A Review of Groundwater Dependent Terrestrial Vegetation and Groundwater Depth for the Namoi Catchment Management Authority, NSW.

June 2013

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Table of Contents

Cover photograph–Eucalyptus in wetland. Photo by Peter Serov, Stygoecologia.

Executive Summary

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 terrestrial Groundwater Dependent Ecosystems (GDEs) and groundwater resources, along with possible impacts on surface water in connected environments.

The Namoi Catchment Management Authority (Namoi CMA) identified in its assessment of Groundwater Dependent Ecosystems as part of the development of the‘Namoi Catchment Action Plan 2010-2020 (See page 52-54) that a threshold of 30m was important to sustain and protect GDEs within the Namoi CMA. The Namoi CMA commissioned Stygoecologia to conduct a literature review examining the relevance of this threshold in the context of the range of groundwater ecosystems present within the Namoi valley, with a specific focus on the water level requirements of groundwater dependent terrestrial woody vegetation communities.

Groundwater dependent ecosystems cover a broad range of both surface and subsurface ecosystems, with each type having a specific water level requirement. Of the seven types of GDE’s listed within Serov et al. 2012, there are six types identified within the Namoi CMA area. These include: karst and caves; subsurface phreatic aquifer ecosystems; baseflow stream (hyporheic or subsurface water ecosystems); groundwater dependent wetlands; baseflow streams (surface water ecosystems); and phreatophytes –groundwater dependent terrestrial ecosystems. All of these ecosystems with the exception of the stygofauna community within the aquifers and the Terrestrial ecosystems have a requirement for the groundwater watertables to be at or within 1-5m of the land surface depending on the GDE type. In these cases the 30m depth threshold is insufficient to sustain or protect these ecosystems. Subterranean stygofauna ecosystems, on the other, while being obligate to the groundwater are more likely to be impacted by water level changes via the secondary changes such as water chemistry and flow direction changes.

Groundwater dependent terrestrial ecosystems that rely on groundwater are particularly at risk from water level fluctuations due to the roots being distributed just above the water table in the vadose zone (the unsaturated zone above the water table). Parameters of the groundwater regime that influence the viability of these GDEs 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 of these fluctuations 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.

The groundwater dependent terrestrial ecosystems include a broad range of subtypes that range from native grasslands to large woody forest species with rooting ranging depths from 1-2m down to >30m depth. The literature highlights that the deeper rooting depths of 30m or greater for the larger tree species are the exception rather than the rule, with the majority of deep rooted woody species only extending down to approximately 10m. With this in mind it

is clear that the suggested 30m groundwater level threshold suggested by the Catchment Action Plan 2010-2020 would not be sufficient to sustain and protect the large woody groundwater dependent terrestrial vegetation within the Namoi CMA area. Instead, it is suggested that groundwater level thresholds be reviewed to 10m in order to appropriately manage these priority ecosystems.

1. Introduction

The Namoi Catchment Authority identified within the Resilience Assessment for Groundwater Dependent Ecosystems of the Namoi Catchment Action Plan 2010-2020 that a threshold of 30m was important to sustain and protect GDEs within the Namoi CMA area. It was also noted within the Namoi Catchment Action Plan 2010-2020 that this threshold "*has been drawn from the available literature but is not specific to the Namoi Catchment and will thus require further specific investigation and adjustment based on local conditions*". This report provides a summary of the information from a literature review of the major papers concerning the water level depth requirements of Ground water dependent ecosystems in Australia, with a particular focus on terrestrial woody phreatophytic vegetation communities (woody Regional Vegetation Communities - RVC) within the Namoi Valley, and the factors that influence their groundwater dependency and their association with groundwater depth.

Many land and water use activities within a catchment have the potential to affect terrestrial groundwater dependent ecosystems (GDE's) function and viability by altering subsurface conditions outside their physiological tolerance ranges. There are a growing number of examples of catastrophic crashes in groundwater ecosystems due to water chemistry alteration such as the activation of acid sulphate soils or saline intrusions, (Ergil, 2000) and water level fluctuations caused by over-extraction. Therefore, an understanding of the groundwater requirements and thresholds for each groundwater dependent community of terrestrial ecosystem is vital in any planning and the setting of appropriate management.

Accordingly, in New South Wales 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 *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, i.e. 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.

Groundwater dependent ecosystems or GDE's is a broad term that encapsulates a vast range of ecosystems across the landscape that relies on accessing groundwater for their survival. One of the largest GDE types in aerial extent is the groundwater dependent phreatophytic terrestrial vegetation communities (Naumburg *et al*, 2005). These are surface vegetation communities that do not rely on the surface expression of water for survival, SKM, 2001. They instead, depend on the subsurface presence of groundwater, often accessed through the capillary fringe; i.e. the subsurface water just above the water table that is not completely saturated, Eamus *et al*, 2006. As water is removed by transpiration it is continually replenished from the water table through capillary rise. Access to the groundwater is dependent on a number of factors with the core factor being the depth to the watertable. As terrestrial vegetation communities are composed of a range of vegetation types with a range of rooting depths and strategies it is only natural that there is a definite relationship between groundwater depth and the types and composition of the vegetation that is able to access it.

2. Review of Key Literature

a) Groundwater in the Namoi Valley

The upper catchment has 13 discrete zones with the lower catchment treated as 1 separate zone. The water sharing plan for the Upper and Lower Namoi Groundwater Sources covers 12 of the upper zones and the lower Zone. The Peel Valley groundwater source will have its own water sharing plan. Deep bores in the lower Namoi access the Great Artesian Basin water source. (Namoi CMA, 2013)

b) Types of GDEs Identified in This Report

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.(Serov *et al*, 2012)

Of the seven types of GDE's listed within Serov et al. 2012 there are six types identified within the Namoi CMA area. These include (and are listed in order of occurrence and an estimated percentage):

- Phreatophytes – Groundwater dependent terrestrial ecosystems supporting terrestrial vegetation and associated terrestrial vertebrates and invertebrate (Common, >50%);
- Subsurface phreatic aquifer ecosystems supporting stygofauna (Common, >50%);
- Baseflow streams (surface water ecosystems) supporting aquatic vertebrate and macroinvertebrates) (Sparse, 10-20%);
- Baseflow stream (hyporheic or subsurface water ecosystems) supporting hyporheic fauna, stygofauna and riparian vegetation (Sparse, <10%);
- Groundwater dependent wetlands supporting surface aquatic vegetation, aquatic vertebrates and invertebrates (Rare, <5%);
- Karst and caves supporting both aquatic stygofauna and terrestrial Troglofauna (Rare, <1%).

The occurrence of these ecosystems within the Namoi CMA area varies considerably from a small number of locations (rare) to GDE types covering vast areas. It is not possible at this point to give accurate percentage coverage of each GDE type as most have not been mapped, however, in terms of aerial coverage the Phreatophytes is the dominant type occupying a significant proportion of the land surface. This is followed by the Subsurface phreatic aquifer ecosystems and the other major type. The other GDE types are regarded as sparse or rare.

All of these ecosystems with the exception of the stygofauna community within the aquifer and the Terrestrial Phreatophytes have a requirement for the aquifer water levels to be at or within 1-5m of the land surface depending on the GDE type. The Terrestrial Woody Phreatophytes have been identified as a priority within the Namoi valley due the dominant coverage of this GDE type within the catchment. These GDEs relies on the availability of groundwater below the surface but within its rooting depth. It is differentiated from wetland vegetation by not requiring seasonally or perennially saturated soil profiles and groundwater at or near the lands surface although in reality distinguishing between the two can be difficult. Woody phreatophytes are generally characterised by a large deep tap root that extends to the water table. Water is generally accessed from the capillary fringe immediately above the saturated zone (Eamus *et al.* 2006). Wetland species, on the other hand, are adapted to permanently waterlogged conditions.

c) What is Phreatophytic Vegetation?
Species of vegetation can be considered to be dependent on groundwater if at some point during their life history or at particular time of the year if they:

- Occupy a habitat that is associated with or maintained by groundwater discharge;
- Occupy a habitat that is associated with or maintained by a shallow water table;
- Require water chemistry or quality conditions that are provided by or significantly influenced by groundwater.

Phreatophytes are plants that meet their water requirements by water uptake from groundwater or its capillary fringe. In summary, terrestrial vegetation can extract water from:

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

Trees mostly take up groundwater from the capillary fringe. Direct uptake 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. As water is removed by transpiration it is continually replenished from the water table through capillary rise. The rise and fall of the capillary zone reflects the rise and fall of the water table. The height of the capillary zone depends largely on soil type; ranging between 40 and 50 cm in sandy soils and between 1.5 – 2 m in heavy clay soils (Eamus *et al.*, 2006).

Groundwater, for many terrestrial plants, forms only part of the overall water requirement, particularly where rainfall is seasonal and soil water has the potential to be regularly replenished (Howe *et al* 2007). Vegetation will extract water from 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 first before seeking deeper soil water or groundwater (Eamus and Froend, 2006). Where there is insufficient soil water to meet plant water requirements, plants that can access groundwater will become increasingly dependent on that water source as soil water is depleted (Howe *et al* 2007).

Some plants can adapt to changes in groundwater levels by extending root networks to greater depths. The relative change in depth to groundwater will determine how well root systems can transport water from a greater depth. If the groundwater depth exceeds the maximum rooting depth of a species, groundwater cannot be accessed as a water source. A water table that declines at a rate that exceeds the capability for root growth to pursue it will leave a plant stranded and dependent on other sources of water such as rainfall and residual soil moisture (Dillion *et al* 2009). Differences between species can however, limit the capacity of plants to rapidly switch to shallower soil water (if it is there), meaning that each species will be uniquely affected by declines in groundwater levels (Naumburg *et al.* 2005). Therefore, even if a species can still tap into groundwater, transport limitations (which vary between species) may reduce water availability and cause a reduction in above ground biomass (Naumburg *et al*. 2005).

It is important to note that the dominance of shallow rooted vegetation in wetlands means that wetlands are more susceptible to water table declines than phreatophytic vegetation (Dillion *et al* 2009). A decline in water tables can result in the loss of species intolerant of drying and their gradual replacement by more drought-tolerant terrestrial species with broader ecohydrological ranges. Dillion's *et al* (2009) investigation of the impact of water table decline suggests that many wetlands display a proportional response to drawdown and concluded that the magnitude and rate of water level change is critical in determining potential impact on a wetland (see also Froend *et al.* 2004; Dillion *et a*l 2009).

d) Groundwater Dependency of Terrestrial Vegetation Ecosystems
Plants potentially have access to a range of water sources including groundwater, soil water, stream water or recent rainfall, and, in many cases, may use water from a variety of these sources simultaneously (Dawson and Pate 1996; Zencich *et al.* 2002). Phreatophytes dependence on groundwater can be variable, ranging from partial and infrequent dependence, i.e. seasonal or episodic, to total (entire / obligate), continual dependence. The fundamental tenet of ecology is *that ecosystems will generally use resources in proportion to their availability and the availability of different resources will be a significant determinant of structure and composition* (Eamus *et al* 2006). It is assumed, therefore, that if a terrestrial vegetation ecosystem can access groundwater then that ecosystem will (generally) develop some degree of dependence and that dependence will likely increase with increasing aridity (Hatton and Evans, 1998) i.e. as other resources or sources of water become depleted.

Groundwater dependency can be inferred by examining factors that include distribution, landscape location, and physiological water requirements. See Table 1 below for a list of factors for determining groundwater dependence of terrestrial vegetation, (extract from Serov *et al*, 2012).

Table 1: Determination of Groundwater Dependency (Serov et al, 2012).

General questions for all GDE types:
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 (e.g. 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? (e.g. topographically low areas, major breaks of topographic slope i.e. cliffs or escarpments, alluvial and coastal sand beds aquifers, gaining streams)?
Does the ecosystem withstand prolonged dry conditions without obvious signs of water stress?
Expert opinion indicates that the ecosystem is groundwater dependent?
GDE Type specific questions:
Phreatophytes –Groundwater Dependent Terrestrial Vegetation
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 (i.e. accessing) with this groundwater?
Is the vegetation community known to function as a refuge for more mobile fauna during times of drought?
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 annual rate of water use by the vegetation significantly larger than annual rainfall at the site ie. for sites that are not receiving significant amounts of lateral surface and sub-surface flows?
Does the vegetation in a particular community occur along stream lines?

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?

These questions should be considered as a guide only as some species use groundwater to variable degrees and may not always require groundwater to meet its habitat requirements. In some locations, species can occur in habitats that are maintained by groundwater but the same species can also occur in locations that are not maintained by groundwater as long as their habitat requirements are met. In some arid areas, a species may not require the presence of groundwater but it may grow more vigorously if groundwater is available (Naumberg *et al.*, 2005).

Studies undertaken in Pioneer Valley, Queensland (Howe *et al*, 2005) indicate that plants occurring in areas of shallow water tables are more likely to exhibit a higher degree of dependence on groundwater than vegetation occurring in areas where water tables are deep. Froend & Zencich (2001) suggest that the greater the depth to groundwater, the lower the requirement for groundwater and the more tolerant vegetation is to water table decline due to a corresponding reliance on alternative water sources such as soil moisture. Froend & Loomes (2005) report that groundwater becomes less important to terrestrial vegetation when depths to groundwater exceed 10 m while Froend and Zencich (2001) note that the probability of accessing groundwater at depths of greater than 20m is low. While it possible that vegetation might use groundwater at depths of 10 to20 metres (e.g. Jarrah trees – Dell *et al* 1983), Froend and Loomes (2006) suggest that groundwater use at those depths is negligible in terms of total plant water use.

Griffith and Wilson (2007) and Griffith *et al.*, (2008) divide vegetation into facultative and obligate GDEs. This division is based predominantly on depth to the water table and generalised topographic location. Swamp sclerophyll shrublands, wet heathlands and sedgelands growing in swales and swamps and subject to shallow water table levels were classified as obligate GDEs whereas dry sclerophyll tree Mallee, dry sclerophyll shrublands and dry heathland occurring on beach ridges and dunes and subject to deeper water table levels were classified as facultative GDEs

Driscoll and Bell (2006a&b) also established that facultative and obligate species within the Tomago Sandbeds (NSW) could be correlated with various water table levels:

- Obligate wetlands occurred generally in areas where depths varied between 0 to 1 m.
- Obligate terrestrial GDEs occurred generally in areas where depths varied between 1 and 2 m.
- Obligate/facultative mixed GDEs occurred generally in areas where depth varied between 2 and 3 m.
- Facultative GDEs occurred generally in areas greater than 3 m.

While depth to groundwater is often the most important attribute for vegetation relying on the subsurface provision of groundwater, for wetlands it is the depth of inundation and frequency of inundation that appears most important to ecosystems relying on both surface expressions of groundwater and overland flow of surface waters

3. Groundwater Depth and Terrestrial GDE's

The critical issue for phreatophytic vegetation is the depth of the water table below ground surface, and its accessibility by roots. The root systems of woody trees and shrubs typically extend vertically and laterally into the soil for considerable distances, and in so doing, retrieve water and nutrients from both deep and shallow soil layers. Since the availability of water at different soil depths varies markedly with season, roots exhibit corresponding adaptive spatial and temporal patterns of uptake and redistribution of water (Burgess et al., 2000). The rooting depths can vary not only among plant types, but also among different soil types for the same plant. If roots can reach a source of fresh water it is generally accepted that this water will be absorbed by the roots and transpired by the canopy (Eamus 2009). The shallower the water table the more likely it will be that the vegetation can access groundwater during dry periods. The deeper the water table the harder it will be for the vegetation to access that groundwater.

The importance of groundwater to plants will be determined by five factors:
1) The proximity of groundwater to plants (i.e. rooting depth vs water table depth);
2) The distribution of roots;
3) The availability of shallow soil water;
4) Aquifer type;
5) Landscape Setting.

The importance of these factors to a terrestrial vegetation community is described below and can also be determined through the series of questions listed below (See Table 1).

1) Plant Rooting Depths verses Water Table Depth

The literature indicates that depth to groundwater can have a significant impact on plant water use and growth (Thorburn *et al*, 1995; Cramer *et al.,* 1999; Morris 1999; Silberstein *et al.,* 1999; Hatton and Evans 1998; Eamus *et al.,* 2006; Froend and Loomes, 2006; Brownlow *et al.,* 1994).

Cannadell *et al*., (1996) reviewed rooting depth of vegetation world-wide and concluded that the average root depth for sclerophyllous forest trees was approximately 4m and around 3m for grasslands and herbaceous plants. Schenk and Jackson (2002) report that maximum rooting depths and lateral root spreads of different plant growth forms were positively related to their typical above-ground sizes, with trees having the largest root systems and annuals the smallest. Many species in arid and semi-arid environments have shallow, spreading root systems ((e.g. herbaceous annuals, desert ephemerals and succulents have shallow roots systems (<0.3 m) as does herbaceous perennials (<1.5 m)) (Maitre *et al* 1999). Schenk and Jackson (2002) review indicated that maximum ecosystem rooting depths for herbaceous plants is less than 2 m for most arid environments and 4 m in climates with >750 mm precipitation.

Most riparian plant communities use groundwater to degrees which vary spatially and temporally (Baird *et al.* 2005; Naiman *et al.,* 2005). Along the Daly River in the Northern Territory for example, trees nearer the river used more groundwater than those further away and higher above the river (O'Grady *et al.* 2006). In arid areas, the growth of riparian vegetation is influenced by depth to the water table, which fluctuates seasonally (Martí *et al.*, 2000). In artesian areas, groundwater is able to support shallow-rooted vegetation communities because pressure brings the water to the surface at springs.

The literature indicates that for some Australian phreatophytic vegetation, water table depths greater than 2m is considered deep (Jackson *et al* 1996). For example, Veneklaas and Poot (2003) found that Western Australia *Banksia* species associated with GDEs of the Swan

Coastal Plain accessed groundwater 2m deep, whilst Groom *et al*. (2000b) classified native species of the Swan Coastal plain as shallow (<1m), medium (1-2m) and deep rooted (>2m).

Wetlands that dependent on groundwater require that the water table be at or near the ground surface and that groundwater levels be episodically or periodically within the root zone for use when soil water availability is low. Wetlands usually have shallow groundwater, allowing plant roots to reach the groundwater, if necessary, and satisfy demands for water and nutrients (Groom *et al.,* 2000a&b). Many of the species common to wetlands have shallow roots systems and are relatively intolerant of drying out. In general however, little is known about the rooting depths of wetland plants and reliance on groundwater when surface water is unavailable.

The deepest roots of shrubs reach greater depths of about 5m in climates with >125 mm precipitation, but slightly less in drier climates. If water is found at such depths, it could potentially be made available to more shallowly rooted plants by hydraulic redistribution (Schenk and Jackson 2002). Investigating Wallum vegetation along the east coast of Australia, Griffith et al (2008) reported that plant roots were present at the upper boundary of the aquifer, that is, at depths of up to 10.5 m, suggesting that some wallum species are capable of developing deep root systems to access soil moisture associated with the aquifer.

The roots of many eucalypts can draw water from depths of greater than 20m and are able to transpire water from depths normally out of reach by grasses and shrubs (Stirzaker *et al*. 1999; Stirzaker and Vertessy 2000). Work undertaken by Griffith (2004) indicates that rooting depths within sand-plains can exceed 10m. Griffith (2004) recorded roots up to 15m deep and root to shoot ratios of 5:1 for plants less than 1.5 metres tall on high sand dunes. This means that a 1 metre shrub is capable of extending root growth to 5 metres. Smith (2006) based rooting zones on the idea that sub humid woody species and Mediterranean woodlands were more likely to target deeper aquifers, with the majority of woodland systems having rooting depths <17 m; that larger, taller trees generally have deeper root systems; and maximum rooting depths for Eucalyptus species was around 30 m (based on those recorded in previous studies).

Maitre *et al* (1999) reported that Eucalyptus is a genus which has deep root systems, often reaching 10 m and greater .Dell *et al.* (1983) recorded *Eucalyptus marginata* roots at depths of 40 m in the south-west of Western Australia. O'Grady *et al.* (2006) found that *Corymbia clarksoniana* appeared to be accessing groundwater at depths of 12 m and Howe *et al.* (2007) reports evidence of groundwater uptake by *Corymbia opaca* in the Ti Tree Basin in central Australia at groundwater depths of up to 20 m. Allison *et al*., (1990) and Nulsen *et al (*1986) documented the rooting depth of predominant Mallee trees (Eucalyptus, Acacia and Casuarina) to be in the range of 20-30m. Research by Dawson and Pate (1996) indicate that root systems of phreatophytic woody plants (*B. prionotes*, *B grandis*, species of Grevillea) within Mediterranean type environments of south western Australia have both nutrient acquiring lateral roots within the top 40cm of the soil profile and deeper tap roots that reached the water table at 2 to 5m. Maximum rooting depth of deep-rooted phreatophytic species (Banksia woodlands) of the Swan Coastal plain ranged between 6 and 9m (Groom 2000a, Groom 2004).

Information on rooting depths is limited. A comprehensive list of phreatophytes does not exist, particularly in view of the fact that some species may access groundwater only if required. Literature searches list the following as potential phreatophytic species (this list is not inclusive)

Table 2 lists the known rooting depths for some Australia species. The ones highlighted are those found within the Namoi CMA area and the Darling River system. The others provide an indication of rooting depths for other related vegetation.

Table 2: Rooting of Australian vegetation species.

Species	Max rooting depth	Habitat	Region	Author
Eucalyptus signata	3	sandy soil	NE Australia	Westman and Rogers 1977
Eucalyptus sp.	10	sand dune	NE Australia	Westman and Rogers 1977
Banksia marginata	2.4	sandy soil	SE Australia	Specht and Rayson, 1957
Banksia ornata	2.4	sandy soil	SE Australia	Specht and Rayson, 1957
Daviesia brevifolia	2	sandy soil	SE Australia	Specht and Rayson, 1957
Eremaea pauciflora	2.4	grey sands with hardpan	SE Australia	Dodd et al 1984
laudonia behrii	2	sandy soil	SE Australia	Specht and Rayson, 1957
Leptospermum myrsinoides	2.3	sandy soil	SE Australia	Specht and Rayson, 1957
Phyllota pleurandroides	2.3	sandy soil	SE Australia	Specht and Rayson, 1957
Phyllota remota	2.4	sandy soil	SE Australia	Specht and Rayson, 1957
Spyridium subochreatum	1.9	sandy soil	SE Australia	Specht and Rayson, 1957
Banksia sp.	5	podsolized sand	SW Australia	Low And lamont, 1990
Calytrix flavescens	2	grey sands with hardpan	SW Australia	Dodd et al 1984
Casuarina mueleriana	2	Sandy soil	SW Australia	Specht and Rayson, 1957
Casuarina pusilla	2.4	sandy soil	SW Australia	Specht and Rayson, 1957
Eremaea beaufortioides	6	alluvial sand with colluvial	SW Australia	Hnatiuk and Hopkins 1980
Hibbertia hypericoides	2.1	grey sands with hardpan	SW Australia	Dodd et al 1984
Jacksonia floribunda	3.1	grey sands with hardpan	SW Australia	Dodd et al 1984
Jacksonia furcellata	2	grey sands with hardpan	SW Australia	Dodd et al 1984
Melaleuca scabra	2	grey sands with hardpan	SW Australia	Dodd et al 1984
Melaleuca seriata	2.1	grey sands with hardpan	SW Australia	Dodd et al 1984
Petrophile linearis	2	grey sands with hardpan	SW Australia	Dodd et al 1984
Schltzia involucrata	1.9	grey sands with hardpan	SW Australia	Dodd et al 1984
Stirlingia latifolia	2.6	grey sands with hardpan	SW Australia	Dodd et al 1984
Xanthorrhoea australis	2.4	grey sands with hardpan	SW Australia	Dodd et al 1984
Eucalyptus marginata	15	lateritic, sandy-clay	SW Australia	Kimber 1974
Eucalyptus marginata	20		SW Australia	Carbon et al 1980
Eucalyptus marginata	40	fissured granite, clay subsoil	SW Australia	Dell et al 1983
Eucalyptus regnans	2.7		SW Australia	Incoll 1969

Eucalyptus trees have an extensive network of horizontal roots, allowing them to scavenge for moisture from many metres beyond their canopy (Johns *et al*., 1984) as well as from depth. The roots of eucalypts can draw water from depths greater than 20 m and are able to transpire water from depths normally out of reach by grasses and shrubs (Stirzaker *et al*. 1999). *Eucalyptus macrorhyncha*, for example, grows on range of soil types but which are usually clayey and well-drained. Its root system is moderate to deep or shallow and spreading. Depending on local conditions, it can therefore rely on groundwater for survival. Swamp sclerophyll communities (*Eucalyptus largiflorens; E. camaldulensis* and *E. microtheca*) are common along inland rivers and on floodplains subject to periodic inundation. There is clear evidence based on isotope and sap flow studies that groundwater can play a key role in the maintenance of these woodlands by providing a source of water during dry seasons and droughts.

Site investigations have indicated that *E. coolabah* relies on groundwater. This tree has evolved strategies to meet its transpiration requirements under extreme conditions of flow variability, low rainfall and high salinity. An example is its distribution within the riparian zone, influenced by groundwater salinity and flooding frequency. The shallow water tables and extended drought periods can limit accessible water to a relatively narrow zone where trees must compromise between the reliability and quality of water. *E populnea* is known to occur on shallow aquifers on the floodplain of the upper Namoi and considered to be a GDE (http://www.cottoncrc.org.au/files/34511bd2-3364-4cc0-9281-994d00a45def/BDRES.pdf)

The rooting depth of Mallee trees (*Eucalyptus*, *Acacia* and *Casuarina*) can be in the range of 20-30m (Allison *et al.*, 1990). Unlike the more shallow rooted herbaceous species, Mallee Eucalypts tend to grow in summer, even though this is the drier season. The sandy soils of the Mallee country tend to favour Mallee trees rather than herbaceous plants because most of the water in the soil is found at depth rather than near the surface. As well, Mallee vegetation concentrates rainfall down their stems to the base of the tree, to such an extent that the amount of water in the soil around the base can be up to ten times higher than the actual rain received (Allison et al., 1990). Ogyris (2002) noted that rooting depths for many species within the Mallee country are no greater than 2m. The author suggested that in the low lying parts of the Mallee landscape (those regions typically at high risk of salinisation), an underlying shallow calcrete layer occurs and it is likely that where this calcrete layer exists, Mallee perennial species such as *Eucalyptus gracilis* will have roots that spread out more laterally than vertically. The author also suggested that some Mallee Eucalypts have the ability to selectively utilise moisture from different zones of the profile (according to moisture availability).

The root systems of tussock grasslands, particularly where *Austrostipa* spp. and *Gramineae* spp. dominate, can extend up to 4m. (e.g. Eyre Peninsula). It is likely groundwater is accessed by such plants in areas over shallow water tables (Cannadell *et al*,.1996). Other genera that have shallow rooting depths that occur within the Namoi CMA include: *Melaleuca* spp. (e.g. *M. helmaturorum* or Swamp Paperbark); *Allocasuarina* spp. (e.g. *Allocasuarina verticillata*); Rushland/sedgeland (predominantly *Gahnia* spp. and *Lomandra effusa*), typically associated with wetter soil conditions, may also rely on groundwater to some degree, especially where they occur in association with wetlands (Cannadell et al 1996); *Acacia pendula* is common on the medium to heavy, dark riverine soils of New South Wales. This tree is widespread on the fertile clay soils of the Darling River system, especially where there is good access to groundwater.

2) Plant Rooting Structure

Root structure and rooting depths vary across vegetation communities and range from shallow to deep. Schenk and Jackson (2002) note that root systems tended to be shallower and wider in dry and hot climates and deeper and narrower in cold and wet climates (except for trees). Deep rooted species with a dimorphic root structure have a large root capture zone and are capable of using (if available) unsaturated soil moisture (both shallow and at depth) and groundwater (at depth), either derived from the capillary fringe or directly from the water table (Froend and Loome 2005). The root systems of many woody trees and shrubs typically extend vertically and laterally into the soil retrieving water and nutrients from both deep and shallow soil layers. Deeply rooted shrubs and trees are found in all climates, a result of phreatophytic species occurring wherever groundwater is within reach of their roots (Schenk and Jackson 2002). Plant roots will only grow as deeply as needed to fulfil plant resource requirements with rooting depths increasing if water is available at depth or if there is transpirational demand for it (Schenk and Jackson 2002).

In general, shallow root systems are favoured over deep root systems (Schenk and Jackson 2002) because (a) energy costs for construction, maintenance and resource uptake are lower for shallower roots (Adiku *et al* . 2000) and b) nutrient concentrations are often greater in the upper soil layers (Jobbágy and Jackson 2001). The depth to which plant roots can grow is a key constraint in their ability to exploit groundwater. Although the majority of root biomass occurs in the top 50cm of the soil profile, it is well established that plants have the capacity to explore soil profiles to much greater depths (Cannadell *et al.*, 1996). There are examples of roots penetrating compact clay soils, rocky soils or through hard pans. Roots can follow cracks, fissures or channels to access groundwater at depth (e.g. Crombie *et al* 1988; Dell *et al.* 1983; Nambiar and Sands 1992; Poot and Lambers 2008, cited in O Grady *et al* 2010).

3) Soil Characteristics

Vegetation growing on soils of lower water holding capacity is more likely to require additional water (i.e. groundwater) than vegetation growing on soils with high water holding capacity. The soils on hill tops and steep slopes have a low water holding capacity. The soils on foot-slopes are likely to have a moderate water holding capacity. The water holding capacity of floodplains can vary, depending on the nature of the substrate.

Soil type and structure plays a major role in a plants ability to access ground water. Soils that are deep and well drained provide no apparent impediment to rooting depth. Many species develop larger, deeper root systems within coarse textured soils (Martre *et al*. 2002; Xu and Li 2008). Extensive and deep root systems with a large surface area facilitate greater soil water uptake) and allows extraction of water from a larger soil volume (Xu and Li, 2008). Deeper roots allow plants to shift water uptake to deeper layers during drought and avoid hydraulic failure (Hacke *et al*. 2000).

Finer textured subsoil can frequently have low permeability and high soil strength, restricting water entry and reducing root growth and water availability (Xu and Li, 2008). Plants with a larger canopy may also need larger root systems in coarse textured soils, because such soils have smaller water-holding capacities and deeper infiltration depths (Schenk and Jackson 2002)

4) Vegetation type associated with aquifer types.

The type of aquifer and its porosity can influence both the levels of groundwater as well as the accessibility of the water to plants. Terrestrial vegetation and wetlands located within alluvial or coastal sand aquifers are likely to be dependent on groundwater.

Unconfined aquifers are located close to the permeable ground surface and have a strong interaction with waterways, wetlands and terrestrial vegetation. An unconfined aquifer is typically shallow and comprised of surface sands and sandstones. A common example of an unconfined aquifer system is a coastal dune system with the water table forming the upper boundary of the aquifer. Unconfined sedimentary aquifers are also known as water table aquifers. Unconfined aquifers can contain clay or peat lenses that impede vertical water flow

Within alluvial aquifers, groundwater is stored in the pore spaces in the unconsolidated floodplain material in which floodplain vegetation grows and wetlands are situated. Significant interaction between ground and surface water can occur where alluvial aquifers occur in up-river situations and that are made from coarse materials such as sand and gravel.

In the lower catchment areas (i.e. coastal floodplain alluvium), where alluvial materials tend to be finer, there is less inter-play between ground and surface water (Department of Water and Energy, 2007).

Confined aquifers have an impermeable or semi-permeable layer above them (an aquitard) which prevents the vertical movement of water. Groundwater levels do not vary as much as in unconfined aquifers as they are usually further from the surface. They have limited or no interaction with the ground surface above them. Recharge typically occurs where the aquifer outcrops at the surface or between aquifers. The annual recharge rate is often small relative to the amount of water stored in the aquifer. Discharge typically occurs down flow of the recharge areas, and it can often take hundreds or thousands of years for the recharge water to move through the system to a discharge points Confined aquifers interact with ecosystems within the aquifers themselves and also at surface discharge points.

5) Landscape settings for terrestrial GDE's

Phreatophytes can occur in upland and riparian settings in both humid and arid areas.

a) Upland settings.

Plants in upland settings have two potential sources of water:
1) Soil moisture; and
2) Groundwater.

It can however be difficult to determine groundwater dependency for trees higher in the landscape**.** Phreatophytic trees use soil water when supplies are non-limiting and may only revert to groundwater during prolonged drought (Dawson and Pate 1996). The hydrology of mountainous terrain is characterized by highly variable precipitation and water movement over and through steep land slopes. On mountain slopes, macropores created by burrowing organisms and by the decay of plant roots have the capacity to transmit subsurface flow downslope quickly. In addition, some rock types underlying soils may be highly weathered or fractured and may transmit significant additional amounts of flow through the subsurface. In some settings, this rapid flow of water can result in hillside springs. Near the base of some mountain-sides, the water table can intersect the valley wall some distance up from the base of the slope, resulting in perennial discharge of ground water and, in many cases, the presence of wetlands.

b) Riparian setting.

Plants growing in valley bottoms and along river margins generally have better access to water than plants growing in upland areas. Although plants growing in riparian areas can access stream water, a number of species have been identified that use groundwater as their main water supply, particularly in gaining river systems (where the water table is higher than the river), while other species can use both stream water and groundwater.

4. Threatening Processes for Terrestrial GDES.

a) Impact of Water Level Changes to Terrestrial Vegetation Ecosystems

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.

A decreasing water table often results in plant water stress and reduced live biomass. Phreatophytes depend on groundwater to prevent water stress. Water stress can led to a change in plant condition and/or reduced vigour or mortality of leaves, branches or the entire plant. Changes in the composition and/or structure of vegetation and animal communities in response to changes in groundwater availability or quality can be observed or measured (Froend, *et al.*, 1993; Roberts *et al.*, 2000). Measurable changes in the vigour of vegetation, associated with reduced water availability, are the precursor to changes in distribution and composition. As water requirements are not being met, the vigour of individuals within a population will decline (water stress, branch die-back, reduced growth, leaf shed, chlorosis), leading to loss of individuals at drier areas of the water availability gradient (altered distribution), or total loss of the local population. Any such changes provide an indication that the ecosystem under consideration is potentially groundwater dependent.

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.

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A community's response to an impact can be subtle. For example, excess lowering of water levels may 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.

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 rate of water level change (rate of drawdown).

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. The length of time the alteration is in effect.

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 seasonal timing of the alteration.

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; i.e. as the water table drops the condition decreases relative 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.

A secondary effect on terrestrial ecosystems and other GDE’s from the alteration of groundwater levels is the mobilisation and transport of salts. 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.

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.

5. Current Legislative Management for Phreatophytic Vegetation.

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.

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.

1.0 Regulatory Rules
There are five main types of regulatory rules which operate to protect groundwater dependent terrestrial vegetation communities in the water sharing plans. These are summarised as follows:

1.1 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.

1.2 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.

1.3 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.

1.4 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.

1.5 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.

2.0 Implications of Recommendations

This report and its findings is a component of the on-going adaptive management strategy incorporated into the macro water sharing plans. As new information if acquired it is incorporated into the strategy for a more equitable and sustainable sharing of the groundwater resource between the community, industry and the environment. This adaptive management 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 on-going data gathering program is to ensure that the ecological values identified within the environment and the water quality and quantity values required by the community are retained and/or improved by mitigating any identified risk.

The Namoi Catchment Management Authority (Namoi CMA) identified in its assessment of Groundwater Dependent Ecosystems (as part of the development of the‘Namoi Catchment Action Plan 2010-2020 (See page 52-54)) that a threshold of 30m was important to sustain and protect GDEs within the Namoi CMA. This threshold however, needed to be considered and assessed in terms of the requirements for terrestrial vegetation GDE’s against the ever increasing pressure on the limited groundwater resources within the Namoi CMA area. This is particularly important in terms of the risk posed by over-extraction of groundwater to the sustainability of terrestrial Groundwater Dependent Ecosystems (GDEs) and the quality and quantity of groundwater resources, along with possible impacts on surface water in connected environments.

This literature review examined the relevance of this threshold in the context of the water level requirements of groundwater dependent terrestrial woody vegetation communities. In the light of the information presented in this report it is recommended that the groundwater threshold of 30m be reviewed and changed to 10m.

The implication of this change is as follows:
1) There will be no immediate impact to current entitlements or rules within the Namoi Water Sharing Plans. As part of the adaptive management process each of the Water Sharing Plans are developed and implemented over a five year cycle, with new information progressively acquired and fed into the decision making process for the future round of individual Water Sharing Plans. In most aquifers, there is insufficient information to develop adequate plan rules to manage the specific elements in 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 to water users.

2) This information will have long term benefits for the environment and the community by providing adequate water levels that are more closely in line with the natural fluctuations and in turn. This recommendation is intended as a starting point that will inform future decisions making for the management of the water resources within the Namoi catchment. This information is intended to ensure that water levels in an aquifer are not depleted detrimentally beyond seasonal variations. As water quality can also decline as a resulting of excessive extraction this information and future management strategies will ensure sustainable water levels will also assist in maintaining water quality for all water users for the benefit of both present and future generations.

6. Recommendations

Groundwater dependent ecosystems cover a broad range of both surface and subsurface ecosystems, with each type having a specific water level requirement. Of the seven types of GDE's listed within Serov et al. 2012 the woody terrestrial vegetation community is identified as a priority GDE within the Namoi CMA area. The examination within this report of the range of rooting depths for many species of terrestrial ecosystems has identified that there is a requirement for the aquifer water levels to be at or within 1-10m of the land surface in order to sufficiently sustain or protect these ecosystems.

Froend & Loomes (2005) report that groundwater becomes less important to terrestrial vegetation when depths to groundwater exceed 10 m while Froend and Zencich (2001) note that the probability of accessing groundwater at depths of greater than 20m is low. While it is still likely that vegetation might use groundwater at depths of 10 to20 metres (e.g. Jarrah trees – Dell *et al* 1983), Froend and Loomes (2006) suggest that groundwater use at those depths is negligible in terms of total plant water use.

Terrestrial ecosystems that rely on groundwater are particularly at risk from water level fluctuations due to the roots being distributed just above the water table in the vadose zone. The terrestrial vegetation ecosystems however, have a broad range of subtypes that range from native grasslands to large woody forest species with rooting ranging depths from 1-2m down to >30m depth. The deeper rooting depths of 30m or greater for the larger tree species are shown to the exception rather than the rule, with the majority of deep rooted species only extending down to approximately 10m. With this in mind it is clear that the 30m groundwater level threshold suggested by the Catchment Action Plan 2010-2020 would not be sufficient to sustain and protect any of the six GDE types recognised within the Namoi CMA area. Instead, it is suggested that groundwater level thresholds be determined by the level requirements of each type and subtype (in the case of Phreatophytic vegetation).

In the light of this finding it is recommended that the groundwater threshold of 30m be reviewed and changed to 10m. The implications of this change will have long term benefits for the environment by providing water levels that are more closely in line with the natural fluctuations and long term benefits to the community in terms of groundwater water resource security. This recommendation is intended at this point in time only as a starting point for current and future discussion that will inform future decisions making for the management of the water resources within the Namoi catchment.

7. Acknowledgements

This report was prepared for and funded by the Namoi Catchment Management Authority. We wish to thank Laura Kuginis for her invaluable expert contribution of ideas and references to this work and Bronwyn Cameron and Francesca Andreoni for her ongoing support and assistance.

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