater discharge to estuaries or the beach shoreline occurs where an aquifer saltwater-freshwater interface intersects the land surface (Appendix 2 – Figure 7). The fresh water flowing to the ocean mixes with the saltwater, with fluctuations in the transition zone caused by daily fluctuations in the tide, season or annual variation in groundwater water recharge rates and changes in sea levels, Pell *et al,* 2004. Pin pointing groundwater discharge to coastal environments can be quite complex. This is largely due to the presence of strong density gradients between seawater and freshwater and the confounding effect of tides, Lamontagne *et al,* 2005. The presence of density gradients along the coastal zone tends to focus groundwater discharge along the shoreline, as denser seawater tends to intrude inland as a salt water wedge under fresher groundwater, Lamontagne *et al,* 2005. Salt water wedges under fresh groundwater can extend for kilometres inland, especially when pumping of fresh groundwater occurs.

Appendix 2 – Figure 7. Groundwater flow into an unconfined coastal aquifer



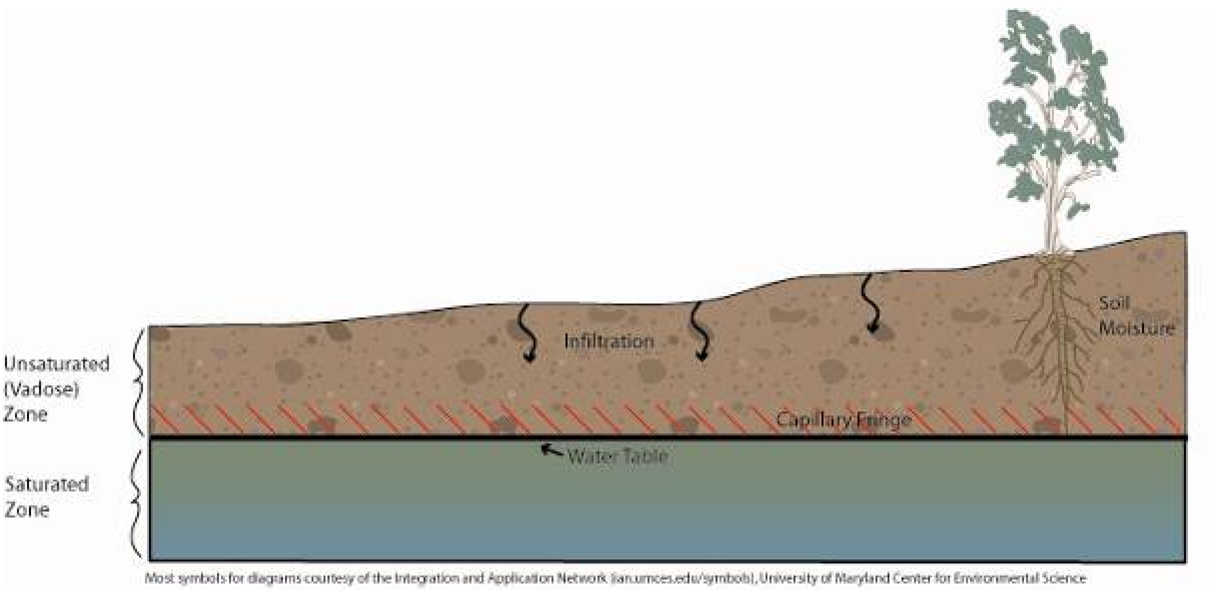
Groundwater interacts with and affects coastal ecosystems in a number of ways. Groundwater discharge can sustain flow and the aquatic habitats of coastal streams during periods when surface runoff is low. Dissolved chemical constituents, discharged with groundwater, can affect the salinity and geochemical budgets of coastal ecosystems, thereby playing a role in the biological species composition and productivity of these systems (http:// www.ozestuaries.org). It is recognised within the scientific literature that fresh groundwater discharge or submarine groundwater discharge (SGD) can have a significant impact and influence on the ecology of estuarine and near shore environments, Johannes, 1980; Valiela *et al,* 1990; Simmons, 1992; Moore, 1996; Hatton and Evans, 1998; Kamermans *et al,* 2002; Burnett et al, 2003. Local and regional surface and groundwater exchanges play a vital role in maintaining and sustaining estuarine wetlands, mainly through controlling the availability and flow of water, Hayashi and Rosenberry, 2002. Coastal mangroves, salt marsh and seagrass beds are known to occupy areas of fresh groundwater discharge (SKM, 2001; PPK 1999), while some marine and estuarine animals depend on this discharge to provide an appropriate environment in which their prey can prosper, Hatton and Evans, 1998; SKM, 2001. Seep zones are often associated with unique and important marginal marine and inter-tidal biological communities of high productivity, Johannes and Hearn, 1985.

3.4. Phreatophytes – Groundwater dependent terrestrial ecosystems

Processes that terrestrial vegetation can depend on groundwater for can include flowering, seed set and germination, seedling establishment and recruitment, Froend and Loomes, 2006.

Groundwater dependent or phreatophytic vegetation, Naumburg *et al,* 2005, does not rely on the surface expression of water for survival, SKM, 2001. It instead depends on the subsurface presence of groundwater, often accessed via the capillary fringe; ie. the subsurface water just above the water table that is not completely saturated, Eamus *et al,* 2006 (Appendix 2 – Figure 8). The soil water in this zone is readily available to plant roots. As water is removed by transpiration it is continually replenished from the water table through capillary rise.

Appendix 2 – Figure 8. The Vadose zone or capillary fringe



Phreatophytes are plants that meet their water demand by water uptake from the groundwater or its capillary fringe. Terrestrial vegetation will extract water from:

1. the saturated zone below the water table by direct uptake
2. indirectly from the water table via the capillary effect
3. the soil profile immediately above where groundwater has moved upwards by capillary rise; ie. the unsaturated (moist) soil above the water table.

Vegetation will extract water from those sources where the combination of soil moisture content, root density and hydraulic connectivity requires the least amount of energy. This means that vegetation will use shallow soil water before seeking deeper soil water or groundwater, Eamus and Froend, 2006. Trees mostly take up groundwater from the capillary fringe. Direct uptake by from the water table is not thought to be common as it is difficult for roots to grow and function under saturated conditions, as oxygen is required for plant respiration.

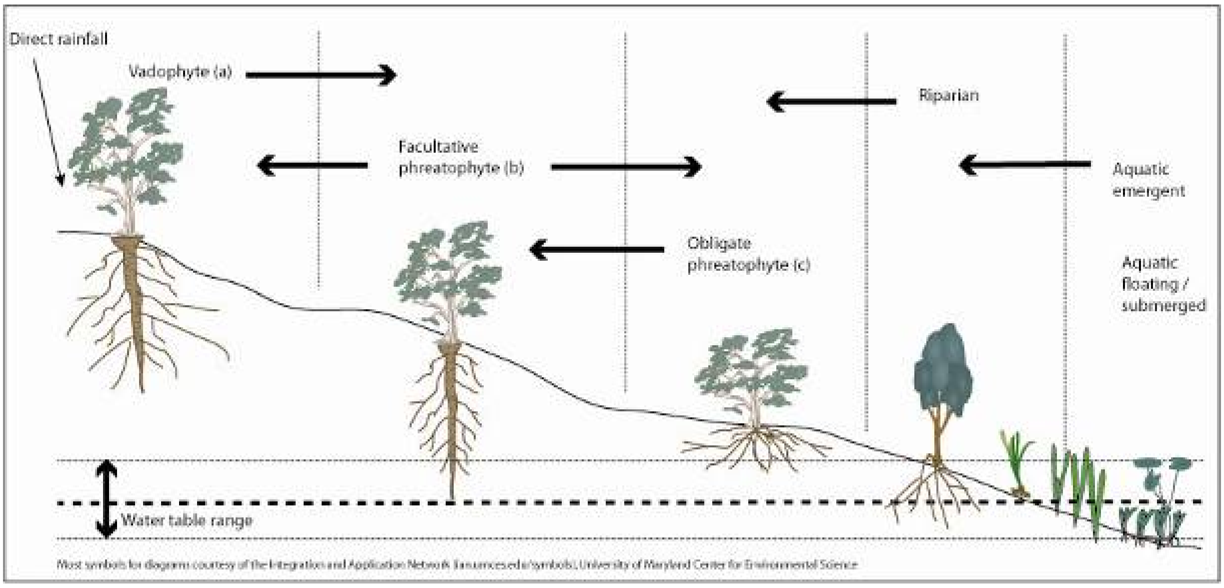
Phreatophytes include both deep and/or shallow rooted vegetation communities. Forests and woodlands can rely on groundwater for survival, particularly in areas of shallow groundwater (Appendix 2 – Photograph 8). Examples occur both on the coast; eg. Melaleuca communities, Blackbutt or Sydney Redgum forests on sand dunes), in some types of hilly country; eg. rainforest plants along spring-fed creeks. and inland; eg. River Red Gums along river banks and on floodplains. Many plant species depend on groundwater for survival in water limiting environments; eg. arid and semi-arid areas as well as some sub humid regions. Plants within water limiting environments are efficient at finding water, each species having their own strategies for accessing water.

Appendix 2 – Photograph 8. Tree roots accessing shallow groundwater at the edge of a baseflow fed creek, Blue Mountains, Klang Canyon, NSW

The degree of groundwater dependence can vary, the literature indicating seasonal variability in both the quantity of groundwater used and the relative importance of groundwater as a water source, Zencich *et al*, 2002. For many plant species, groundwater use is highest during dry seasons when alternative water sources are depleted and transpirational demands are high. Groundwater dependency can range from total reliance to a proportional, opportunistic use of groundwater (Appendix 2 – Figure 9). In many cases, plants that have an opportunistic dependence will be groundwater dependent in some environments, but not in others.

Some phreatophytes will only inhabit areas where they can access groundwater, via the capillary fringe, to satisfy at least some proportion of their water requirement. Other phreatophytes will only use groundwater if it is available; ie. inhabit areas where their water requirements can be met by soil moisture reserves. In these circumstances, the dependence of the species on groundwater is therefore a function of the hydrogeologic setting of the ecosystem which determines whether or not a shallow water table exists that species can access (Appendix 2 – Figure 9). These plants will therefore be groundwater dependent in some environments, but not in others. The dependency of and the degree of adaptation of phreatophytes to using groundwater is directly related to the security of the resource; ie. the permanence and ease of access to the water source.

Appendix 2 – Figure 9. Relationship between vegetation and access to groundwater



Source: Pettit et al, 2007 cited in Pritchard et al, 2010.

a. Species that relies on soil moisture within the vadose zone.
b. Species for whom groundwater dependence is opportunistic; eg. seasonal, extended drought periods.
c. Species that depend entirely on groundwater.

Phreatophytes that will only grow in areas where specific groundwater conditions exist are less resilient to changes in the groundwater condition than those plants whose water requirements can be met by soil moisture. As a whole, those species that inhabit areas where access to groundwater is not critically important for species persistence in the landscape are more resilient to changes in groundwater condition, Pritchard *et al,* 2010.

Demarcation between groundwater dependent terrestrial vegetation, wetlands and base-flow-dependent systems can be difficult, with the three community types often representing a spectrum of habitat, Schofield *et al,* 2003. In artesian areas, where pressure bring water to the surface, groundwater is able to support shallow-rooted vegetation communities, Fensham and Fairfax, 2003, many of which are endemic and under threat (Appendix 2 – Photograph 9).

Appendix 2 – Photograph 9. Artesian spring

Streamside eucalypts; eg. *E. camaldulensis*, along inland (frequently dry) baseflow rivers and streams in the arid zone as well as swamp sclerophyll woodlands, paperbark swamp forests (wetlands) are highly dependent on groundwater.

Although not previously understood to be GDEs, Froend and Loomes, 2006, argue that the direct interaction of woodlands (native remnants and plantation) with groundwater (see Benyon *et al,* 1999; George *et al,* 1999; Vertessy *et al,* 2002) justifies their categorisation as a GDE (cited in O'Grady *et al,* 2007). Research by Cramer and Hobbs, 2002, also suggests that remnant communities may play an important role in regional hydrology.

Appendix 2 – Table 1. Groundwater dependent ecosystem classification guide

Type	Subtype 1	Subtype 2	Subtype 3
Subsurface ecosystems			
Karst / caves ecosystems	Freshwater limestone / carbonate caves.	Not identified.	Not identified.
	Evaporite caves.	Not identified.	Not identified.
	Anchialine (marine) limestone caves.	Not identified.	Not identified.
	Non carbonate caves in pseudokarsts.	Not identified.	Not identified.
Subsurface phreatic aquifer ecosystem	Unconsolidated alluvial aquifers	Palaeochannels	Not identified.
		Unconsolidated Alluvial Aquifers	Not identified.
	Unconsolidated coastal Sandbed aquifers.	Not identified	Not identified.
	Consolidated fractured rock aquifer.	Not identified.	Not identified.
	Consolidated porous sedimentary rock aquifer.	Not identified.	Not identified.
	Unconsolidated perched aquifers.	Not identified.	Not identified.
	Palaeovalley alluvial sediments.	Not identified.	Not identified.
Baseflow streams (hyporheic ecosystems)	Perennial rivers and streams.	Subsurface hyporheic ecosystems.	Not identified.
	Intermittent rivers and streams.	Subsurface hyporheic ecosystems.	Not identified.
Groundwater dependent wetlands (hyporheic ecosystems)	Subsurface hyporheic ecosystems.	Not identified.	Not identified.
Estuarine and near shore marine ecosystems	Near shore marine.	Submarine springs – Wonky holes.	Not identified.
	Marine psammolittoral zone.	Interstitial habitat in sand, shingle or pebble beaches.	Not identified.
	Tidal wetland.	Intertidal sands and mudflats.	Not identified.
Surface ecosystems			
Groundwater Dependent Wetlands			
Inland environments	Inland freshwater floodplain swamps.	Not identified.	Not identified.
	Inland freshwater lakes and lagoons.	Inland billabongs.	Not identified.
		Freshwater lakes and lagoons.	Not identified.
	Inland freshwater springs.	Geothermal springs.	Not identified
		Inland springs and seeps.	Not identified.
	Inland rockpools and	Not identified.	Not identified.

Type	Subtype 1	Subtype 2	Subtype 3
	waterholes		
	Inland cave and karst wetlands.	Not identified.	Not identified.
	Arid zone wetlands.	Saline lakes and lagoons.	Not identified.
		Playa / dunal lakes.	Not identified.
Upland environments	Upland swamps.	Upland bogs and fens.	Not identified.
		Alpine/ montane bogs and fens.	Not identified.
		Upland hanging swamps.	Not identified.
		Alpine glacial lakes.	Not identified.
	Upland lakes and lagoons	Upland freshwater lakes and lagoons .	Not identified.
Coastal environments - Non tidal Freshwater Wetlands	Coastal freshwater wetlands.	Coastal floodplain swamps.	Not identified.
		Coastal heath swamps.	Not identified.
		Coastal dune swamps.	Not identified.
	Coastal lakes and lagoons.	Coastal lakes and lagoons.	Not identified.
Baseflow streams (surface ecosystems)	Perennial rivers and streams.	Surface water riverine ecosystems.	Continuous river.
	Intermittent rivers and streams.	Surface water riverine ecosystems.	Discontinuous river – Chain of pools.
Estuarine and near shore marine ecosystems			
Tidal wetlands	Mangrove wetlands swamps and forests.	Not identified.	Not identified.
	Saltmarsh.	Not identified.	Not identified.
	Seagrass beds and meadows.	Not identified.	Not identified.
Near shore marine	Macro and micro algal communities.	Not identified.	Not identified.
	Fringing reefs and rocky shores.	Not identified.	Not identified.
	Submarine springs – Wonky holes.	Not identified.	Not identified.
Phreatophytes – groundwater dependent terrestrial vegetation*	Not identified.	Not identified.	Not identified.

* Phreatophytes have not been subtyped.

** Some types do not have subtypes as they have yet to be separated into subtypes.

Appendix 3

Policy and legislative framework

1. Polices of relevance to GDE management and protection

The *State Groundwater Policy Framework* document (Department of Land and Water Conservation, 1997) encouraged the ecologically sustainable management of the State's groundwater resources so as to:

- slow and halt, or reverse any degradation of groundwater resources
- ensure long-term sustainability of the systems' ecological support characteristics
- maintain the full range of beneficial users of these resources
- maximise economic benefit to the region, state and nation.

A set of three component policies fall under this framework and include the NSW Groundwater Quality Protection Policy, Department of Land and Water Conservation, 1998, NSW Groundwater Quantity Management Policy and the NSW Groundwater Dependent Ecosystem Policy, Department of Land and Water Conservation, 2002. Of particular relevance is the NSW State Groundwater Dependent Ecosystems Policy, Land and Water Conservation, 2002, which provides guidance on the protection and management of GDEs. It sets out management objectives and principles to:

- ensure that the most vulnerable and valuable ecosystems are protected
- manage groundwater extraction within defined limits thereby providing flow sufficient to sustain ecological processes and maintain biodiversity
- ensure that sufficient groundwater of suitable quality is available to ecosystems when needed
- ensure that the precautionary principle is applied to protect groundwater dependent ecosystems, particularly the dynamics of flow and availability and the species reliant on these attributes
- ensure that land use activities aim to minimise adverse impacts on ground dependent ecosystems.

State policies of relevance to wetlands, including those that are groundwater fed are The NSW Wetlands Management Policy, Department of Environment, Climate Change and Water, 2010a, and the State Environmental Planning Policy No. 14 – Coastal Wetlands (SEPP 14). There are also a number of international agreements that Australia has adopted which aim to protect wetlands which may be groundwater fed, or birds which may rely on wetlands. For base flows in rivers, riparian and estuarine GDEs, the NSW State Rivers and Estuaries Policy, NSW Water Resources Council, 1993, and the NSW Sand and Gravel Extraction Policy for Non-Tidal Rivers, NSW Government, 1992 applies.

Recent developments such as the Draft Aquifer Interference Policy (under development by the NSW Office of Water) will define the approach that will be undertaken with regards to managing the impacts of aquifer interference activities on an aquifer and groundwater and any other connected groundwater and/or surface water sources, and on any groundwater dependent ecosystems. The *Water Management* 2000 dictionary defines an **aquifer interference activity** as an activity involving any of the following:

a. The penetration of an aquifer.

b. The interference with water in an aquifer.

c. The obstruction of the flow of water in an aquifer.

d. The taking of water from an aquifer in the course of carrying out mining, or any other activity prescribed by the regulations.

e. The disposal of water taken from an aquifer as referred to in paragraph (d).

Under s. 344 (1)(a) of the *Water Management Act* 2000 all aquifer interference activities in areas where water sharing plans are operating require an aquifer interference approval.

Other policies of relevance to the management of aquifers and associated GDEs include:

Water Compliance Policy, NSW Office of Water, 2010a – This policy ensure the secure and sustainable allocation of water between communities, industry, farmers and the environment and compliance with the *Water Act* 1912 and the *Water Management Act* 2000 and associated regulations.

NSW Water Extraction Monitoring Policy

http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx

This policy controls the monitoring of water extraction and therefore protects GDEs by allowing daily flow management in unregulated rivers and local management rules in the groundwater systems to be implemented.

Draft Floodplain Harvesting Policy – NSW Office of Water, 2010b

The purpose of this policy is to manage floodplain water extractions more effectively in order to protect the environment, improve the reliability of water supply for downstream water users, ensure compliance with the requirements of the *Water Management Act* 2000 and meet the objectives of the National Water Initiative. The unconstrained harvesting of water from floodplains reduces the amount of water reaching or returning to rivers (and associated GDEs). This decreases the amount of water available to meet downstream river health, wetland and floodplain needs. Floodplain harvesting can affect the connectivity between the local floodplain wetlands and the river, through the loss of flow volume and the redirection of flood flows. It also erodes the reliability of water supply to downstream water users.

NSW Weirs Policy – NSW Government

http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx

The goal of the State Weirs Policy is to, where possible, halt, reduce and remediate the environmental impact of weirs in order to protect rivers, wetlands and riparian vegetation GDEs.

Additional information on these and other polices can be found at the NSW Office of Water website http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Key-policies/default.aspx

1.1. Water sharing plans

Water sharing plans promote the objects and water management principles of the *Water Management Act* 2000 in providing rules for the sharing of water between the environment and water users, and between different types of water users. Each plan will specify the rules for the following (developed through the interagency panels):

- Water reserved for the environment.
- Provision for basic landholder rights.
- Rules for water extraction under existing access licences.
- Rules for granting new access licences.
- Rules for granting and amending water supply works approvals.
- The limits to the availability of water (LTAAEL, and AWDs).
- Rules for managing access licences.
- Rules for managing new and existing water supply works approvals.

- Rules for trading of access licences.
- Mandatory conditions.
- System operation rules.
- Rules for how the Plan may be amended.

There are six main types of rules which operate to protect GDEs in the water sharing plans, which are summarised as follows:

1. Distance rules

'Rules for water supply works located near sensitive environmental areas'. This rule specifies the distance restriction for new bores from high priority GDEs, karsts (karst rule), escarpments (scarp rule) and rivers. This rule is designed to minimise the impacts of extraction on these environments.

'Rules for the use of water supply works located within restricted distances'. This rule specifies the maximum amount of water that may be taken on a yearly basis from existing water supply works that are located within the restricted distance from a high priority GDE, karst, escarpment or river. This rule is designed to minimise the impacts of extraction on these systems.

2. Casing rule

New bores in consolidated aquifers; ie. fractured and sedimentary rock aquifers) are required to be constructed with an impermeable pressure cement plug from the surface to a minimum depth of 30m. This rule is designed to protect tree roots that access shallow groundwater.

3. Drawdown rule

Drawdown rules apply to minimise the negative effects of extraction on water levels. No drawdown is permitted to occur at the outside edge of the perimeter of any high priority GDE listed in the WSP. This rule is designed to minimise the impacts of extraction on high priority GDEs.

4. Cease to pump rule

Base flows in streams are protected by cease to pump rules. Most licensed users are required to cease pumping when there are no visible flows in the river or when flows are less than the 95th percentile.

5. Dealing (trading) rules

Dealing (trading) rules are intended to promote trade of entitlement, including for new development, while minimising environmental impacts. Ideally, dealing arrangements result in environmental improvement rather than harm, for example, by avoiding the concentration of extraction in a particular area. In most aquifers covered by macro plans, trade is allowed within a groundwater source but not into or out of the groundwater source. This recognises that groundwater sources as defined in the water sharing plans represent discrete aquifer systems.

6. Local impact rules

All macro groundwater sharing plans include local impact management rules. These rules are intended to ensure that water levels in an aquifer are not depleted detrimentally, beyond seasonal variations. Water quality can also decline as a resulting of excessive extraction. All the macro groundwater sharing plans include local impact management rules to manage water quality across a groundwater source. Water quality changes resulting from extraction are to be managed consistently with the designated category.

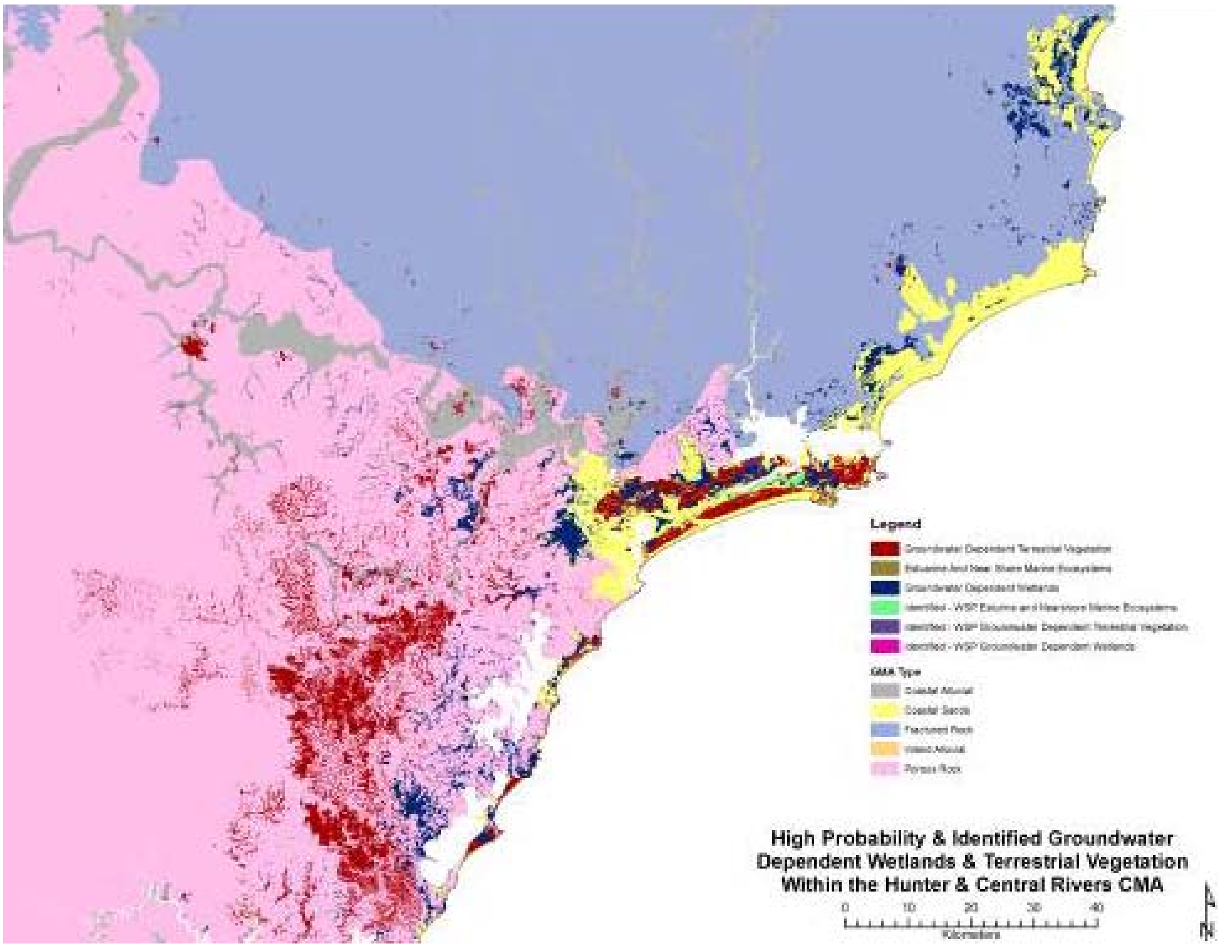
Appendix 4

A method to identify the type and location of GDES within an aquifer and / or defined area

1. Process to identify groundwater dependent ecosystems

There are few assessments with detailed information about the location of GDEs. In many cases, datasets required to conduct such assessments do not exist. The speed with which the identification and assessment of GDEs can be undertaken is a major benefit of desktop approaches. Desktop approaches however only provide a preliminary analysis, highlighting regions or ecosystems warranting further research, Murray *et al,* 2006. A screening at the catchment, region or defined area of interest undertaken by a team of specialists with geological, hydrological and ecological expertise can be used to identify potential areas likely to contain ecosystems dependent on groundwater as illustrated in Appendix 4 – Figure 1.

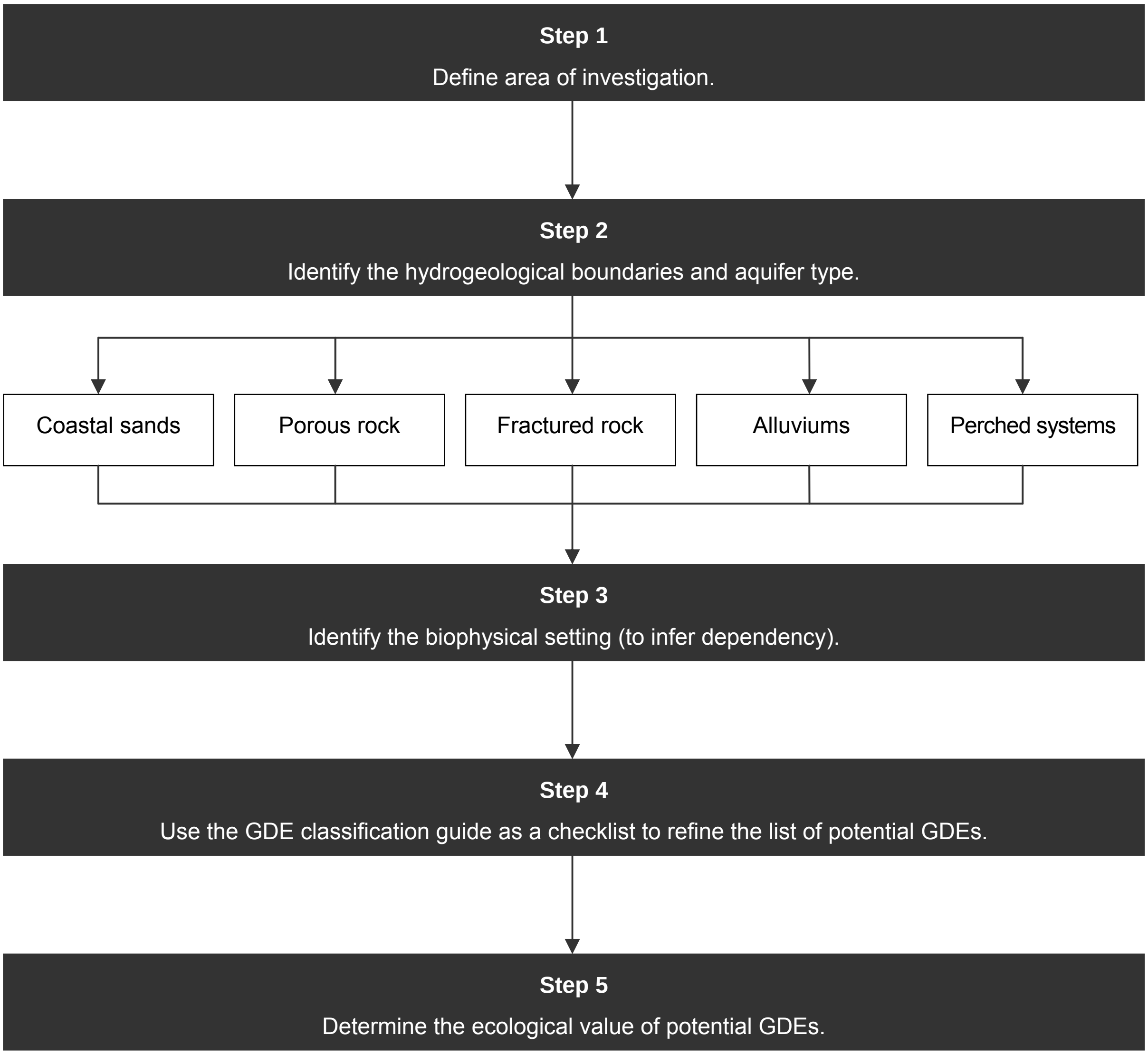
Appendix 4 – Figure 1. High probability and identified groundwater dependent wetlands and terrestrial vegetation within the Hunter– Central Rivers CMA



As this approach is desk top based, it can only, at best, provide red flags as to the location of potential GDEs. In order to identify and describe groundwater requirements in terms supply and quality, detailed and localised review, including fieldwork may be necessary. Text Box 1 describes various methods that can be used to determine dependency of an ecosystem.

The method presented involves five steps and is illustrated in Appendix 4 – Figure 2. The location of potential GDEs, identified through this process is stored on the OEH / NOW Corporate Data Set.

Appendix 4 – Figure 2. Process to identify groundwater dependent ecosystems



Step 1. Define the area of investigation

This step prompts the user to understand the bounds of the geographical area under investigation. The area under investigation can be defined using the following GIS data sets (not inclusive):

- Groundwater management areas – A water management area is that area of land that is constituted as a water management area by an order in force under Section 11 of the *Water Management* 2000 (2000)
- Water sharing plan areas or boundaries.
- Water source areas – A water source is a) any river, lake or estuary and b) any place where water occurs naturally on or below the surface of the ground, and includes the coastal waters of the State.
- Topographic maps (locational information).
- Catchment / subcatchment maps.
- IBRA bioregions/national parks/state forests and reserves.

Step 2. Identify the hydrogeological province / boundaries and aquifer type

Hydrogeology plays a fundamental role in defining groundwater systems, their characteristics and flow mechanisms. For this step, define the hydrological boundaries; ie. aquifer boundaries, see Appendix 4 – Figure 1 for an example, of each Groundwater Management Area (GMA) and any known smaller perched aquifers within the area of investigation and characterise the aquifer into one of the five geological aquifer units. These units correspond with those listed within the macro water sharing plans and are (NOW, 2010c):

- **Inland alluvial aquifers**

  Include sand, clay and gravel sediments associated with inland rivers and streams. Within alluvial aquifers, groundwater is stored in the pore spaces in the unconsolidated floodplain material in which wetlands are situated. Shallow alluvial groundwater systems are associated with coastal rivers and the higher reaches of rivers west of the Great Dividing Range. These groundwater systems are often in direct connection with surface water bodies such as rivers and wetlands. Alluvial aquifers are generally shallower than sedimentary and fractured rock aquifers. Water levels often fluctuate due to varying recharge and pumping rates. Due to their shallow and unconfined nature, alluvial aquifers are susceptible to contamination and pollution.

- **Fractured rock aquifers**

  Include the large tectonic fold belts (consisting of metamorphic and igneous rocks), basalt caps and calcareous formations; eg. New England Fold Belt, Lachlan Fold Belt. In fractured rock aquifers, groundwater is stored in the fractures, joints, bedding planes and cavities of a rock mass (generally impermeable). The fundamental characteristic of fractured rock aquifers is extreme spatial variability in hydraulic conductivity, and hence groundwater flow rate (Cook and Land and Water CSIRO, 2003). Water availability is largely dependent on the nature of the fractures and their interconnection. Recharge in fractured rock aquifers is usually local and intermediate.

- **Porous rock aquifers**

  Include the large sedimentary basins of sandstone with inter-bedded siltstone, shale and coal, and the ‘consolidated’ sands with dual porosity characteristics; eg. Western Murray, Oxley Basin, Gunnedah Basin. These aquifers can store significant quantities of groundwater within the pore space in the rock matrix. Many sedimentary basins contain extensive multi-layered aquifer systems consisting of permeable sediments. Aquifer depths within these basins can range from a few hundred to thousands of meters. Where aquifers outcrop they are recharged by direct infiltration of rainfall, flood events and, where intersected by rivers, river bed seepage. Water quality varies from fresh to saline.

- **Coastal alluvial aquifers**

  Include sand, clay and gravel sediment associated with coastal rivers and streams, and coastal sands, including sands, shells and clays along the coast of NSW; eg. Botany sands.

  Coastal alluvial sediments have been divided into the upriver alluvial aquifers (ie. those alluvial areas upstream of the tidal limit) and the coastal floodplain aquifers; ie. those alluvial areas downstream of the tidal limit). The upriver alluvium is considered to be highly connected to surface water, while the coastal floodplain alluvium is less connected.

- **Shallow perched aquifers**

  Are locally confined shallow aquifers formed when the water percolation is interrupted by another confining layer (clays or rock) thus forming a saturated zone (aquifer) above the main regional water table; eg. Blue Mountain Hanging Swamps.

Shallow perched aquifers are typically composed of unconsolidated material including fine to course grains sediments and organic deposits such as humus or peat. These systems are highly permeable and easily recharged through rainfall and seepage from porous or fractured rock aquifers. The groundwater within these systems supports wetlands (eg. upland headwater and valley fill swamps, hanging swamps), terrestrial vegetation, baseflow streams and hypogean ecosystems. Groundwater contained in these systems moves slowly downslope towards the downstream exit where it emanates as seepage and baseflow into the receiving drainage system (Planning Assessment Commission, 2009).

- **Palaeovalley alluvial aquifers**

  Represent remnants of river channels that are associated with prehistoric drainage basins. Although surface water no longer flows in most palaeovalleys, the sediment which has filled these old river channels still retain recharge and storage capacity. These aquifers are capable of storing significant quantities of groundwater which can support a variety of GDEs. Palaeovalley aquifers are limited by their shallow depth (typically <50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of the palaeovalley, Magee and Geoscience Australia, 2009.

Hydrogeological provinces, as described above, can be further divided along catchment management boundaries. Within each of these provinces, the State's major aquifers are named, numbered and their boundaries mapped.

Step 3. Identify the biophysical setting (to infer groundwater dependency of an ecosystem)

This step prompts the user to understand the biophysical setting in which GDEs might occur. Understanding the physical environment and variables (eg. geology; shallow depth to groundwater; landscape position such as proximity to permanent water courses, climate, soil type, specific vegetation or wetland types) that support potential dependence allows the user to establish the context within which groundwater use by that ecosystem could take place, Clifton *et al,* 2007. This can be illustrated in Appendix 4 – Photograph 1, taken in the Blue Mountains, where groundwater dependent ecosystems such as seeps and hanging swamps (near the top of the photograph), and baseflow fed creeks and associated riparian vegetation are typical.

Appendix 4 – Photograph 1. Groundwater dependent ecosystems, Blue Mountains, NSW

To characterise the biophysical setting, GIS data sets, as listed below, can be used to assist in predicting areas where ecosystems, including wetlands, have the potential to be reliant on groundwater and/or have potential access to groundwater. These data sets can include (not inclusive):

- **Hydrogeological landscapes**
  - Identifies shallow water tables, includes information on geology, soil types, groundwater salinity.
- **Wetland type and location**
  - Identifies areas of potential shallow groundwater.
- **Extant vegetation and reconstructed vegetation**
  - Identifies local communities which can then be classified as a potential GDE (or not) through the described desktop process.
- **Satellite imagery using NDVI / MODIS** or others to identify vegetation communities that are sustained during dry periods.
- **River Styles® Mapping,** a nationally adopted method developed by Macquarie University. Information within this dataset include: the River Styles® type, geomorphic condition and recovery potential of a particular stretch of river. This information can be used to provide indicative location of potential wetland and baseflow GDEs (Appendix 4 – Figure 3).
- **Location of bores and associated water levels**
  - Identifies areas of shallow water tables.

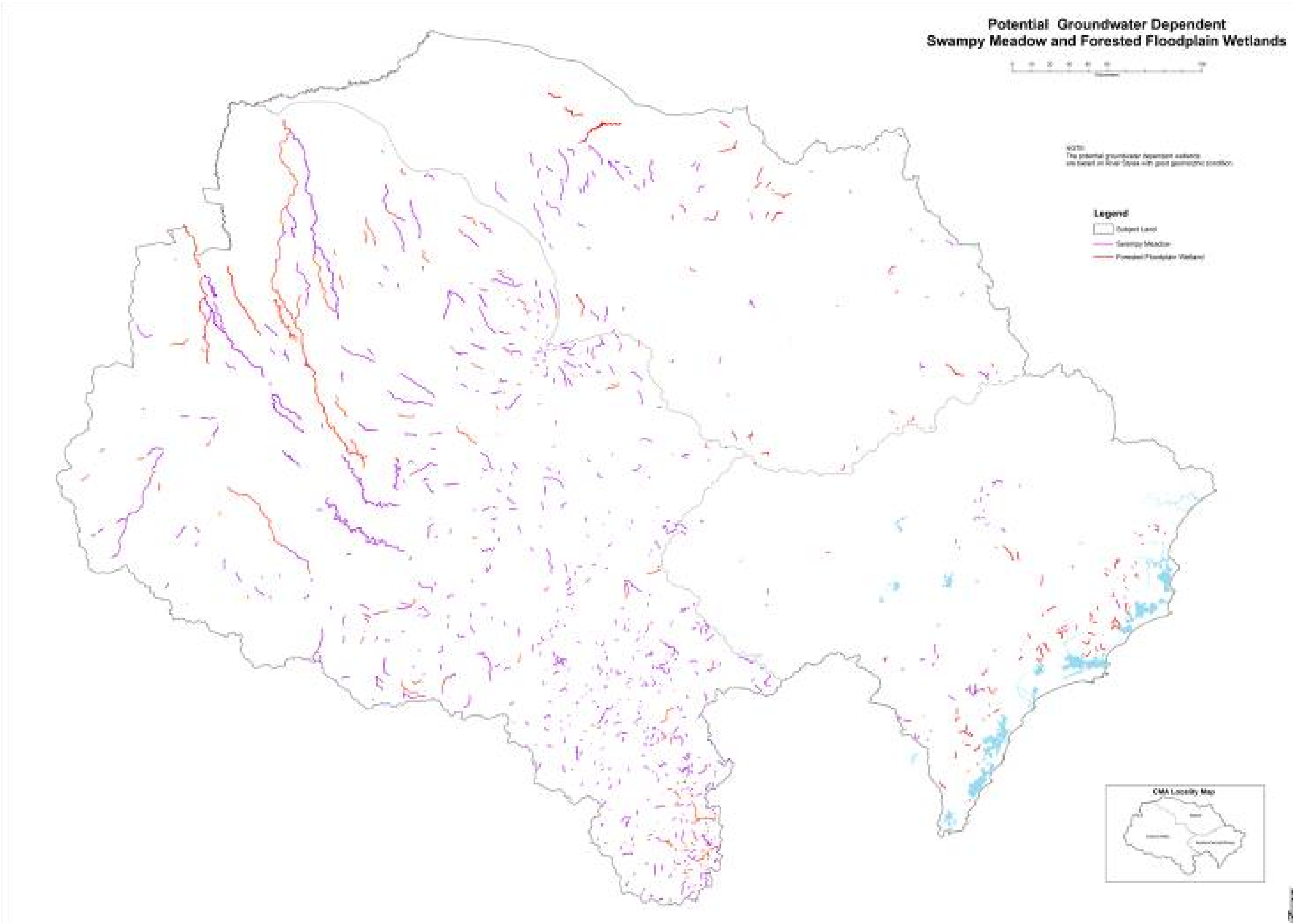
- **Geology and soil type**
  - Identifies particular geology and soil type that may indicate particular GDEs such as Karst and Caves in limestone or wetlands associated with shallow groundwater such as in acid sulfate soils areas.
- **Water quality**
  - Identifies areas of groundwater discharge through changes in water quality such as DO, temperature, pH and conductivity.
- **IBRA bioregions**
  - Identifies vegetation communities associated with altitudinal and climatic conditions that often dictate the type of groundwater systems and therefore potential GDE types within an area.

It is a fundamental tenet of ecology that ecosystems will generally use resources in proportion to their availability. It is therefore assumed that if groundwater can be accessed, ecosystems will generally develop some degree of dependence and that dependence will likely increase with increasing aridity, Hatton and Evans, 1998.

For many communities, depth to groundwater is an important parameter controlling the availability of groundwater to a plant, Hatton and Evans 1998; Eamus *et al,* 2006; Froend and Loomes, 2006. Groundwater dependent communities require that groundwater levels be episodically or periodically within their root zone for use when soil water availability is low so as to satisfy demands for water and nutrients, Hattermann *et al,* 2008; Groom *et al,* 2000. Information on root depth and morphology can therefore be used to determine dependency. However, little is known about the rooting depths of plants and reliance on groundwater when surface water is unavailable.

The groundwater dependence of many ecosystems can be inferred from their position in the landscape, their response to altered water regimes and the occurrence of vegetation or species associated with shallow groundwater, Froend *et al,* 2004. The groundwater dependency of many ecosystems for example is self evident; eg. cave and aquifer ecosystems, base flow dependent ecosystem. Groundwater dependency of wetlands and terrestrial vegetation can be inferred through the impact of altered water regimes on the distribution and composition of species. For example, in response to declining groundwater levels, species can be lost; migrate towards more suitable water levels or be replaced by more xeric species, Froend *et al,* 2004; Groom et al, 2000.

Appendix 4 – Figure 3. Potential groundwater dependent swampy meadow and forested floodplain wetlands (using the River Styles® type as a surrogate)



Sequential questions, based on the hydrogeologic setting of an ecosystem (PPK, 1999, SKM 2001; SKM, 2007; Brown et al, 2007), can be used to infer dependency on groundwater. This initial determination of groundwater dependency is based on a correlation with a number of factors, including location, ecology, and/or function of an ecosystem. It is a rapid desktop approach that can be used to highlight those ecosystems that have a high potential to be groundwater dependent. This approach is based on the methods by the Nature Conservation Council (PPK, 1999), and the Department of Land and Water Conservation, 2002.

The importance of groundwater to an ecosystem can be determined through a series of general questions (Appendix 4. Table 1 – Inferring of groundwater dependency). This series of yes/no questions can then be used to infer groundwater dependency based on the requirement of water permanence of particular species and communities, PPK, 1999. Positive answers to the questions below do not however provide any information about the nature of the dependencies or about the groundwater regime (eg. timing of groundwater availability, volume of availability, location of surface expression, the hydraulic head of the groundwater aquifer required to support the surface discharge of groundwater) needed to support that ecosystem. The questions are divided into general questions for all types of GDEs and more specific questions for each potential GDE type.

Appendix 4 – Table 1. Inferring groundwater dependency

	Yes	No	Unknown
General questions for all GDE types: (X appropriate box)			
Is the ecosystem identical or similar to another that is known to be groundwater dependent?			
Does the community contain species known to require permanent saturation such as within aquifers, karsts, or mound springs or some wetlands?			
Is the distribution of the ecosystem consistently associated with known areas of groundwater discharge; eg. springs, mound springs or groundwater seeps in terrestrial and/or near shore marine environments?			
Is the distribution of the ecosystem typically confined to locations where groundwater is known or expected to be shallow? For example topographically low areas, major breaks of topographic slope; ie. cliffs or escarpments, alluvial and coastal sand beds aquifers, gaining streams?			
Does the ecosystem withstand prolonged dry conditions without obvious signs of water stress?			
Does expert opinion indicate that the ecosystem(s) is groundwater dependent?			
GDE Type specific questions			
Aquifer ecosystems			
Is the aquifer highly porous, that is, is it composed of unconsolidated sediments such as gravels, sand layers or contain palaeochannels, or, if consolidated (solid rock), is the rock matrix fractured?			
Is there an aquatic invertebrate community within the aquifer (sampled from bores) composed of groundwater obligate species; ie. phreatic stygofauna species?			
Karsts and cave ecosystems			
Is there visible water such as pools, sumps, stream flow, wet walls (lamellar flow) or active stalactite/stalagmite formation in the cave during prolonged dry conditions?			
Is the aquatic community within the cave composed of groundwater obligate species ie. phreatic stygofauna species?			
Are there high moisture dependent cavernicolous species such terrestrial cave invertebrates with aquatic larval stages such as glow worms?			

	Yes	No	Unknown
Base flow streams			
Is there visible water in pools consistent or is flow along the streams consistent or increasing downstream during prolonged dry conditions; ie. perennial stream?			
Is the stream or sections of the stream known to be gaining; ie. receiving water from groundwater discharge where surrounding groundwater levels are higher than the stream bed or there is groundwater up-welling?			
Is the stream bed composed of course grained unconsolidated sediments such as sand or gravel?			
Is the aquatic invertebrate community within the surface water composed of long lived, short range endemic species?			
Is the aquatic invertebrate community within the hyporheic zone (within the stream bed substrate) composed of groundwater obligate (stygofauna) species; ie. phreatic or permanent hyporheic species?			
Estuarine and near shore marine ecosystems			
Is the estuary fed by perennial / baseflow streams or associated with permanent wetlands during prolonged dry conditions?	X		
Is the estuary or near shore marine environment associated with or adjacent to shallow groundwater aquifers such as alluvial or coastal sand bed aquifers?	X		
Is the vegetation, vertebrate or invertebrate community composed of species known to require freshwater or high nutrient contributions?	X		
Is there any known submarine groundwater discharge areas?	X		
Phreatophytes – Groundwater dependent terrestrial vegetation (Eamus et al, 2006)			
Is the watertable level near or at the surface or within the root zone of the surrounding vegetation? If roots can reach a source of fresh water it is generally true that this water will be absorbed by the roots and transpired by the canopy			
Is the vegetation community composed of species known to require permanent saturation (wet rainforest or wet sclerophyll forests) or high soil moisture levels (dry rainforest)?			
Is the vegetation associated with the surface discharge of groundwater different (in terms of species composition, phenological pattern, LAI or vegetation structure) from vegetation close-by but which is not associated; ie. accessing) this groundwater?			
Does the vegetation in a particular community occur along stream lines?			
During extended dry periods, does a significant proportion of the vegetation remain green and physiologically active? The green region might be using groundwater to maintain its physiological activity.			
Is the vegetation community known to function as a refuge for more mobile fauna during times of drought?			
For sites that are not receiving significant amounts of lateral surface and sub-surface flows, is the annual rate of water use by the vegetation significantly larger than annual rainfall at the site?			
Does the vegetation in a particular community support greater leaf area index and more diverse structure than that in nearby areas in somewhat different positions in the landscape?			

	Yes	No	Unknown
Groundwater dependent wetlands			
Is the vegetation, vertebrate or invertebrate community composed of species known to require permanent saturation in situations that are not obviously fed by surface water?			
Does the location of the wetland suggest that it is likely to be groundwater dependent; eg. permanent wetlands on coastal sandbeds or back dune swales, streams with consistent or increasing flow along the flow path during extended dry periods?			
Is the wetland associated with a spring or a seep? Groundwater discharge that is concentrated and occurs adjacent to a wetland, suggests that groundwater may be an important source of water to that wetland. *			
Is there visible water in the wetland (especially during prolonged dry conditions) and does the wetland lack surface inflow (stream flow)? A wetland that lacks surface inflow is likely to be obtaining its water from groundwater. Check: Some permanent wetlands that lack distinct surface water inflows can be perched on hardpan soils and are isolated from groundwater. An aquitard created by clay soils or hardpans will prevent groundwater from reaching the wetland. The source of water for these wetlands is generally rain or surface runoff.			
Does the wetland 1) Occur a break in the slope? A break in the slope occurs when the slope of the land surface changes from steep to gentle. Groundwater may intersect the ground surface at this point. In these situations, groundwater is below the ground surface at the top of the slope and moves downhill. Once groundwater nears valleys and depressions, it will often intersect the surface and emerge from the ground. **			
Does the wetland 2) Intersect a confined aquifer with a slope? When groundwater is confined within a permeable deposit such as sand or gravel by deposits that are less permeable, water will move laterally rather than downwards. When that permeable layer intersects a slope, groundwater discharges at the surface. These locations can be recognised in the field by the presence of springs, seeps or wetlands on slopes. **			
Does the wetland 3) Occur a point of stratigraphic change? These areas of groundwater discharge occur when groundwater, moving in a permeable geologic deposit, follows a downward topographic gradient and meets a less permeable deposit. At contact, water is forced to discharge at the surface. Geologic contacts can be located when adjacent geologic deposits of differing permabilities are identified. **			
Does the wetland lack signs of surface inflow? A wetland that lacks surface inflow is likely to be obtaining its water from groundwater.			
Is the wetland considered seasonal? Seasonal wetlands are unlikely to receive significant, season long inputs of groundwater and are likely to be maintained by surface water inputs. However be aware that it may be a wetland that remains dry because of a drop in water table levels and may fill once the aquifer is recharged.			

* Springs tend to occur in two types of hydrological settings:

1) Where surface topography causes the water table to intersect the land slope. This setting can often be predicted or identified on the landscape using surface topography as a guide. In general, springs of this nature tend to be supported by more local groundwater flow systems and are at risk from activities that threaten shallow water tables.
2) Where subsurface geologic structure forces groundwater to emerge at the surface. These springs are not defined by surface topography but by subsurface geological conditions. Often, these springs are supplied by deeper, more regional groundwater flows and are at risk from activities that threaten the deeper water flow system.

** Groundwater discharge is likely to occur and produce groundwater dependent wetlands in the described hydro-geologic settings. Depending on the underlying and surrounding geology, a wetland will be more or less strongly associated with and dependent on groundwater. Field visits and examination of geology and topography data layers and maps for an area can help determine if these conditions exist.

To confirm dependency of an ecosystem

There are many methods for determining dependency. The method will depend on the type of GDE. Many of these methods are field-based and although may provide detailed information on groundwater use and dependence, they can be both costly and time consuming.

Investigation at the local scale can provide site specific information on groundwater use and dependence which can be extrapolated to similar ecosystems in different areas. Site based methods can include, SKM, 2005:

- Long term physical observation of changes in ecosystem health, soil moisture, climatic and groundwater conditions. Measurable changes in the vigour of vegetation can occur when water availability is reduced. These changes can include branch die-back, reduced growth and leaf shed.
- Analysis of the physical properties of water – pH, conductivity and temperature variations can be used to establish a groundwater connection. The use of temperature as an indicator to determine the interaction between surface and groundwater in baseflow streams is being trialling in the USA and within the Cockburn River, NSW, pers comm, Dawit Berhane, Hydrogeologist, NOW.
- Chemical analysis of surface and groundwater can be used to identify mixing relationships so as to determine groundwater contributions. Surface water chemistry is often modified predictably by groundwater discharge, SKM, 2007. Groundwater generally contains higher concentrations of major ions than surface water runoff. Abrupt increases in major ion chemistry concentrations in surface water can be used indicate groundwater discharge, SKM, 2007, and therefore dependency of that ecosystem.
- Groundwater modelling can be used to simulate groundwater flow systems, thereby assessing the level of interaction between groundwater and a wetland.
- An analysis of the water balance will determine the source and use of the various components of the water cycle.
- See page meters can be used to capture the volume of water passing through a wetland.
- Remote sensing and GIS techniques – Smith *et al*, 2006, identified groundwater dependent terrestrial vegetation within the Lower Macquarie, west of Narrandera, Central West NSW.
- Naturally occurring stable isotopes concentrations can be used to demonstrate differences in hydrogen isotope ratios between potential plant water sources, such as soil water and groundwater to determine the dependence particularly of terrestrial vegetation, Ehrlinger and Dawson, 1992; Hatton and Evans, 1998.
- Identification of groundwater dependent wetlands on the Alstonville Plateau (NSW) using local scale site investigations which included a hydrogeological assessment of the aquifer and detailed mapping of springs and seepages and associated flora and faun dependencies, Brodie and Green, 2002.
- Geochemical and stable isotope data together with traditional hydraulic data was used to determine the interaction between surface and groundwater of coastal dune wetlands in a semi-arid area near Esperance, Western Australia, Marimuthu *et al,* 2005.
- Groundwater dependence of wetlands within the Burnett catchment (Qld) was based on depth to water table maps, degree and duration of wetland inundation and soil maps, SKM, 2005.
- The presence of stygofauna within caves, aquifers and the hyporheic zone of baseflow streams and rivers is being trialled in the Lachlan, Namoi and Gwydir River in NSW, Jiwan and Serov, 2003.

Step 4. Use the GDE classification guide as a checklist to refine the list of potential GDEs

This step uses the GDE Classification as a filter to remove non groundwater dependent ecosystems and refine the list to those that are known GDEs or potential GDEs within each aquifer.

Each defined geographic area may contain a number of different GDEs types as described in the GDE Classification Guide (Appendix 2). Each aquifer type identified in step 2 may contain a number of different groundwater dependent ecosystem types and subtypes, each with varying water requirements. Each GDE type represents a distinct ecological community that has no overlap with the other types, although there may some overlap between subtypes, particularly for groundwater dependent wetlands and terrestrial vegetation.

Step 5. Determine the ecological value of potential GDEs

To determine the ecological value of potential GDEs refer to Section 4.2 – Ecological valuation.

2. The aquifer information sheet

For each of the aquifers identified within the area of investigation complete the *'The Aquifer Information Sheet'* (Appendix 4 – Table 2). The Aquifer Information Sheet was created to assist Departmental staff in managing development applications by providing a consistent format for compiling aquifer-based information. This format is also compatible with the *Groundwater Dependent Ecosystem Records*.

Record all aquifer information in the relevant fields and any extra information in comments at the end of the list.

Appendix 4 – Table 2. Aquifer / GDE information sheet template

Criteria	Attributes
Development proposal	Eg. assessment of current allocation/extraction levels.
Groundwater management area / zone	Eg. Tea Gardens Coastal Sands.
Aquifer type	Eg. Coastal Sands.
GDE types	Eg. Groundwater Dependent Wetlands, Groundwater Dependent Terrestrial Vegetation.
GDE subtypes	Eg. Freshwater wetlands.
Description	
Bioregion (terrestrial)	
Catchment / subcatchment	
Landform description	
Geology description	
Area of aquifer (hectares)	
Area of GDE (hectares)	
No. of GDE communities within aquifer	
No. of unique GDE communities with aquifer	
Any buffer zone, if prescribed	
Aquifer description	
Depth to water table (m) and variations and date recorded.	
Current climatic conditions (when depth to water table was recorded). Record rainfall and temperature	
Species List (if known) for GDE	
Keystone / flagship / indicator / endemic species (if known)	
Land tenure	
Land use	
GDE / Aquifer impact checklist	
Recharge (ML/yr)	
Current allocation (ML/yr)	
Topographic map name, number and scale	

Criteria	**Attributes**
MGA zone	
Elevation (AHD) (m)	
Water quality	Salinity index:
Other water quality / chemistry details	
Value	
High ecological value assets / high priority GDEs within the aquifer	Refer to Table 1.
Individual GDE ecological valuation	Refer to Table 2.
Aquifer ecological evaluation	Refer to Table 3.
Ecological hot spots; ie. those subtypes determined to be of high ecological value	
Protection status; ie. area and type of protection	eg. the percentage of national park / reserve
Risk	**eg. Moderate.**
Management action	**eg. See Category B – Table Management actions and mitigations actions to be applied.**
Information sources	
Last updated	
Comments	

Description of criteria

The following is a description of each of the criteria with the associated attributes.

Groundwater management area and zone number

Groundwater management areas and zones have an established numbering system.

Name

Officially recognised names are used whenever available; eg. Name of Groundwater Management Area, otherwise for unnamed aquifers then the closest town or recognised landmark should be used.

Location

This criterion is a general description of the site location relative to the nearest town or landmark feature; eg. Peery Lake, 45km East of White Cliffs.

Aquifer type

Within the macro water sharing plans all aquifers have been broadly categorised as belonging to four types. These are Coastal Sands, Alluvium, Fractured Rock, and Porous Rock.

GDE type

GDEs have been divided into major distinct ecological and geomorphic units.

GDE subtype

Each GDE class has been further divided into. Identifying subtypes will generally necessitate a detailed field assessment therefore if uncertain do not fill in.

Description

The description is a detailed overview of the aquifer and its ecosystems and includes the following subsections:

Bioregion (Terrestrial)

This refers to the terrestrial vegetation bioregional units that were established by the Interim Biogeographic Regionalisation for Australia. This criteria is used to assist with the determination of the ‘Rarity’ and ‘Representative’ attributes for terrestrial ecosystems within the Ecological valuation assessment. An aquatic bioregionalisation has not as yet been defined. For further details on bioregions see: http://www.deh.gov.au/parks/nrs.ibra

Catchment

The catchment(s) that overlie the aquifer.

Subcatchment

The subcatchment(s) that overlie the aquifer.

Landform description

A description of the general landforms.

Geology description

Give a description, if known, of the aquifer geological unit.

Area of aquifer (hectares)

Include any buffer zone, if prescribed.

Aquifer description

Give basic details as follows:

- Depth to water table and date depth recorded.
- Position of any GDEs within aquifer.
- Rainfall and temperature.

Species list for GDE

Species recorded from within the GDEs.

Keystone / flagship / indicator species:

- A **keystone species** is one, which has a disproportionately large effect on other species in a community (Gordh and Headrick, 2001).
- A **flagship species** is one that gains public and political sympathy based on charismatic appeal, serving to increase public awareness (New ,1995).
- An **indicator species** is one, which is used as a gauge for the condition of a particular habitat, community or ecosystem (Gordh and Headrick, 2001).

Land tenure

List of tenure types.

Land use

List of land use types.

Potential impacts on aquifer

List of potential impacts.

Topographic map

This refers to the name of the 1:25 000 topographic map sheet on which the GDE is located.

Elevation (AHD)(m)

Either average elevation across the aquifer or a range in metres above sea level.

Water quality

- **Salinity index** – Fresh, brackish or saline or conductivity reading if known. Thresholds for each class of water as per the ANZECC guidelines.
- **Other water quality / chemistry details** – References to Triton and GDS or as per the ANZECC guidelines.

Value

Ecological value – High, medium or low plus reason for listing. Refer to Water Assessment Guide for an assessment guide and definitions for rating levels. The ecological value is divided into the five criteria as listed on the Ecological Classification Summary Sheet. The criteria include: ecosystem condition/level of disturbance; rarity of the dependent biota or physical features; diversity; and special features.

Protection status

Or percentage of aquifer within National Park or other recognised reserve (including marine reserves).

Risk

Risk of impact from current or proposed activity – High, medium or low plus reason for listing.

Management action

The most appropriate management response for a given environmental value under a particular extraction regime as a result of applying the risk matrix process. (Refer to Table 7).

Information Source: Data sets, reports and/or references.

*Last Updated: Give details of who and when updated any of the above information.

Appendix 5

Surface and subsurface activities that threaten aquifers and / or associated GDES

1. Impact of changes to water quantity

In Australia there is a growing demand for the extraction of groundwater for production and urban purposes. The effects of this extraction, combined with the impacts of multiple droughts, on surface and subsurface ecosystems are not yet fully understood. Over-extraction of groundwater does however pose a significant threat to the sustainability of GDEs and groundwater resources, along with possible impacts on surface water in connected environments.

Parameters of the groundwater regime that influence the viability of a GDE include the alteration of water level and pressure regimes. Water level parameters include depth to water table, variability in water table level fluctuations, timing and magnitude at a range of temporal scales (days to decades or longer), groundwater pressure, and flow rate, Boulton, 2005. Activities associated with water and land use development have the potential to alter any of these parameters, and therefore, the water regime required by particular GDEs, SKM, 2001. This may in turn produce changes in the composition and function of an ecosystem in the immediate vicinity of an activity but also in those ecosystems that require the flow-on of that groundwater such as in baseflow river systems.

Under natural conditions, water tables fluctuate both on a micro scale (daily fluctuations influenced by diurnal vegetation water uptake as well as by solar and lunar cycles) and a macro scale (monthly to seasonal fluctuations (depending on aquifer porosity) in response to seasonal rainfall patterns. Progressive reductions in the availability of groundwater may lead to a gradual decline in the health of an ecosystem and/or a reduction in its spatial extent. In more extreme cases, thresholds of environmental requirements may be exceeded, resulting in the ecosystem collapsing or sustaining irreversible damage, Hatton and Evans, 1998. A change in groundwater level can lead to a loss of aquatic habitat at particular levels, for example, within wetlands with an open water body, the habitats are stratified by degree of saturation and depth of water where each habitat has a suite of dependent species. A drawdown of the water table can cause wetlands to become recharge instead of discharge zones, altering both the soil water regime, water chemistry, which then influences the vegetation and fauna communities, Le Maitre *et al,* 1999.

The lowering of the water table will have a significant impact on all GDE types but in particular those communities that are entirely dependent and have narrow environmental physiological tolerances such as ecosystems within karsts, baseflow and some wetland communities. The community response time to a significant drawdown event or period where the water table lowers below the threshold of the dependent communities' resilience may be immediate or be delayed until well after the event.

A community's response to an impact can be subtle. For example, excess lowering of water tables can prevent seedling recruitment and alter vegetation dynamics with little obvious impact in the short term but which can completely change the vegetation community composition in the long term (Le Maitre et al, 1999). A drop in water table levels in disturbance sensitive ecosystems on the other hand may result in an immediate and complete collapse of that ecosystem, Le Maitre et al, 1999. The impacts may be rapid and dramatic, for example, rapid loss of water level in a permanent wetland such as a mound spring where the species are endemic, totally dependent, with no ability to withstand desiccation could mean the complete and irreversible loss of that community.

The degree to which GDEs are impacted by altered water regimes will depend on four factors:

1. The degree of groundwater dependence of the ecosystems.
2. The rate of water level change (rate of drawdown).
3. The length of time the alteration is in effect.
4. The seasonal timing of the alteration.

These factors can work individually or in combination. The possible impacts from each of the above factors are outlined below.

1. Highly or totally dependent ecosystems and those that occupy a very narrow ecological range may be completely eliminated by even relatively small changes in the water regime. Changes in the overlying vegetation can alter hydrological linkages and water levels in caves and their aquatic ecosystems with devastating impacts on their fauna. For example, the quantity of available water and the transport of dissolved and particulate organic matter, critical as an energy source for subterranean food webs, are impeded by changes in hydrological linkages and vegetation cover, Boulton *et al*, 2003.
2. The disconnection of roots from its aquifer by a rapid drop in the water table can cause severe stress and partial or complete mortality in large trees which cannot grow their root systems rapidly enough to maintain adequate water supplies to their extensive canopies, Le Maitre *et al,* 1999.
3. A prolonged period of drawdown can result in the disconnection of the root zone from the water table, resulting in the subsequent drying out of the ecosystem over time. The loss of species and changes in the vegetation community structure may have time lags of years to decades before becoming evident as different species of plants within a community have varying groundwater dependency and stress thresholds, Le Maitre *et al,* 1999.
4. The impact of a rapid or an extended drawdown is exacerbated if it occurs at particular times of the year for example during periods of environmental stress such as summer or drought.

As previously indicated, the condition or ‘health’ of a GDE relies on a combination of timing and availability of groundwater but the response functions of these ecosystems are seldom known, Boulton, 2005. Although the health of some GDEs, such as alpine bogs, might show a linear response; ie. as the water table drops the condition decreases to groundwater availability, other ecosystems such as salt marshes may respond in a stepped fashion with minimal change in condition until a threshold of water availability is reached, Evans and Clifton, 2001.

Inland, rising water tables and increased soil salinity have affected the health and distribution of native plants species, Cramer and Hobbs, 2002. Secondary dryland salinity affects agricultural landscapes where native vegetation is often highly fragmented, of small size and already degraded by land use activities, Hobbs 1993; Hobbs, 1998. The alteration of hydrological processes could force an ecosystem, already stressed, across a threshold resulting in its collapse.

The ecosystems at most risk from saline discharge are those systems that occur in the lowest topographic positions in the landscape. These ecosystems include: riparian zones, floodplains, and wetlands, both fresh and naturally saline. The risk to low lying vegetation beyond riparian zones is uncertain, Cramer and Hobbs, 2002. Wetland vegetation often relies on the regular flushing of salt from the root zone for continued survival. A change in hydrology that leads to the constant presence of a shallow saline water table could reduce the leaching of salt from the root zone and cause a decline in vegetation health, Cramer and Hobbs, 2002. Wetlands that form terminal systems (those that hold water after flood flows have receded) are potentially at greater risk than flow through systems as evaporation from terminal systems will result in high salt concentrations in the remaining body of water and in the surrounding soil, Murray Darling Basin Ministerial Council, 1999.

The raising of groundwater levels by over irrigation can cause the transport of salt to the surface resulting in the development of shallow saline groundwater. This in turn can cause salinisation of the plant root zone and subsequent collapse of the ecosystem. Diversions and/or impoundments of surface waters can change groundwater levels, particularly in near stream alluvial aquifers, SKM, 2001. Groundwater levels can increase if the post regulation stream flows exceed natural flows or they may be lower, particularly if river regulation is associated with out of basin transfers of water. Elevated groundwater levels may benefit some groundwater dependent species whilst detrimentally affecting others.

2. Impact of changes to water quality

The alteration of natural water chemistry can result from a myriad of causes and, therefore, have a myriad of impacts depending on whether the change is caused by:

- point source pollution
- diffuse source pollution
- alterations to natural patterns of hydrological connectivity such that a water of lesser quality is drawn in from other formations, seawater or surface water bodies.

Aquifer water level changes can result in internal aquifer chemical changes such as the exposure of acid sulfate soils or contamination by saltwater intrusion through drawdown of shallow coastal aquifers or the salinisation of soil and water by raising the water tables through excessive irrigation.

2.1. Groundwater contamination by salt water intrusion

The expansion of development within the coastal areas of NSW will continue to increase demand for water resources, in particular groundwater resources. The impacts of increasing water extraction in coastal areas have wide ranging implications for both the environment and the quality of the groundwater resource. Over extraction of coastal aquifers can and has resulted in the contamination of freshwater aquifers from the intrusion of salt water.

Under natural conditions along the coast, the regional flow of fresh water is towards the ocean. The continuous flow of groundwater limits the landward encroachment of sea water into aquifers. When groundwater is pumped in sufficient volumes that a reduction in the hydraulic head or aquifer pressure occurs from an aquifer that is hydraulically connected with a source of salt water such as within an estuary or a marine near shore environment, the flow regime that results may induce salt water encroachmen; ie. the landward movement of the saltwater wedge into the aquifer. The freshwater / saltwater interface is referred to as the saline or saltwater wedge. This is because salt water is heavier than freshwater and lies underneath the freshwater column in the shape of a wedge. It should be noted that even though the fresh-saltwater interface may be well below the ground surface, a relatively minor lowering of the water table by pumping can result in a significant rise of salt into the upper aquifer, Department of Environment and Climate Change, 2007. The implications of saltwater intrusion into previously fresh or brackish environments that are adapted to lower salinities are:

- The degradation or permanent loss of these ecological communities.
- The loss of the associated ecosystem services that are performed by these environments.
- A loss of water utility / resource to the community.

2.2. Acid sulfate soils

Acid sulfate soils (ASS) are associated with tidal plains and barrier beach coasts. They are derived from saline soils or sediments that have accumulations of iron sulphides and whose stability is maintained by waterlogged or strongly reducing conditions. Once these soils are exposed to the air, either through drainage or the lowering of the water table, the sulphides oxidise and produce large amounts of sulphuric acid. Soil pH falls below 3.5 and acid drainage water is produced, McKenzie *et al,* 2004.

Agricultural land use, residential development, golf course and marina developments in coastal areas all have potential to activate acid sulfate soils. Acid sulfate soils are extensive along the eastern and northern coastline of Australia, and are also found in inland areas derived from marine sediments, Powell and Ahern, 1997. GDEs affected by acid sulfate soils will most commonly be those occupying the area above the soils and downstream of the soils as well as groundwater discharge areas in estuarine or coastal environments. These ecosystems include the freshwater / brackish / saline wetlands above the acid sulfate deposits, and the mangroves and sea grass beds and their associated vertebrate and invertebrate communities, as well as the aquatic ecosystems in base flow dependent streams and coastal wetlands supplied by groundwater, SKM, 2001. In some coastal aquifers, groundwater levels can therefore strongly influence ecosystem health. The activation of acid sulfate soils may result in sensitive species being killed or displaced. Flocculation of iron in the water as a result of the precipitation of iron from the soluble state may result in aquatic or marine communities and water body substrates being smothered.

3. Impact of changes to aquifer structure

Aquifer structure can be altered through activities such as mining and urban development. The direct impacts of mining on GDEs will vary with the type of mining, the geology of the area, the need for and intensity of groundwater pumping and the proximity of the mine to GDEs.

3.1. Mine dewatering

Mine dewatering is the practice of pumping out water that enters the mining area. This water can be either rainwater or groundwater if the mined deposit is below the water table. Dewatering can significantly lower water table levels. The magnitude and speed of change will be relatively great for large open cut mines and underground long-wall mining or where the mine intersects highly transmissive (porous) aquifers. Mine-related construction activities, such as diversion and / or canalisation of streams, may also contribute to changes in riverine aquifer levels. Impacts on GDEs in proximity to the mine could be substantial. Lowering of water table levels could reduce or even eliminate an aquifer and its associated GDEs such as wetlands, cave or aquifer ecosystems that are situated in close proximity to the mine. The development of a mine within a highly porous alluvial aquifer or floodplain adjacent to a gaining (base flow) river system may cause the groundwater flow to be reversed resulting in the draining of the river system downsteam of the mine.

Wetlands and groundwater dependent terrestrial or riparian ecosystems may be threatened by large changes in groundwater level or pressure. Mine dewatering has potential to reduce discharge flux and the volumes of water available for habitat for aquatic ecosystems in wetlands and downstream base flow streams. Dewatering may alter the environment experienced by (affected) cave or aquifer ecosystems. Ecosystems sensitive to those changes may be simplified or even eliminated by such changes. The use of toxic chemicals like cyanide may completely destroy any aquifer ecosystem present. Accidental spillage from coal washing or tailings dams may contaminate surface water and groundwater systems and damage the ecosystems they support.

3.2. Subsidence and bedrock / streambed cracking

Subsidence associated with large scale mine dewatering or the collapse of mine shafts either accidentally or when decommissioning an underground mine may indirectly affect GDEs through the fracturing of the bedrock / aquifer substrate. Subsidence can and has affected surface water flow processes in streams and adjacent riverine aquifers. In coastal areas, it could increase the risk of seawater intrusion into groundwater dependent coastal wetlands.

One of the recent concerns involving the mining industry, and the coal industry in particular, is the impact to overlying bedrock strata as a result of ‘long-wall’ mining operations. In particular, the impact on the rock strata following the decommissioning of longwall mines by the destruction of the mine’s support pillars which causes the mine to collapse into itself. Both the mining operation and the decommissioning of old mines can and has fractured the overlying rock layers producing minor to major cracking of the substrate. The impact of this can include the drainage of surface waters into fractures/cracks following streambed cracking and the drainage of groundwaters out of aquifers through the cracks leading to either or both:

1. Drying of overlying aquifers.
2. Drying of entire river systems.
3. Contamination of underlying aquifers and outflow streams.

The impact of this threatening process could have rapid and irreversible affects on all connected riverine or groundwater dependent environments.

3.3. Sand mining

Sand mining is the activity of removing sand and gravel by excavation or dredging from beaches, coastal and inland dunes and rivers for the purposes of commercial use of the sand or for the deepening of channels for boat movement. Land and river based sand extraction can cause the biological and geomorphic degradation of rivers and groundwater systems and their associated GDEs by the alteration of water levels, water chemistry and the removal of habitat, Uunona, 2010. The removal of sand and gravel within rivers can lower the stream bottom leading to bank erosion and / or changes in the flow direction in baseflow systems. This may, in turn, lower the surrounding groundwater levels which riparian, floodplain terrestrial vegetation and wetlands may depend on for survival.

In-stream sand mining results in the destruction of aquatic and riparian habitat through large changes in the channel geomorphology. Impacts include bed degradation, bed coarsening, lowered water tables near the streambed, and channel instability. These physical impacts cause degradation of riparian, surface aquatic and groundwater biota. Continued extraction may also cause the entire streambed to degrade to the depth of excavation.

Depletion of sand in the streambed and along coastal areas can cause the deepening of rivers and estuaries, lowering of connected groundwater systems and the enlargement of river mouths and coastal inlets. It may also lead to saline-water intrusion from the nearby sea, The Ojos Negros Research Group, 2010.

4. The impact of land use activities

There are significant links between groundwater and surface water; eg. many surface waterways are recharged from groundwater, or vice versa, so that alterations to quantity and quality of one can have direct effects upon the other. Changed land use can increase or decrease water availability (water quantity by changing the balance between surface runoff and groundwater recharge). The hydrological impacts of different land-use types on aquifer behaviour, including the change in the volume of recharge, the change in discharge patterns, flooding, water-logging and water chemistry, is however, not well understood.

4.1. Water quantity

The widespread removal of native vegetation has had a dramatic and immediate impact upon ecosystem function, causing major changes in the hydrological cycle. The introduction of dryland agriculture has resulted in increased groundwater recharge. This has lead to groundwater levels rising across the landscape and increased discharge at certain points; eg. break of slope, valley floors, Coram *et al,* 1999. The complex root systems of grasses, shrubs and trees and their symbiotic relationship with soil fungi provide a vast network for recycling and redirecting water and nutrients. Large-scale clearing of native vegetation and its replacement with annual crops and pastures have substantially increased the amount of water leaking beneath the root zone and entering the internal drainage and groundwater systems of the landscape. This has caused water tables to rise, bringing salt into the topsoil.

The amount of water leaking into groundwater systems depends on the climate (particularly the distribution and amount of rainfall); the depth, water storage-capacity and permeability of soils and subsoil; and vegetation characteristics. Not all the water leaking beyond the root zone necessarily ends up in groundwater. It also moves laterally through the soils to drain into surface streams. In other situations, leakage can occur from the base of streams into groundwater systems. Once the leakage beneath the root zone is increased, the water begins to transport salt stored in the landscape, either to land surfaces and / or to rivers and streams.

The discharge and disposal of saline groundwater into streams and wetlands as a result of elevated groundwater levels can contribute to increased salt concentrations within these ecosystems. Saline groundwater discharge into streams can result in the formation of saline pools (haloclines) in the floor of streams ie. salty water lying under a freshwater layer. These pools, once feed by relatively fresh groundwater, turn anoxic (oxygen depleted) and can no longer act as refuges for aquatic fauna during periods of low or no flow. Flushing of these pools during high flow events may also send a pulse of highly saline de-oxygenated water along the stream which may affect sensitive aquatic species, SKM, 2001. High water tables within wetlands can bring about a change in the water regime and affect current species composition. Fragmented remnant vegetation in the lower parts of the landscape are particularly vulnerable to the changes in shallow water tables and salinity.

There is growing concern that various land use changes such as land clearing may impact upon the long-term catchment yield and water quality for groundwater and surface water. Converting wooded land to annual cropping or plantation forestry is reported to have significant effects on long-term catchment yield, Leaman, 2003. Recent theoretical work on catchments in mid to low rainfall environments suggest that revegetation for forestry and agroforestry can significantly reduce the amount of water entering rivers and streams, Schofield and Bari, 1991; Le Maitre *et al,* 1999. In these environments, a careful analysis is needed of the relative benefits of groundwater recharge management compared to the contribution of low salinity freshwater to stream flow. The amount by which revegetation can reduce river flow is predicted to be much smaller in mid to low rainfall catchments than for high rainfall catchments.

Within coastal areas, drainage and the construction of canals and marinas can lower groundwater levels. Depending on the scale of the change in groundwater levels, this may lead to a decline or total loss in dependent wetlands, terrestrial and riparian vegetation. It may also activate acid sulfate soils in susceptible areas and degrade nearby ecosystems. Watering of domestic gardens and urban parkland, discharge from septic tanks, leakage from sewerage pipes and disposal of stormwater can contribute to elevated water table levels and the development of dryland salinity in some urban areas. While the impact of this would normally be confined to urban and residential infrastructure, it has the potential to affect native vegetation remnants, wetlands, riparian vegetation within urban areas, some of which may be groundwater dependent. Higher levels and greater salt concentration may also affect any aquifer ecosystems present, SKM, 2001. Submarine groundwater discharge (SGD) flows can also be altered by developments along the coast line. This, in turn, can result in changes in the distribution, structure, function and dependency of ecosystems dependent on SGD quantity.

4.2. Water quality

Urban, commercial and tourist developments as well as intensive agricultural land use can adversely affect groundwater quality and, therefore, the ecosystems that depend on that groundwater, SKM, 2001. Nutrients from fertilisers and septic tank effluent, agricultural pesticides, metals and hydrocarbons from commercial and urban land uses; eg. leakage from underground fuel tanks, can contaminate groundwater. Exposure to such contaminants can pose a direct short and long term threat to ecological processes. Elevated nutrient levels may result in algal blooms of surface aquatic systems that could render (at least temporarily) marine and estuarine habitats unsuitable for many key species. A paradox, however, may arise in the management of submarine groundwater discharge flows where groundwater nutrient concentrations play a role in the functioning of particular estuarine/marine GDEs such as sea grass beds. Ecologically, it may be that the anthropogenically-elevated nutrient concentrations (especially nitrate) in part currently offset the reduced groundwater flow resulting from terrestrial extraction, thus maintaining an equitable nutrient load for coastal marine GDEs. If so, interventions to reduce nitrogen contribution to groundwater for socioeconomic purposes (for example, reduced fertiliser use and nitrate levels in potable water to meet human health requirements, (Thornburn *et al,* 2003) could be to the detriment of coastal GDEs if there is not commensurate reduction of groundwater extraction. Due to the interconnection between GDEs within the estuarine and near shore environment and the surrounding groundwater system, any human impacts to groundwater quality (and flows) therefore should also be considered as impacting upon the estuarine and marine system.

GDEs may be poisoned directly by pesticides and hazardous chemicals. Impacts from these hazards are likely to be greatest on aquatic ecosystems – in the aquifers themselves, in wetlands and base flow dependent streams. Contamination of alluvial aquifers by nutrients, pesticides and other toxicants can adversely affect dependent ecosystems in base-flow streams, particularly aquatic communities, SKM, 2001. Surface and groundwater quality in karst systems may be affected by upstream land uses, particularly if the catchment includes agricultural land or land used for timber production. Water quality affects natural processes of erosion and sedimentation in karst systems, and can influence their aquatic ecosystems. Maintaining water quality parameters of both surface and groundwater within natural ranges is fundamental in managing karst systems for nature conservation, DPIWE, 2001.

Although groundwater contamination by metals will primarily affect the potential human use of the groundwater resource, the presence of metals can also affect aquatic organisms both within the aquifer and when contaminated groundwater discharges to surface waters or is taken up by vegetation and crops. The metals of principle concern include arsenic, lead, copper, nickel, chromium and zinc. Research shows that most metals are likely to tend to accumulate within the soils close to their source (such as the base of a wetland). However, in sandy and loamy soils, significant downward movement of copper and iron is observed. Therefore, if the groundwater adjacent to a wetland is acidic, these and other metals can be mobilised and move into the surrounding groundwater system. As the solubility of most metals increases with decreasing pH, the risk of acidification and metal release following oxidation could be greatly increased in acid sulfate soils.

Phosphorus, in the dissolved form (orthophosphorus), can move freely from a wetland into the surrounding groundwater system. Nitrates are one of the most frequently encountered contaminants in groundwater. Whenever nitrogen containing compounds come in to contact with soil, there is the potential for nitrate to leach into the groundwater. Nitrates are highly soluble, and so it can be relatively easy for their transfer from a wetland into the surrounding aquifer.

Appendix 6

Glossary

Artesian aquifer

An artesian aquifer is an aquifer that is under pressure as a result of being overlain by a confining layer. This pressure is the result of the recharge area of the aquifer being at a higher level than the rest of the aquifer region. The force of gravity pulls the higher water down which creates extra pressure inside the aquifer. This is why artesian wells flow by themselves; the pressure forces the water out of the well.

Artesian well (flowing)

A flowing artesian well is one that has penetrated into an artesian aquifer. Artesian aquifers have pressure built up within them. This pressure results from a portion of the aquifer being at a higher elevation as shown in the figure. The pressure is released when a well is bored into it. This causes the well to flow spontaneously.

Artesian well (non-flowing)

A non-flowing artesian well occurs when the pressure is not great enough to force the water out of the well. The flowing artesian well is at a lower elevation than the non-flowing artesian well.

Aquaclude

geologic formation which contains water but can not transmit it rapidly enough to furnish a significant supply.

Aquifer

A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

Aquitard

A saturated but poorly permeable bed, formation, or group of formations that does not yield water freely to a well or a spring. An aquitard may transmit appreciable water to or from adjacent aquifers.

Baseflow

The component of stream flow that is sourced from groundwater discharging into the stream.

Biospeleology

The scientific study of organisms living in caves.

Capillary fringe

The zone immediately above the water table, where water is drawn upward by capillary action.

Cavernicole

A terrestrial animal which normally lives in caves for the whole or part of its life cycle.

Cavernicolous

Animals that inhabit caverns or cave.

Cone of depression

A depression in the groundwater table or potentiometric surface that has the shape of an inverted cone, and develops around a well from which water is being withdrawn. It defines the area of influence of a well.

Confined aquifer

An aquifer that lies below a low permeability material. The piezometric surface in confined aquifers is above the base of the confining material; eg. artesian aquifers.

Confining bed

A confining bed is a layer of ground that resists water penetration. This layer is typically finer textured and denser than above layers of soil. Confining beds can keep water from seeping to unreachable depths, but can also prevent water from reaching aquifers.

Consolidated rock

Consolidated rock is rock that contains very few holes or cracks for water to get through. Unconsolidated rock is rock such as gravel. Consolidated rock can serve as a confining bed.

Critically endangered

A taxon is critically endangered when it is facing an extremely high risk of extinction in the wild in the immediate future (2000 IUCN Red List).

Deep cave zone

The area of a cave where environmental conditions are stable.

Detritivore

Organisms which feed on organic detritus, such as the dead parts of plants or dead bodies and waste products of animals.

Drawdown

The distance between the static water level and the surface of the cone of depression.

Ecosystem

A functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area, and all the non-living physical and chemical factors of their environment, linked together through nutrient cycling and energy flow.

Ecosystem function

Fundamental characteristic of ecosystems related to conditions and processes necessary for maintaining ecosystem integrity. Ecosystem function will include such processes as decomposition, nutrient cycling and production. It is generally considered that maintenance of biodiversity is integral to ecosystem function. The term is sometimes used interchangeably with ecosystem function or condition.

Edaphobites

Deep soil dwelling (or endogean) species that frequently display troglomorphisms and may sometimes occur in caves.

Endangered

A taxon is endangered when it is not critically endangered but is facing a high risk of extinction in the wild in the medium term future, 2000, IUCN Red List.

Endemic

Pertaining to organisms in a specific geographical region or ecological habitat; organisms native to a region and not introduced, Gordh and Headrick, 2001.

Entrance zone

The area of a cave where surface and underground environments meet each other. Refer to twilight zone, transition zone and deep cave zone.

Environmental flows

Amount of water required by the environment (ie. river system) to maintain ecosystem function.

Environmental water requirement

The environmental water requirement (EWR) for any GDE describes the water regime that is necessary to sustain the ecosystem's key ecological values. An EWR will either be the same as, or more than, an EWP.

Extinct

A taxon is extinct when there is no reasonable doubt that the last individual has died, 2000 IUCN Red List.

Extinct in the wild

A taxon is extinct in the wild when it is known only to survive in cultivated captivity or as a naturalised population (or populations) well outside the past range. A taxon is presumed extinct in the wild when exhaustive surveys in known and / or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxons life cycle and life form, 2000 IUCN Red List.

Facultative GDE

A GDE that is not entirely dependent on groundwater, and may rely on groundwater on a seasonal basis or only during extended drought periods. At other times, water requirements may be met by soil or surface water (see Obligate GDE).

Flow or flux

the rate and volume of supply of groundwater.

Groundwater dependent ecosystem or GDE

Is a broad, overarching term encompassing all ecosystems that use groundwater either permanently or occasionally to survive. In this context the term covers a vast majority of terrestrial and aquatic ecosystems.

Gaining stream

A stream where baseflow, or groundwater discharge, serves to maintain and even increase stream flow as one goes downstream (see losing stream).

Hydraulic conductivity

A coefficient of proportionality describing the rate at which water can move through a permeable medium. Horizontal hydraulic conductivity (Kh) refers to the coefficient of proportionality in the horizontal direction, whereas vertical hydraulic conductivity (Kv) refers to the coefficient of proportionality in the vertical direction.

Hydraulic gradient

The rate of change in total head per unit distance in a given direction. The direction of gradient is that yielding the maximum rate of decrease in head.

Hydrogeologic

Those factors that deal with subsurface waters and related geologic aspects of surface waters.

Hyporheic zone

The ecotonal zone below and within the porous sand and gravel substrate of a river bed. This ecotonal zone often connects the surface running water system to that of the deep subterranean.

Hyporheos

The characteristic fauna that inhabit the hyporheic zone of rivers.

Impacts

Impacts are the positive and negative consequence of management actions, NRC, 2005.

Karst

Terrain with special landforms and drainage characteristics on account of greater solubility of certain rocks in natural waters than is common.

Level

For unconfined aquifers, the level is the depth below surface of the water table.

Losing stream

A stream where water is lost to the surrounding and underlying groundwater system (see gaining stream).

Meiofauna

Sediment – Associated organisms intermediate in size between the microbes and macrofauna; eg. occur between the sand grains on beaches.

Naturalness – How much has the area been protected from, or not been subjected to, human induced change. It also reflects the condition or health of an ecosystem, Dunn, 2000.

Obligate GDE

A GDE that is entirely dependent on groundwater. Typically most karst, wetland and hypogean/aquifer GDEs, all baseflow and some terrestrial GDEs will be obligate (see facultative GDEs).

Perched water table

This occurs when the water percolation is interrupted by another confining layer above the main regional water table.

Permeability

The property or capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

Pholeteros

Aquatic fauna inhabiting the burrows of freshwater crayfish.

Phreatic water

Water below the level at which all voids in the rock are completely filled with water.

Phreatic zone

Zone where voids in the rock are completely filled with water. Also refers to deep groundwater.

Phreatobite

Are stygobites that are restricted to the deep groundwater substrata of alluvial aquifers (phreatic waters), Gibert *et al,* 1994. All species within this classification have specialised morphological and physiological adaptations.

Phreatophyte

Plant that draws water from the saturated zone (ie. below water table) so as to maintain vigour and function.

Piezometer

A narrow tube, pipe or borehole for measuring the moisture in a soil or water level in an aquifer.

Porosity

The percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Potentiometric surface

The level to which water will rise in wells screening a discrete aquifer. The water table is a particular potentiometric surface for an unconfined aquifer.

Pressure

For confined aquifers, the potentiometric head of the aquifer and its expression in groundwater discharge areas.

Psammon

The community inhabiting the narrow pore spaces of freshwater and marine sandy beaches, Pascalis, 2003.

Rare species or community

taxa with small world populations that are not at present 'Endangered' or 'Vulnerable', but are at risk. These taxa are usually localised within restricted geographic areas or habitats or are thinly scattered over a more extensive range, Horwitz, 1990.

Recharge zrea

A recharge area is an area that allows water to enter the aquifer. The area is particularly vulnerable to any pollutants that could be in the water.

Relict Species or relictual species

Species belonging to an ancient group whose distribution is NOW restricted to a few locations.

Riparian zone

Riparian zones are narrow strips of land that border creeks, rivers, lakes, or other bodies of water.

Risk - Risk is a measure of the likelihood that some external factor will reduce the ability to achieve a desired outcome, NRC, 2005 (refer to Impacts definition).

Saturated zone

The zone in which the voids in the rock or soil are filled with water. Sometimes referred to as the phreatic zone.

Semi-confined, or leaky confined aquifer

An aquifer that lies below a relatively low permeability material. The semi-confining material allows small quantities of water to pass between aquifers. The piezometric surface is often above the base of the semi-confining material.

Spring

A natural spring occurs when the water table is higher than the ground surface. Pressure forces the water out the aquifer and onto the land at a weak point, which creates the spring.

Stagnant air zone

A cave environment found in North Queensland characterised by elevated carbon dioxide concentrations and depressed oxygen levels. This zone may support a unique cave-adapted community.

Stygobite

Organisms that are specialised subterranean forms, obligatory hypogea. Some are ubiquitous, widely distributed in all types of groundwater systems (both karst and alluvia).

Stygofauna

This an all encompassing term for all animals that occur in subsurface waters, Ward *et al,* 2000.

Stygophiles

Having greater affinities with the groundwater environment than stygoxenes, because they appear to actively exploit resources in the groundwater system and /or actively seek protection from unfavourable situations in the surface environment resulting from biotic or stochastic processes. Stygophiles can be divided into:

1. occasional or temporary hyporheos
2. permanent hyporheos.

The occasional or temporary hyporheos include individuals of the same species that could either spend their lives in the surface environment or spend a part of their lives in the surface environment and a part in groundwater (Ceratopogonidae fly larvae). The permanent hyporheos is present during all life stages in either groundwater or in benthic habitats (Gibert et al, 1994.) and possess specialist adaptations for living in this environment.

Stygoxenes

Organisms that have no affinities with the groundwater systems, but occur accidentally in caves and alluvial sediments. Some planktonic groups (Calanoida Copepoda) and a variety of benthic crustacean and insect species (Simuliidae Fly larvae, Caenidae Mayflies) may passively infiltrate alluvial sediments, Gibert *et al,* 1994.

Sustainability

is the ecosystems ability to maintain its functions or meet the demands on it in the face of threats. The significance and sustainability of a waterway or ecosystem include both objective and subjective elements.

Threatened species or communities

Refers collectively to threatened species, populations or ecological communities listed under the *Threatened Species Conservation Act* 1995 and the *Fisheries Management Act* 1994.

Transition zone

The area of a cave where light is non existent but the environmental effects from the surface are still felt.

Troglobite

A cavernicole unable to live outside the cave environment.

Troglophile

A cavernicole, which frequently completes its life cycle in caves but is not confined to this habitat.

Trogloxene

A cavernicole which spends only part of its life cycle in caves and returns periodically to the surface for food.

Twilight zone

The area of a cave where light progressively diminishes to zero.

Unconfined aquifer

A water table aquifer or an aquifer that does not have an impermeable bed between the water table and the lands surface eg. Alluvial and Coastal Sand Bed aquifers.

Unsaturated zone

The zone between the land surface and the water table. Sometimes referred to as the vadose zone.

Value

The ecological or conservation value or uniqueness of an ecosystem.

Vulnerable

Taxa believed likely to move into the 'Endangered' category on the near future if the causal factors continue operating. Included are taxa of which most or all the populations are decreasing because of over-exploitation, extensive destruction of habitat or other environmental disturbance; taxa with populations that have been seriously depleted and whose ultimate security has not been assured; taxa with populations which are still abundant but are under threat from severe adverse factors throughout their range. In this work the IUCN explanation will be interpreted to include populations which are geographically isolated, and genetically and/or morphologically distinct, Horwitz, 1990.

Vulnerability

The severity of decline in ecosystem health or function if a threat was realised.

Water quality

The chemical quality of groundwater expressed in terms of pH, salinity and/or other potential constituents, including nutrients and contaminants.

Water table

The water table is the level at the very top of the zone of saturation. A few centimetres above this level water can also be found due to capillary action. In the presence of a pumping well, the water table will drop around the well. This situation is called drawdown (see perched water table).

Water table aquifer

The water table aquifer is the top aquifer that supports the water table. The top limit to this aquifer is the water table itself.

Water table well

A water table well is a well that only extends down into the water table aquifer.

Well

A borehole that has been cased with pipe, usually steel or PVC plastic, in order to keep the borehole open in unconsolidated sediments or unstable rock. Often used interchangeably with the term bore although wells are generally larger.