Expert Review of groundwater depend ecosystems assessment for the Narrabri Gas Project EIS.

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Summary

1. . The aquatic ecology of Bohena Creek is not generally in poor condition as claimed in the EIS. Surveys found while some areas show dieback, most parts of the creek are in a good condition, supporting old growth red gum-rough-barked apple woodlands and permanent/semi-permanent waterholes (about 30).
2. Hydrological modelling on the impacts of treated water release into Bohena Creek relies on a principle of maximum dilution during periods of high flow but ignores the fact that surface flow can be trapped in creek features and can accumulate on the creek bed and within the shallow aquifers. No assessment has been undertaken on the impact of toxins within waterholes, which get recharged during periods of high flow.
3. The EIS states that depressurisation of aquifers may result in a drop of 0.5m, though even a drop of 0.5m could have significant impacts on the permanence of some waterholes and shallow water tables associated with alluvial areas. However, the modelled drawdown impact on groundwater in the EIS is not credible given lack of supporting data.
4. It seems a stygofauna survey was conducted in a way to minimise the chances of obtaining results, with poor coverage of 'control' areas and serious methodology constraints. Independent surveys conducted by Stygoecologia has discovered a relatively diverse stygofauna (11 taxa), both in alluvial and sandstone aquifers. Any claim that there will be no impact on stygofauna is not credible given this lack of information and given questions relating to the modelled groundwater drawdown and treated water release.
5. Invertebrate surveys have been poorly done with no sampling from good condition waterholes on Bohena Creek. The survey missed a key species, the freshwater mussel *Velesunio ambiguous*, a strong indicator of good health and permanence of these waterholes. These holes also provide refuge for the native fish, freshwater sponges and a range of invertebrates which rely on good water quality.
6. Santos have contradicted the GDE Atlas by claiming that the only surface groundwater ecosystems in Bohena Creek are a few unidentified waterholes which are in poor condition. The Atlas identifies the creek itself as a GDE, 'moderately dependent upon surface expressions of groundwater', the 30 odd waterholes and the upstream springs are the surface expressions of this system. Overall, the Bohena GDE is currently in a good condition and meets the criteria of being a 'High Priority Ecosystem'.
7. . Overall, the aquatic and GDE assessments have been poorly undertaken and should be rejected by both state and Commonwealth consent authorities as being insufficient in detail and lacking in due diligence. A GDE risk assessment carried out here shows all risks fall within the moderate to high category.

Existing Environment

A strong contention within the Aquatic Ecology assessment of the EIS is that,

"*The aquatic ecology communities of Bohena Creek and the Narrabri River/Narrabri Creek are generally in a reduced ecological condition.*" (p.16.1).

This claim is not supported by the evidence on the condition of the riparian vegetation along and within Bohena Creek, provided in the EIS and verified by subsequent independent surveys conducted Ethical Ecology (Survey of Bohena Creek riparian plant communities, report to the Upper Mooki Landcare Inc). In the EIS, ELA report that only four of the sites subject to an aquatic environment assessment were found to be in a degraded condition, mainly due to impacts from surrounding land uses.

Apart from some local areas of dieback, the riparian vegetation associated with Bohena Creek, a tall woodland community dominated Blakely's Red Gum, Rough-barked Apple and White Cypress Pine, was found to be in a 'moderate to good' condition as defined under the BioBanking Assessment Methodology (BBAM), containing a relatively diverse understorey dominated by leaf-litter, grasses and forbs. EcoLogical Australia (ELA) also found threatened orchids, *Diuris tricolor* and *Pterostylis cobarensis* in this community.

Figure 1 (a) Near Oil Well Road *(b) Near Garlands Crossing*

Important features of this riparian environment were the presence of semi-permanent/permanent waterholes, all surrounded by aquatic vegetation in good health. Three of these were inspected during field surveys by Ethical Ecology, only one, 'Toms Hole' was identified and its condition assessed in the EIS (Figure 2). In relation to these waterholes, The EIS states that associated with Bohena Creek,

"*… there are deeper intermittent pools that contain permanent water*" (p. 16-7)

This admission is not further clarified in the EIS, except to contend that these are a few in number and we not found to be in good condition, according to the groundwater dependent ecosystem assessment. However, the aquatic ecology assessment states that

"*Large woody debris, overhanging and trailing vegetation, and benthic leaf packs were also present at the permanent sites*".

How these important habitat features could be construed as being in 'poor condition' for the purposes of the GDE assessment in the EIS is difficult to understand. The number and the location of these waterholes is not identified in the EIS, except for Teds Hole, which was actually found to have the highest Riparian and Channel Environment score (RCE) in the ELA study – 83%.

No biological surveys were undertaken at the holes inspected by Ethical Ecology, though the presence of one key species was easily detected at all of the holes inspected due to its high abundance, the freshwater mussel *Velesunio ambiguous*.

V. ambiguus occurs throughout the Murray-Darling Basin and beyond, including part of the Lake Eyre drainage and coastal areas of New South Wales, Victoria and Queensland. It is associated with impoundments, lakes, billabongs and minor streams, but is not found in large rivers except in regions influenced by dams or weirs and has and is able to withstand periods of water stress (Sheldon and Walker 1989).

However, the presence of this species large numbers at these waterholes suggest a level of permanency of these areas. Other species observed were the freshwater sponge (Spongillidae), water scorpion *Laccotrephes tristis*, gastropods and caddis fly (Trichoptera) larvae. These species are usually typical of diverse macro-invertebrate faunas under the AUSLIG assessment procedure.

There are two other locations for the mussels in the study area within the Australian Museum database,

- AMS_396521. Bohena Ck, 11km from Narrabri, on Culgoora Rd, 300m S of rail bridge., New South Wales, Australia [-30.325, 149.69 ± 1 km].
- AMS_396515. 17 km S of Narrabri, Bohena Creek on Newell Highway, 100m E of road bridge (In sandy mud, in isolated pools), New South Wales, Australia [-30.447, 149.671 ± 1 km]. AMS_100841


Figure 2(a) WH1, Bohena Creek Road *(b) WH2, near Newell Hwy Bridge.*

While it is unclear as to the extent of biodiversity at these water holes, as they remain largely un-surveyed, permanent water like these within an larger ephemeral surface water system are important for river functions, particularly as drought refuge and for connectivity, refuge pools which will support species and population during periods of low flow and then replenish surrounding creek areas during times of high flow.

Figure 3. Velesunio ambiguous from WH1

Analysis of satellite imagery along the course of Bohena Creek within the study area indicated approximately 30 of these waterholes. Most are located downstream of the proposed Bohena Creek treated water release point (Figure 3).

Ground-truthing of three of these locations confirmed they contained permanent pools, but while it cannot be certain that all the location indicated by the satellite imagery currently contain standing water, it is likely that most do, given observed water levels with the satellite imagery matched closely the water level found on the ground.

Figure 4. Location of waterholes along Bohena Creek

Issues relating to the methodology

The ELA study was conducted at 11 aquatic survey sites, most north of the treated water release point. In terms of site selection this study suffers from a lack of sites within control areas south of the release point, important for subsequent monitoring. It also appears that sites were selected during times of high water flow, which diminished in water holding at sites capacity of time. There appears to be have no deliberate sampling of the permanent waterholes, refuge areas where local diversity and function are more likely to be relatively high when compared to the surrounding creek bed.

Water Quality

The EIS found that water quality within Bohena Creek and within the alluvial aquifer was generally found to be within the ANZECC guidelines for water quality, with electrical conductivity (an indicator for dissolved solids) low within Bohena Creek. This is indicative of high quality water.

Studies on groundwater condition within the Bohena alluvial aquifer (Stygoecologia 2017) support this assessment of the alluvial groundwater as being in good condition.

Macro-Invertebrates and fish

"*SIGNAL scores for survey sites in Bohena Creek ranged between 2 and 4.6, indicating severe to moderate disturbance*". (p. 16-12)

The EIS found that macro-invertebrate diversity was poor at all sites, though questions as to the suitability of sampling sites remain. It appears as though refuge areas, important for local diversity were not sampled adequately and that low diversity scores were obtained by sampling drying ephemeral pools on the edge of the creekbed.

"*The Bohena Creek sites were generally in forested areas, so were less vulnerable to historical and ongoing agricultural activities. Here, the invertebrate community was determined by the drying hydrological phase extant during the surveys*." (p.16-12)

Bohena Creek fish surveys identified seven species, two of which are exotic, including the now rare Unspeckled Hardhead, described in the EIS as *Craterocephalus stercusmuscarum fulva*, though which current taxonomy recognises as a separate species *Craterocephalus fulva*. This species was absent from the Namoi River/Creek. This is a reasonably good fish fauna, supporting the notion that Bohena Creek is an aquatic system in good condition.

Stygofauna

Remarkably, no stygofauna were detected during stygofauna surveys conducted by ELA for the EIS, whereas surveys conducted by Stygoecologia (2017) has detected 11 taxa at locations in the Namoi/Pilliga/Warrumbungle area from Namoi Alluvium, Quaternary Colluvium and Jurassic Sandstone aquifers. The presence of species in sandstone aquifers, typically found in more shallow locations is indicative of hydrological connectivity between aquifers.

A likely explanation for this is the poor site selection for stygofauna in the EIS. The survey methodology noted that two of the sample sites were dry, with many from water within the coal bearing seams. Other bores sampled were located next to existing well infrastructure and some sites were surveyed by digging shallow holes into the creek substrate.

Most of these sites have strong constraints and are unlikely to yield stygofauna. Sampling stygofauna from deep coal seams seems incredible as they are not known from these depths (Stygoecologia 2017).

Adequacy of Impact Assessment

Several impacts on the aquatic ecology are identified in the EIS, mainly as a result of impacts arising from the release of treated water into Bohena Creek;

- Impacts as a result of increased water volume
- Impacts as result of changed water quality
- Impacts from water course crossings
- Impacts on stygofauna
- Impacts on riparian vegetation

Aquifer depressurisation

Impacts as a result of drops in the water table as a result of depressurisation from gas well activities is considered in conjunction with impacts upon GDEs but only passingly within the context of general aquatic ecology. It is stated that a likely drop of 0.5m (though possibly more in alluvial areas) is expected in time across the study area. While dismissed as being within normal variation of water table fluctuation in the EIS, this drop has to be considered within the context of a permanent drop in the 'average' water level.

Even this drop in the water table can affect sensitive biota, particularly surface species which require groundwater discharge, such as the freshwater mussel at the waterholes. The water column of alluvial aquifers are not that deep, Serov (2017) measured a depth of between 10-30m at ten Namoi alluvium sites. The water column within Quaternary Colluvium associated with riparian zones the forest may be as little as 2m in depth.

However, given the uncertainty associated with the adequacy of the proponent's groundwater modelling, as raised by some key groundwater experts, this maximum drop of 5 or so metres as a result of the cumulative impact of the production field may be conservative.

Treated water release impacts

The impact resulting from the treated water release are dealt with in the EIS with the contention that:

"*Bohena Creek experiences surface flow approximately 15 percent of the time – generally if rainfall in the catchment exceeds 100-110 millimetres in a given month. During dry periods the water table is an estimated two metres below the creekbed … Historic data from 1995-2005 shows that Bohena Creek flow exceeds 100 megalitres per day at the Newell Highway gauging station around 12 percent of the time.*"

It is proposed to release treated water during time of high flow, though the EIS does not rule out releases at times of lower flow if the need arises. Given that it is claimed high flow only occurs 12% of the time in Bohena Creek, that means for 88% of the time, release of water will be inhibited. It is difficult to see, how this could work given the volumes of water which is being proposed to be produced at the Leewood facility.

According to the data provided, surface flow in Bohena Creek occurs 15% of the time on average, with high volumes occurring 12% of the time. This means that surface flow that is <100 megalitre per day happens only 3% of the time. This does not seem to make sense and does not reflect recent observations of times of high flow in Bohena Creek. Periods of high stream flow in 2016 lasted only a few days following high rainfall.

But even in times of high flow, the stream discharge does not move rapidly and discharge at these times would increase sedimentation rates of heavier particles onto the stream bed and possibly infiltration into groundwater. Times of high flow also connect waters with isolated waterholes raising risks of toxin accumulation in these sensitive sites.

Impacts on stygofauna

Given the lack of results and the survey constraints in the stygofauna survey which was undertaken for the EIS, the assessment of impact on stygofauna is lacking in data and cannot be regarded as being adequate.

Impacts on riparian vegetation

Trees are thought to be more resilient to changes in water availability and quality than understorey vegetation as they may derive some water from groundwater sources. This is particularly true for River Red Gums where even trees close to the stream bed are not reliant on surface water (Thorburn et al. 1996). While the root depth of red gums in the study area is not certain, the current condition of some areas of red gum along Bohena Creek is poor suffering from dieback, with patches of dead trees and with some areas of tree regeneration. These areas also show educed ground-storey diversity and high levels of weed cover.

Figure 5. Red Gum die-back on Bohena Creek.

Whatever the causes of this localised deterioration in conditions in the riparian woodland community, these signs of system stress highlight that sensitivity of these woodlands to current stress factors. Additional impacts from possible contamination and aquifer depressurisation may push areas with reduced resilience past points of recovery.

Type of GDE associated with Bohena Creek

The EIS sums up the presence and significance of GDEs associated with Bohena Creek by stating that there are a number of Type II (surface groundwater system, according to Eamus et al. (2006) – 'waterholes' associated with Bohena Creek, but these are in 'poor condition' and do not meet the requirements of being a High Priority GDE' and therefore not requiring any further consideration. Such a categorisation would most likely negate any trigger under the EPBC Act conditions relating to impacts from groundwater from mining and unconventional gas activities.

However, this is a highly flawed assessment and while reference is given to Eamus et al. (2006) and Hatton & Evans (1998), the procedure followed in the EIS has not referenced the most recent DPI Water guidelines (Serov et al. 2012) which contains a methodology to identify the type and risk that activities may have on GDEs.

Consultants EcoLogical describe the groundwater ecosystem environment in the project area the following way in their EIS for the Dewhurst and Bibblewindi Pilots Projects (Ecological 2012):

"*Within the study region, groundwater is generally close to the surface (<5 m) in the quaternary alluvium associated with the major creeks and floodplains (e.g. Bohena Creek, while generally being much deeper in those areas characterised by Jurassic quartz sandstone (20–50 m) (SKM 2010). The majority of the vegetation within the study region on alluvial soils is likely to have a proportional association with groundwater. Vegetation along the major creeks and floodplains has the potential to be dependent on base-flow groundwater, whilst the vegetation on the alluvial plains is likely to utilise groundwater resources proportionally (depending on rainfall) whilst vegetation on Jurassic quartz sandstone is unlikely to be groundwater dependant*."

"There are minimal areas of permanent surface water within the study region over the course of a year; creeks within the study region were observed to flow for a period of days to weeks following significant rainfall (depending on stream order) and then cease flowing. The few permanent areas of surface water include constructed dams and a number of relatively small groundwater-fed springs. There are three springs listed as high priority GDEs: Eather Spring, Hardy's Spring and Mayfield Spring. These springs are understood to comprise recharge rejection springs associated with the junction of the unconfined Pilliga Sandstone and the underlying Purlewaugh Formation. The Purlewaugh Formation acts as a barrier to further percolation of groundwater within the Pilliga Sandstone and thus groundwater discharges to surface at this interface."

This general understanding has been followed in the current EIS, except that while baseflow conditions have been attributed to the Namoi River, this has not been recognised in the Bohena Creek where the presence of a 'perched aquifer' 2-5m below the surface is acknowledged. This aquifer interface is not associated with the Purlewaugh/Pilliga sandstone interface.

While the three springs mentioned are identified as being the only currently recognised High Priority surface GDEs under the current Water Sharing Plan system, there has been a short-sighted consideration to the GDE associated with Bohena Creek in the EIS, which describes 'waterholes' as having a 'low priority'.

The GDE Atlas classifies the whole Bohena Creek system as being 'moderately dependent upon surface expressions of groundwater', but in their mapping of GDEs, ELA have overlain the Atlas mapping with a revised layer showing that the Bohena system is no different to the general groundwater dependency found throughout the forest, that is with an uncertain connection with sub-surface water.

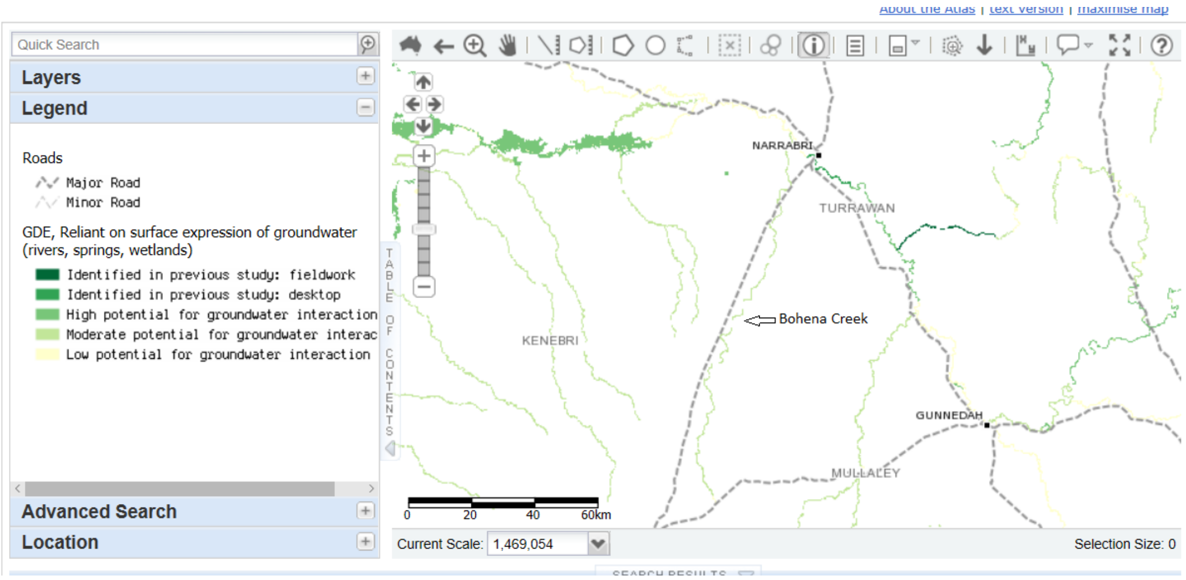

Figure 6. Surface groundwater dependent ecosystems from the Bureau of Meteorology GDE Atlas

This is certainly not consistent with the acknowledgement in the EIS of the shallow perched aquifer associated with this system, the upper catchment spring discharges and the mid-catchment waterholes which are generally semi-permanent or permanent in nature as described above. Rather than the surface GDEs being confined to some waterholes (whose location has not been indicated in the EIS apart from Tom's Hole) the Bohena Creek system, in its entirety, should be regarded as being a 'baseflow stream', as described by Serov et al. (2012) and that the permanent waterholes are the surface expressions of this system.

Is the GDE of a High Environmental Value?

For the purposes of this assessment, the GDE in question is considered here to be both the surface environment containing the terrestrial riparian vegetation, waterholes and their biota and the environment within the alluvial aquifers underlying this system where the stygofauna reside. Both of these should be considered in conjunction as they are essentially part of the same groundwater system, called here the 'Bohena GDE'. Serov et al. (2012) outline an 'Ecological valuation and risk assessment process' to determine environmental value. It states that a:

"High ecological value for an ecosystem is defined as an ecosystem which is in a natural or near natural condition, or that fulfils 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.*

The ecosystems associated with the Bohena GDE are likely to be sensitive to small changes in groundwater discharge or water table levels. Surface waterholes can potentially lose considerable size and extent with only small reduction in groundwater table, due to the shallow grade of the substrate and shallow depth of these features. Species like mussels and freshwater sponges inhabit the shallower fringe of these features and are sensitive to reductions in water depth.

Stygofauna within the shallow alluvial aquifers tend to inhabit a narrow depth of aquifer and are more diverse within areas of surface and aquifer connectivity (Stygoecologia 2017). As such they are sensitive to small changes in the aquifer environment.

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.

The Bohena GDE is partially within the current reserve system, with the upper portion of the creek and the major tributaries of Borah and Yaminbah Creeks (5th order streams) are located within the Pilliga East State Conservation Area an into the Pilliga Nature Reserve.

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. "

It is contended that Bohena Creek supports the threatened ecological community 'White Box-Yellow Box-Blakely's Red Gum Woodland', as listed under the *Threatened Species Conservation Act 1995* (Ethical Ecology 2017).

The Bohena GDE conforms to the definition of being of a High Environmental Value.

Is the GDE a 'High Priority Ecosystem"?

A High Environmental Value 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.

However, the methodology outlined by Serov et al. (2012) includes a process for those GDEs that have either not previously been assessed or acknowledged under existing environmental protection legislation or acknowledged by a State or National Environmental agency, a second mandatory framework to assessed key values and a process for listing newly identified 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 four criteria:

1. GDE environment (surface and subsurface landscape) condition. Evidence presented here indicates that both the surface and sub-surface environments are in a high condition, both the terrestrial vegetation (apart from local patches of dieback) and aquifer environment with the stygofauna present (Stygoecologia 2017).

2. Rarity within catchment and / or hydrological unit. It is contended that Bohena Creek supports the threatened ecological community 'White Box-Yellow Box-Blakely's Red Gum Woodland', as listed under the *Threatened Species Conservation Act 1995* (Ethical Ecology 2017).

3. Diversity within catchment and / or hydrological unit as appropriate. Both the surface ecosystem with a relatively high diversity of plant and associated fauna species and the sub-surface environment with 11 stygofauna species have a high diversity.

4. Special features within catchment and / or hydrological unit as appropriate. A system of surface waterholes in Bohena Creek provide drought refuge in times of low flow and are source areas for time of high flow.

The Bohena GDE could be listed as a High Priority Ecosystem, following further assessment of its values by the relevant authorities.

Environmental Risk Assessment

Serov et al (2012) outline an Aquifer and GDE risk assessment for potential impacts to groundwater. Given the information provided in this report, this assessment has been undertaken here, the assessment table is shown on the net page.

For the water quantity assets, the risk has to be regarded as 'high' given the permanent nature of the impacts of depressurisation on aquifers over the longer term.

For the water quality assets, the risk should be regarded as being moderate to high, given that while water quality changes may for the most part be temporary given natural flushing of the system during high water flows, accumulation of toxins and residuals along the stream bed may occur, leading to reduced water quality over time.

For the aquifer integrity test, it is likely that well development in the catchment, will increase inter-aquifer connectivity, mainly through the construction of hundreds of deep wells through the aquifer layers. It is possible that drilling activity cold damage surrounding aquifer rock and increase fractures. This is a 'moderate' risk in the assessment table.

For the biological integrity assets, a decline in 10% of local diversity or change in species composition warrants a 'high risk' assessment. While it is not possible to be able to accurately predict how a sensitive riparian system may respond to acute stress, current indications within areas of riparian dieback show a system sensitive to stress, and can lose the majority of species and tree cover with increased levels of weed infestation under existing levels of stress. The potential species losses as a result of aquifer depressurisation or contamination may in itself not be high but when considered with existing impacts on stressed systems, the impact may be compounded. A 'moderate' risk in this category seems justified for all four tests.

In summary, the GDE risk assessment procedure using the additional information provided in this report would give a result of 3 categories of high risk, 3 categories of moderate-high risk and five categories of moderate risk. None of the tests in the assessment were thought to have a 'low' risk of impact.

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.

References

Dunn, H., 2000, Identifying and protecting rivers of high ecological value, LWRRDC Occasional Paper, 01/00

Eamus, D. et al., 2006. A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. *Australian Journal of Botany*, 54, pp.97–114.

Eco Logical Australia, 2014. Dewhurst 13-18H, Dewhurst 26-31 and Bibblewindi Multi-Lateral Pilots Biodiversity Management Plan. Prepared for Santos NSW (Eastern) Pty Ltd

Ethical Ecology, 2017. Survey of Bohena Creek riparian plant communities. Report for Upper Mooki Landcare Inc

Hatton, T. & Evans, R., 1998. Dependence of Ecosystems on Groundwater and its Significance to Australia L. and W. R. R. and D. Corporation, ed., 12/98, p.77.

Stygoecologia, 2017. An Investigation of the Stygofauna Community in the Pilliga Area 2016-17. Report for the Great Artesian Bore Water Users Association.

Serov, P., Kuginis, L. and Williams, J.P. 2012, Risk assessment guidelines for groundwater dependent ecosystems, Volume 1 – The conceptual framework, NSW Department of Primary Industries, Office of Water, Sydney

Sheldon, F. and Walker, K. F. 1989. Effects of Hypoxia on Oxygen Consumption by Two Species of Freshwater Mussel (Unionacea: Hyriidae) from the River Murray. *Aust. J. Mar. Freshwater Res.,* 1989, 40, 491-9

Thorburn, PJ, Mensforth, LJ and GR Walker, 1994. Reliance of creek-side river red gums on creek water. Australian Journal of Marine and Freshwater Research 45(8) 1439 - 1443