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If further information becomes available, or additional assumptions need to be made, CDM Smith reserves its right to amend this report.

Appendix B – Groundwater Dependent Ecosystems (Springs) Risk Assessment Report

Groundwater Dependent Ecosystems (Springs) Risk Assessment Report

Narrabri Gas Project

Prepared for
Santos NSW (Eastern) Pty Ltd

September 2016

This report should be cited as 'Eco Logical Australia 2016. *Groundwater Dependent Ecosystems (Springs) Risk Assessment Report*. Reference 2640_007. Prepared for Santos NSW Eastern Pty Ltd.'

ACKNOWLEDGEMENTS

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Abbreviations

Abbreviation	Description
ANAE	Australian National Aquatic Ecosystem Framework
BoM	Bureau of Meteorology
CMA	Catchment Management Authority
DEM	Digital Elevation Model
DotE	Commonwealth Department of the Environment
EHZ	Eco-Hydrogeological Zones
EPBC	Commonwealth *Environmental Protection Biodiversity Conservation Act 1999*
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GIS	Geographical Information System
GMA	Groundwater Management Area
HEV	High Ecological Value
HSU	Hydrostratigraphic Unit
IESC	Commonwealth Government Independent Scientific Committee on Coal Seam Gas
LSTU	Less significant transmissive units
NPWS	National Parks and Wildlife Service
NOW	DPI Water, formerly New South Wales Office of Water
NSW	New South Wales
NTU	Negligibly transmissive units
PTNU	Probable negligibly transmissive units
SEWPaC	Department of Sustainability, Environment, Water, Population and Communities, now Commonwealth Department of Environment
SoC	State of the Catchment
STU	Significant transmissive units
WAIT	Water Asset Information Tool
WM Act	NSW Water Management Act 2000
WSP	Water Sharing Plan

Glossary of Terms

Term	Description
Aquiclude	A saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.
Aquifer	A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.
Aquitard	In relation to an aquifer, a geological unit exhibiting lower permeability. These units may be permeable enough to transmit water in quantities that are significant in the study of regional groundwater flow, but their permeability is not sufficient to allow the completion of production wells within them.
Artesian discharge spring	Springs supported by groundwater pressure and discharge and sourced from confined aquifers.
Confined aquifer	An aquifer that is confined between two aquitards or aquicludes and in which the water level may rise above the upper surface of the aquifer.
Ecosystem	The community of a plant, animal and other organisms existing within a defined area, and their interactions within the community and their non-living environment
Groundwater Dependent Ecosystem (GDE)	Ecosystems which have their species composition and their natural ecological processes determined by groundwater
Spring	A permanent natural surface expression of groundwater (Queensland Herbarium, 2012).
Spring vent	The single point where groundwater is discharged at the surface. This includes mounded or flat areas, or areas represented by wetland vegetation without visible water present on the surface.
Spring complex	If spring vents are located in close proximity to each other, in similar geology and fed by the same aquifer, then the grouping of vents is referred to as a spring complex. No adjacent pair of springs in the complex can be more than approximately 6 km apart. Complexes can contain both active and inactive springs.
Unconfined aquifer	An unconfined aquifer is one that is open to receive water from the surface and there are no overlying "confining beds" of low permeability to physically isolate the groundwater system.
Watercourse spring	This occurs where groundwater enters a stream from an underlying aquifer through the streambed.
Water table spring	Water table seepage to the surface from unconfined aquifer.

Executive summary

Project context

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri. The Narrabri Gas Project (the project) seeks to develop and operate a gas production field, requiring the installation of gas wells, gas and water gathering systems and supporting infrastructure.

In order to address regulatory requirements and enable approval of the project, Groundwater Dependent Ecosystems (GDEs) in the potential impact zone of the project are required to be identified and characterised with respect to their hydrogeological and ecological conditions. Where GDEs are identified within the potential impact zone of the project, appropriate management measures may be required to minimise or mitigate potential impacts to GDEs. This study presents the findings of an assessment of the potential for GDEs reliant on the surface expression of groundwater (Type 2 GDEs, Richardson et al, 2011) to be present within the study area, following the conceptual framework presented in the New South Wales Office of Water's (now Department of Primary Industries (DPI Water)) *Risk assessment guidelines for groundwater dependent ecosystems – Volume 1* (NOW 2012), as summarised below.

Phase 1 - Identification of study area and GDEs

The study area was defined by the numerical model-simulated cumulative maximum predicted extent of drawdown exceeding 0.5 m in key model layers arising from Santos' proposed development, extrapolated vertically to the ground surface. The output from numerical modelling-simulations undertaken as part of a groundwater impact assessment (CDM Smith 2016a) for the project was utilised.

Potential GDE features were identified through a review of literature, databases and following the implementation of remote sensing. A total of 54 potential Type 2 GDE features were identified. These features were subject to an initial screening exercise in order to identify medium to high confidence GDEs for further assessment. Each feature was examined at a greater level of detail, with consideration to the location, type of feature, topography, proximity to natural drainage features and geology, in order to assess the potential for groundwater dependency. As a result, 21 potential Type 2 GDEs of medium to high confidence were taken forward into Phase 2.

Phase 2 – Hydrogeological Dependency and Ecological Value Assessment of GDEs

Characterisation of potential Type 2 GDEs was undertaken to ascertain the groundwater dependency and ecological value to feed into the risk assessment process. A characterisation exercise was undertaken for each of the 21 potential Type 2 GDEs, identifying the hydrogeological conceptualisation of the site. This was supplemented, where possible, by a site inspection undertaken by a suitably-qualified hydrogeologist and groundwater ecologist. Site visits to all locations were not possible either due to refusal of access by the landowner or the lack of information on the relevant landowner to enable contact to be made and access to land to be granted.

The potential for species and habitats protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which could be defined as Matters of National Environmental Significance (MNES), was assessed in detail during Phase 2. The potential for MNES at the 21 potential Type 2 GDEs was considered to be very low. There are no known listed groundwater dependent species present in the study area, and the majority of the observed potential GDEs were considered to be at least moderately modified, and therefore unlikely to contain listed species.

Upon completion of the characterisation, the groundwater dependency of the potential GDE was assessed. A total of nine water dependent ecosystems were considered likely to have part of their water supplied from shallow aquifers. An assessment of ecological value was also undertaken. All nine potential Type 2 GDEs were considered to have low ecological value. On this basis, as per the NSW Risk Assessment Guidelines for Groundwater Dependent Ecosystems (NOW, 2012), it is concluded that the nine potential Type 2 GDEs do not meet the definition of being High Priority GDEs requiring management and therefore do not fall within the requirements of the NSW Aquifer Interference Policy.

Phase 3 – Risk Assessment

A risk assessment was completed based on the guideline methodology. The risk assessment considers the ecological value of the GDE and the potential impact of the project. The potential impacts of the project were assessed based on the findings of the Groundwater Impact Assessment (GIA) (CDM Smith 2016a) which identified the main risk as being the propagation upwards of drawdown as a consequence of depressurisation.

The Groundwater Impact Assessment (CDM Smith 2016a) indicates that there will be negligible drawdown in the formations overlying the Purlawaugh Formation, notably the Quaternary alluvial and Pilliga Sandstone aquifers. These are the identified source aquifers for the GDEs classified as probable recharge springs, with the exception of Drysdale and GDE 65 which are considered artesian discharge springs, within the study area. The magnitude of impact is considered to be low for these GDEs.

The overall risk score compares the ecological value of the GDE to the likelihood of impact score. In the case of each of the nine potential Type 2 GDEs, the overall risk score is considered to be very low.

Phase 4 – Management, Mitigation and Monitoring

Given the overall risk score is considered to be very low, there are no prescribed management or mitigation measures other than continued monitoring and adaptive management.

Adaptive management measures include future updates to the hydrogeological conceptual model as and when further baseline data or project operational data are received, or when third parties provide additional data. In addition, surface infrastructure will avoid potential Type 2 GDEs.

1 Introduction

1.1 Overview

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri (refer Figure 1-1).

The Narrabri Gas Project (the project) seeks to develop and operate a gas production field, requiring the installation of gas wells, gas and water gathering systems and supporting infrastructure. The natural gas produced would be treated at a central gas processing facility on a local rural property (Leewood), approximately 25 kilometres south-west of Narrabri. The gas would then be piped via a high-pressure gas transmission pipeline to market. This pipeline would be part of a separate approvals process and is therefore not part of this development proposal.

The primary objective of the project is to commercialise natural gas to be made available to the NSW gas market and to support the energy security needs of NSW. Production of natural gas under the project would deliver economic, environmental and social benefits to the Narrabri region and the broader NSW community. The key benefits of the project can be summarised as follows:

- Development of a new source of gas supply into NSW would lead to an improvement in energy security and independence to the State. This would give NSW gas markets greater choice when entering into gas purchase arrangements. Potential would also exist for improved competition on price. Improved competition on price would have flow on benefits for NSW's economic efficiency, productivity and prosperity.
- The provision of a reduced greenhouse gas emission fuel source for power generation in NSW as compared to traditional coal-fired power generation.
- Increased local production and regional economic development through employment and provision of services and infrastructure to the project.

  The establishment of a regional community benefit fund equivalent to five per cent of the royalty payment made to the NSW Government within the future production licence area. If matched by the NSW Government, the fund could reach $120 million over the next two decades.

1.2 Description of the project

The project would involve the construction and operation of a range of exploration and production activities and infrastructure including the continued use of some existing infrastructure. The key components of the project are presented in Table 1-1, and are shown on Figure 1 1. The project is expected to generate approximately 1,300 jobs during the construction phase and sustain around 200 jobs during the operational phase; the latter excluding an ongoing drilling workforce comprising approximately 100 jobs.

Subject to obtaining the required regulatory approvals, and a financial investment decision, construction of the project is expected to commence in early 2018, with first gas scheduled for 2019/2020. Progressive construction of the gas processing and water management facilities would take around three years and would be undertaken between approximately early/mid-2018 and early/mid-2021. The gas wells would be progressively drilled during the first 20 or so years of the project. For the purpose of impact assessment, a 25-year construction and operational period has been adopted.

Table 1-1 Key project components

Component	Infrastructure or activity
Major facilities	
Leewood	• a central gas processing facility for the compression, dehydration and treatment of gas • a central water management facility including storage and treatment of produced water and brine • optional power generation for the project • a safety flare • treated water management infrastructure to facilitate the transfer of treated water for irrigation, dust suppression, construction and drilling activities • other supporting infrastructure including storage and utility buildings, staff amenities, equipment shelters, car parking, and diesel and chemical storage • continued use of existing facilities such as the brine and produced water ponds • operation of the facility
Bibblewindi	• in-field compression facility • a safety flare • supporting infrastructure including storage and utility areas, treated water holding tank, and a communications tower • upgrades and expansion to the staff amenities and car parking • produced water, brine and construction water storage, including recommissioning of two existing ponds • continued use of existing facilities such as the 5ML water balance tank • operation of the expanded facility
Bibblewindi to Leewood infrastructure corridor	• widening of the existing corridor to allow for construction and operation of an additional buried medium pressure gas pipeline, a water pipeline, underground (up to 132 kV) power, and buried communications transmission lines
Leewood to Wilga Park underground power line	• installation and operation of an underground power line (up to 132 kV) within the existing gas pipeline corridor
Gas field	

Gas appraisal and production infrastructure	• seismic geophysical survey
	• installation of up to 850 new wells on a maximum of 425 well pads
	  o new well types would include exploration, appraisal and production wells
	  o includes well pad surface infrastructure
	• installation of water and gas gathering lines and supporting infrastructure
	• construction of new access tracks where required
	• water balance tanks
	• communications towers
	• conversion of existing exploration and appraisal wells to production

Ancillary	• upgrades to intersections on the Newell Highway • expansion of worker accommodation at Westport • a treated water pipeline and diffuser from Leewood to Bohena Creek • treated water irrigation infrastructure including: o pipeline(s) from Leewood to the irrigation area(s)

Component	Infrastructure or activity
	o treated water storage dam(s) offsite from Leewood • operation of the irrigation scheme

1.3 Project location

The project would be located in north-western NSW, approximately 20 kilometres south-west of Narrabri, within the Narrabri local government area (LGA) (see Figure 1-1).

The project area covers about 950 square kilometres (95,000 hectares), and the project footprint would directly impact about one percent of that area.

The project area contains a portion of the region known as ‘the Pilliga’; which is an agglomeration of forested area covering more than 500,000 hectares in north-western NSW around Coonabarabran, Baradine and Narrabri. Nearly half of the Pilliga is allocated to conservation, managed under the NSW *National Parks and Wildlife Act 1974*. The Pilliga has spiritual meaning and cultural significance for the Aboriginal people of the region.

Other parts of the Pilliga were dedicated as State forest, and set aside for the purpose of ‘forestry, recreation and mineral extraction, with a strategic aim to “provide for exploration, mining, petroleum production and extractive industry” under the *Brigalow and Nandewar Community Conservation Area Act 2005*. The parts of the project area on state land are located within this section of the Pilliga.

The semi-arid climate of the region and general unsuitability of the soils for agriculture have combined to protect the Pilliga from widespread clearing. Commercial timber harvesting activities in the Pilliga were preceded by unsuccessful attempts in the mid-1800s to establish a wool production industry. Resource exploration has been occurring in the area since the 1960s; initially for oil, but more recently for coal and gas.

The ecology of the Pilliga has been fragmented and otherwise impacted by commercial timber harvesting and related activities over the last century through:

- the establishment of more than 5,000 kilometres of roads, tracks and trails
- the introduction of pest species
- the occurrence of drought and wildfire.

The project area avoids the Pilliga National Park, Pilliga State Conservation Area, Pilliga Nature Reserve and Brigalow Park Nature Reserve. Brigalow State Conservation Area is within the project area but would be protected by a 50 metre surface exclusion zone.

Agriculture is a major land use within the Narrabri LGA; about half of the LGA is used for agriculture, split between cropping and grazing. Although the majority of the project area would be within State forests, much of the remaining area is situated on agricultural land that supports dry-land cropping and livestock. No agricultural land in the project area is mapped by the NSW Government to be biophysical strategic agricultural land (BSAL) and detailed soil analysis has established the absence of BSAL. . This has been confirmed by the issue of a BSAL Certificate for the project area by the NSW Government.

1.4 Project scope

The Proponent is required, under the New South Wales Government Secretary’s Environmental Assessment Requirements to consider whether depressurisation, and associated impacts, for coal seam gas abstraction, will have a significant impact on the environment. Further to this, the project will be assessed against information requirements published by the Commonwealth Government Independent Scientific Committee on Coal Seam Gas (IESC).

In order to address regulatory requirements and enable approval of the project, Groundwater Dependent Ecosystems (GDEs) in the potential impact zone of the project are required to be identified and characterised with respect to their hydrogeological and ecological conditions. Where GDEs are identified within the potential impact zone of the project, appropriate management measures may be required to minimise or mitigate potential impacts to GDEs.

The New South Wales Office of Water (NOW) *Risk assessment guidelines for groundwater dependent ecosystems* (2012) define the conceptual framework for the ecological valuation and risk assessment process for GDEs. The guidelines are based on an assessment of various ecological and risk factors that are important to decisions on the implementation and management of a proposed activity of development. The guidelines provide a conceptual framework by which a methodology can be devised to identify, characterise and assess potential risks to GDEs. In addition, the guidelines specify typical management and mitigation measures that may be adopted based on the risk category assigned to each GDE.

This study seeks to satisfy these requirements for the assessment of GDEs reliant on the surface expression of groundwater (Type 2, Richardson et al, 2011). The study has been divided into phases in accordance with the conceptual framework for the ecological valuation and risk assessment process for GDEs (NOW, 2012) as presented in Table 1-2.

Table 1-2: Report scope

Section	Scope
Section 1	Introduction
Section 2	Project context
Section 3	Study methodology
Section 4	Phase 1: Identification of type and location of potential Type 2 GDEs
Section 5	Phase 2: GDE characterisation & assessment
Section 6	Phase 3: Risk assessment
Section 7	Phase 4: Identification of management and mitigation measures
Section 8	Conclusion

1.5 Aims & objectives

The aim of this report is to undertake a risk assessment of Type 2 GDEs that may be impacted by the project. To achieve this, the following objectives are met:

- Identification of the study area and area of potential impact.
- Identification of landscape features that could potentially represent Type 2 GDEs within the defined study area through desktop and remote sensing analysis.
- Screening exercise to identify medium and high potential Type 2 GDEs within the study area.
- Characterisation of hydrogeology and ecological potential for groundwater dependency of identified medium and high potential Type 2 GDEs through desktop and field based investigation.

- Identification of presence and/or absence of protected species or habitats, including (but not limited to) species protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which defines Matters of National Environmental Significance (MNES). Should MNES be present, a higher ecological value may be warranted.
- Undertake risk assessment of confirmed Type 2 GDEs using the predicted impacts presented in the Groundwater Impact Assessment (GIA) (CDM Smith 2016a).
- Identify, where required as an outcome of the risk assessment, monitoring and mitigation measures to reduce potential significance of the identified impact.

1.6 Limitations

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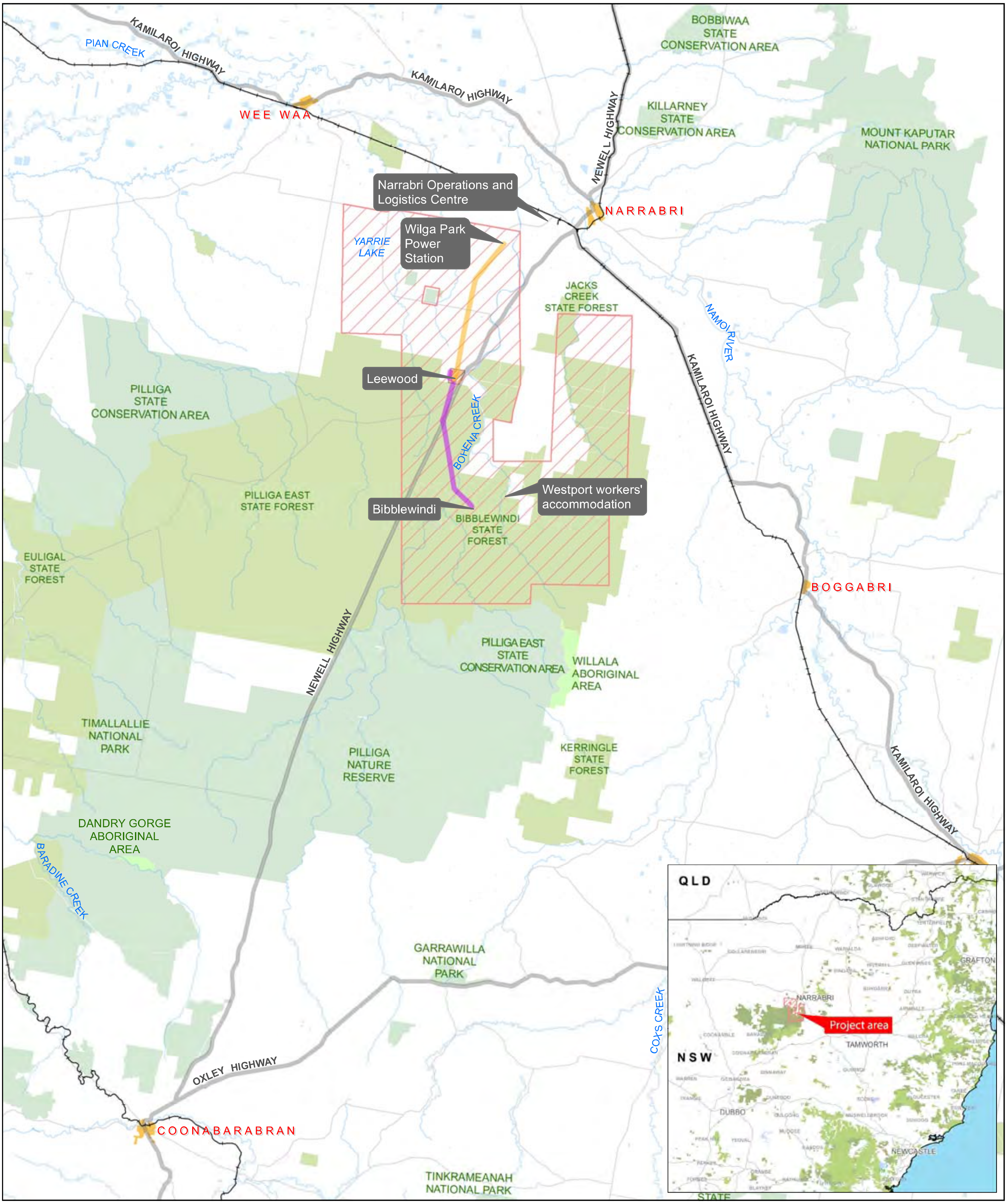
- This report has been prepared using factual information contained in data, maps and documents prepared by others. No responsibility can be accepted by Eco Logical Australia for the accuracy of such information, beyond standard checking procedures.



LEGEND

- Project area
- Leewood
- Urban
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project
EIS Technical Appendix

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context and location of key infrastructure

Figure 1-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by: afoddy

2 Project context

This study informs the impact assessment undertaken in the Groundwater Impact Assessment (CDM Smith 2016a), which presents the predictions of impact as a result of depressurisation of the target coal seams to extract coal seam gas. The following sections places this study in context.

2.1 Study area

The study area is defined by the numerical model-simulated cumulative maximum predicted extent of drawdown exceeding 0.5 m in key model layers arising from the Proponents' proposed development activities, extrapolated vertically to the ground surface. The potential impact of water level drawdown, as a result of project activities, and its maximum simulated extent in individual model layers is identified from groundwater flow modelling simulations undertaken as part of the Groundwater Impact Assessment (CDM Smith 2016a).

The zone of impact for the study area was defined in two steps:

- Determination of the maximum extent of predicted drawdown as presented in the Groundwater Impact Assessment (CDM Smith 2016a) during the 1,500-year simulation for hydrostratigraphic unit (HSU) thirteen (corresponding to the Late Permian Hoskissons Coal Formation) and hydrostratigraphic unit twenty-two (corresponding to the model layer representing the target seams in the Early Permian Maules Creek formation). The maximum extent of predicted drawdown in each hydrostratigraphic unit of interest is limited to a drawdown equalling or exceeding 0.5 m, corresponding to the probable minimum threshold for model prediction.
- Addition of a 5 km buffer area extending outside of the above-defined zone to provide additional conservatism to the estimate of potential impacts to groundwater, noting that the numerical groundwater model is already highly conservative.

It should be noted that the maximum spatial extent of drawdown equalling or exceeding 0.5 m was investigated in all model layers, although only the hydrostratigraphic units stated above are illustrated in Figure 2-1.

A composite of the maximum extent of potential drawdown as a consequence of the proposed development is presented in Figure 2-1.

2.2 Definitions

2.2.1 Groundwater Dependent Ecosystems

GDEs are defined by the Department of Land and Water Conservation as *'ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater'* (2002). An important distinction is needed to differentiate dependency from opportunistic or partial use. In many ecosystems, it is the presence of water, regardless of origin, that is the prerequisite for the ecological community present. Groundwater dependency only occurs when the loss of surface input is long enough to cause a decline in the condition of the ecological community. An ecosystem whose runoff-derived water is supplemented by contributions from aquifers is not necessarily groundwater dependent.

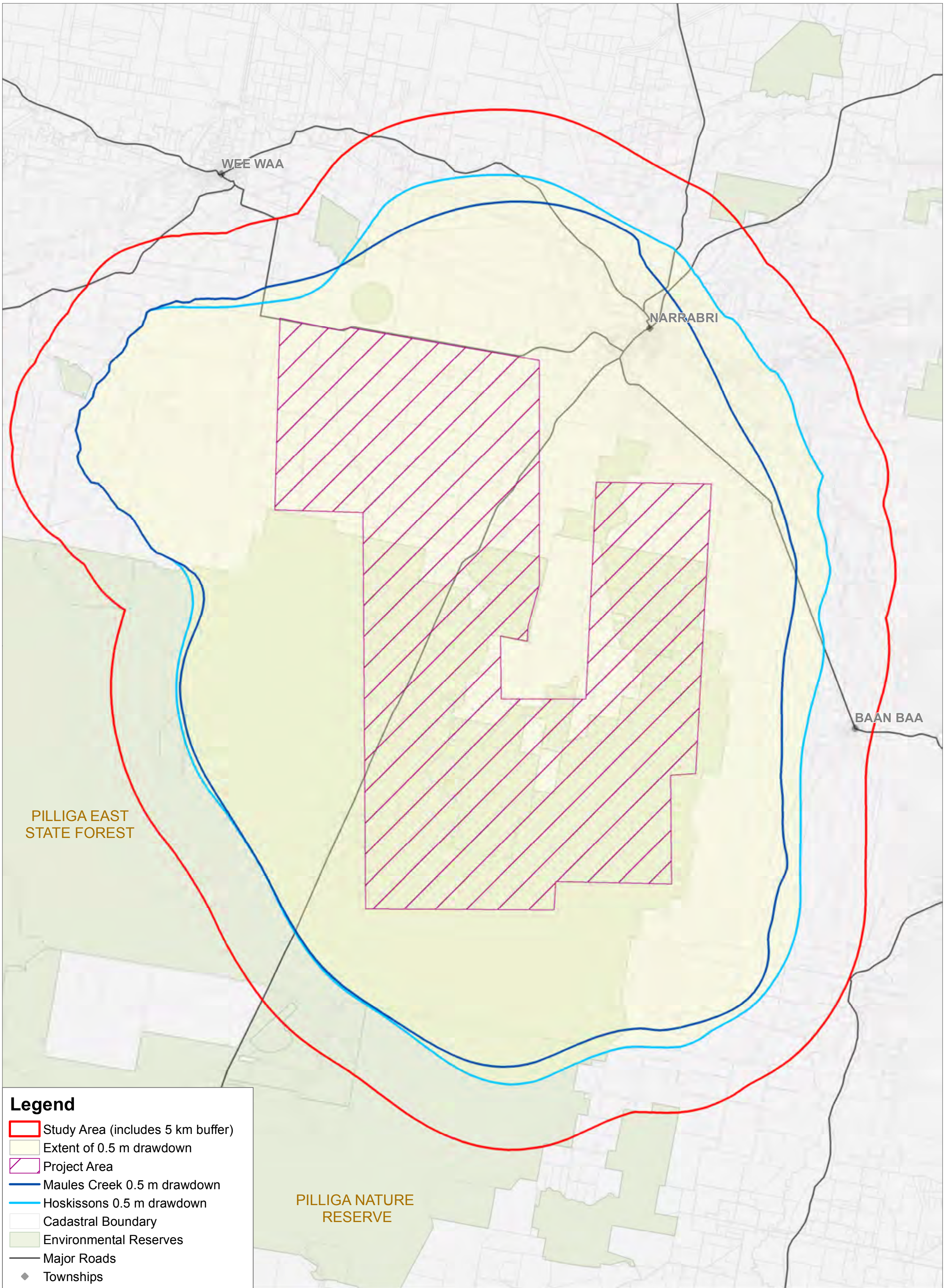
The currently accepted terminology is adopted to be in line with the two current national approaches to GDEs, The National Groundwater Dependent Ecosystem Atlas (BOM 2013) and the GDE Tool Box (Richardson et. al. 2011), both of which were informed by the definition within the Australian National Aquatic Ecosystem Framework (ANAE) and where specifically related to GDEs definitions developed by Eamus and Froend (2006). These definitions describe the nature of the groundwater connection to the ecosystem.

In accordance with Richardson et. al (2011), there exist three classes of GDEs, they are:

- Type 1 GDE: Cave and aquifer ecosystems - referring to ecosystems that reside within the spaces of caves and aquifers.
- Type 2 GDE: Ecosystems dependent on the surface expression of groundwater - referring to ecosystems that are connected to groundwater that comes to the earth's surface, within wetlands, lakes, seeps, springs and river baseflow.
- Type 3 GDE: Ecosystems dependent on the sub-surface presence of groundwater - referring to ecosystems associated with terrestrial vegetation utilising the water table below the natural surface.

A High Priority GDE is defined as having high ecological value (HEV) and is therefore considered a high priority for management action. High ecological value may be considered, for example, where species or habitats protected under the EPBC Act may be present.

Typically, GDEs can be classified under seven ecosystem types, as shown in Table 2-1.



Santos
We have the energy.

eco logical AUSTRALIA

0 3.75 7.5 15 Km

Scale: 1:400,000 @A4
Projection: GDA94

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Narrabri GDE Risk Assessment Report

Figure 2-1: Definition of Study Area

Table 2-1: GDE types

GDE Description	Included in study	Rationale	GDE toolbox typology
Karst and caves	No	Excluded as feature not present within region	Type 1
Subsurface phreatic aquifer ecosystems (including stygofauna)	No	Based on the known hydrogeological conceptualisation of the study area, there is a low likelihood of the presence of subsurface phreatic aquifer ecosystems (Eco Logical Australia, 2016b)	Type 1
Base flow streams (hyporheic or subsurface water ecosystems)	No	Determination of base flow hyporheic or subsurface ecosystems and subsequent impact assessment is beyond the scope of this report. (Eco Logical Australia, 2016b)	Type 3
Groundwater dependent wetlands	Yes	Included as some known features within the study area	Type 2
Base flow streams (surface water ecosystems)	Yes	Included as some known features within the study area	Type 2
Estuarine and near shore marine ecosystems	No	Excluded based on location	Varies
Phreatophytes – groundwater dependent terrestrial ecosystems.	No	The presence and characteristics of groundwater dependent terrestrial ecosystems (such as the Pilliga Scrub) has been assessed as part of the groundwater impact assessment, GDE Impact Assessment (CDM Smith, 2016c)	Type 3

2.2.2 Spring definitions

GDEs located within the study area may be supported by springs. A range of different terms are used within this report regarding various spring types. These are detailed in Table 2-2.

Table 2-2: Spring definitions

Term	Definition
Spring	A permanent natural surface expression of groundwater (Queensland Herbarium, 2012).
Spring vent	The single point where groundwater is discharged at the surface. This includes mounded or flat areas, or areas represented by wetland vegetation without visible water present on the surface.
Spring complex	A group of springs located in close proximity to each other, in similar geology and fed by the same source aquifer. To be classified as a spring complex, at least two such springs must be located within a 6 km proximity. Complexes can contain both active and inactive springs.
Recharge/Reject spring	A recharge or rejection spring occurs when transmissivity of the rock where surface water ingress (recharge) occurs, is decreased to a point where no more water can enter the system and as such pooling occurs surrounding the recharge area (Mancini, 1974). This concept applies only to water table springs (see definition below).
Watercourse spring	Groundwater entering a stream from an underlying aquifer through the streambed. These springs can be water table springs or artesian discharge springs (see below).
Water table spring	Water table seepage to the surface from an unconfined aquifer. Spring types under this category include: **Contact spring** – a spring formed where there is a change in the geology in the landscape. Where a high permeability formation overlies a lower permeability formation, there is a restriction in flow across the boundary, resulting in water flowing laterally and expressing at the surface. **Perched water table spring** – water restricted by a lower permeability formation can flow laterally through a higher permeability layer as a perched water table, finding expression at the surface as a spring. **Change in slope** - a spring formed where there is a change in the slope of the ground surface and an aquifer outcrops high in the landscape. **Window into the water table** - a spring formed where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table.
Artesian discharge spring	Springs supported by groundwater pressure and discharge and sourced from confined aquifers. Spring types under this category include: **Presence of a geological structure** – a geological structure such as a fault can provide a path to the surface along which water can flow. If an underlying aquifer is confined by impermeable material and the water pressure is high enough, water can flow to the surface as a spring. **Thinning of a confining layer** – a thinning of a confining layer can provide a path to the surface along which water can flow. If the pressure in the aquifer is high enough, water can flow to the surface as a spring.

The detailed hydrogeological characterisation and conceptualisation for the study area undertaken to inform the Groundwater Impact Assessment (CDM Smith, 2016a) and other preceding studies indicates that there is a low potential for the presence of **artesian discharge springs**. Given that the study area has, in places, been extensively explored for oil and gas resources, it is feasible that the remains of historical petroleum wells may have created anthropogenic pathways to create artesian springs, which in turn may have wetlands that could be classed as Type 2 GDEs.

On this basis, it is anticipated that Type 2 GDEs present in the study area will be supported by the following types of springs:

- **Contact spring** – a spring formed where there is a change in the geology in the landscape. These springs are considered to be common at the interface of the Pilliga Sandstone and the Purlawaugh Formation.
- **Change in slope** - a spring formed where there is a change in the slope of the ground surface and an aquifer outcrops high in the landscape.
- **Window into the water table** - a spring formed where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table. This is likely particularly around the creek and river systems on the alluvium.
- **Plugged and abandoned petroleum bores** – a spring formed by a former petroleum bore having been historically converted to a water bore in an aquifer shallower than the previous petroleum source.

2.3 Legislative context

2.3.1 Commonwealth

A consideration of this study is to identify if the project may have impacts that could be assessed as significant to Matters of National Environmental Significance in relation to GDEs. Matters of National Environmental Significance are defined in the *Environment Protection and Biodiversity Conservation Act 1999* and could reasonably be expected to include:

- wetlands of international importance (listed under the RAMSAR Convention)
- listed threatened species and ecological communities
- migratory species, listed under international agreements
- a water resource, in relation to coal seam gas development.

The presence or absence of Matters of National Environmental Significance provides an important bearing on the sensitivity of the identified feature.

The predicted impact of the project will be assessed by the Commonwealth Department of the Environment (DotE). Impacts to GDEs will form part of the assessment.

2.3.2 State

The *Water Management Act 2000* (WM Act) is the key piece of legislation for the management of water in NSW. The *Water Management Act 2000* ensures the protection and enhancement of water sources and their associated ecosystems.

The *Water Management Act 2000* provides principles relevant to the management of GDEs, as follows:

- Water sources, floodplains and dependent ecosystems should be protected and restored and, where possible, land should not be degraded.
- Habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and restored.
- The quality of all water sources should be protected and, where possible, enhanced.

- The cumulative impacts of water management licenses and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised.
- The principles of adaptive management should be applied.

The *NSW Aquifer Interference Policy 2012* (NOW 2012a) and Water Sharing Plans (WSP) are the main tools for managing water resources under the *Water Management Act 2000*.

Water Sharing Plans list high priority GDEs within the sharing plan zone and provide conditions on works undertaken in the vicinity of GDEs.

The *NSW Aquifer Interference Policy 2012* specifies thresholds of minimal impact considerations to high priority GDEs within highly productive and less productive groundwater sources.

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC 2002) implements the *Water Management Act 2000* by providing guidance to protect and manage GDEs. The Policy sets out management objectives and principles to:

- Ensure that vulnerable and valuable GDEs 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 made available to ecosystems where needed.
- Ensure that the precautionary principle is applied to protect GDEs, particularly the dynamics of flow and availability and the species reliant of these attributes.
- Ensure that land use activities aim to minimize adverse impacts on GDEs.

2.4 Planning and regulatory requirements

2.4.1 IESC requirements

It is anticipated that the project Environmental Impact Assessment will be referred by the Department of the Environment to the Independent Executive Scientific Committee (IESC) for Coal Seam Gas and Large Coal Mining Projects for assessment. The IESC has published a comprehensive list of information guidelines that present expected content for an environmental assessment. Those relevant to GDEs are listed in Table 2-3.

Table 2-3: IESC requirements relating to GDEs

IESC Requirement	
2i	Identification of water related assets of the site and region, including habitat, fauna and flora surveys as they relate to dependence on surface water and groundwater resources including the location of springs and other GDEs, identification of the hydrogeological unit on which the GDEs are dependent and an estimation of ecological water requirements of identified GDEs. GDEs should be identified in accordance with the methodology outlined by Eamus et. al. (2006)
4h	An assessment of direct and indirect impacts on water related assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (e.g. riparian vegetation, baseflow in streams)

2.4.2 Secretary's environmental assessment requirements

The Secretary's environmental assessment requirements for the project were issued on 25 July 2014. The requirements include general requirements and key issue requirements. The requirements for the key issue of water refer to NSW Trade & Investment's requirements (Attachment 2 of the Secretary's environmental assessment requirements) and address the key issues relating to GDEs as presented in Table 2-4.

Table 2-4: Secretary's environmental assessment requirements

Requirement
Sufficient baseline monitoring for groundwater quantity and quality for all aquifers and GDEs to establish a baseline incorporating typical temporal and spatial variations.
Provide protective/safeguard measures for any GDEs.
Identify any potential impacts on GDEs as a result of the proposal, including: • The effect of the proposal on the recharge to groundwater systems; • The potential to adversely affect the water quality of the underlying groundwater system and adjoining groundwater systems in hydraulic connections; and • The effect on the function of GDEs (habitat, groundwater levels, connectivity).

This project follows the assessment method provided by the NSW Office of Water for the risk assessment of project impacts to GDEs. In doing so, the assessment is targeted to meet State requirements.

2.5 Geology & hydrogeology

2.5.1 Geology

The local geology of the study area is characterised by unconsolidated alluvial and colluvial deposits overlying Jurassic Surat Basin strata, which in turn unconformably overlie indurated Permo-Triassic Gunnedah Basin sediments of the Bohena Trough, resting on Early Permian and older meta-volcanic basement rocks.

The Surat Basin strata present in the vicinity of the study area include the Blythesdale Group (Keelindi Beds), Pilliga Sandstone, Purlawaugh Formation and basal Garrawilla Volcanics. The Gunnedah Basin strata is locally present beneath the Surat sediments and include the Triassic Deriah, Napperby and Digby Formations overlying unconformably the Late Permian Black Jack Group, Middle Permian Millie Group and the Early Permian Bellata Group.

The structure of the Gunnedah Basin Permian sediments in the study area is defined largely by the shape of the Bohena Trough, with dips reflecting the draping of strata on the flanks of the structural highs forming the trough margins. Localised faulting can result in variations from this pattern. Permian strata in the northern part of the Mullaley Sub-basin in which the study area rests are largely confined to the Bohena Trough, terminating on the flanks of Rocky Glen Ridge in the west. Younger Triassic strata extend across Rocky Glen Ridge and onlap the Lachlan Fold Belt basement rocks in the west. Within the Surat Basin sequence, strata dips are typically toward the west or north-west, although locally the infilling and on-lapping of strata mimic the geometry of the Bohena Trough which has resulted in a local stratigraphical sub-basin.

2.5.2 Hydrogeology

The complex litho-stratigraphy of the Groundwater Impact Assessment study area has been classified into hydrostratigraphic units, denoting the significance or propensity of particular formations or groups of formations to transmit or inhibit the movement of groundwater, as follows:

- significant transmissive units (STU)
- less significant transmissive units (LSTU)
- probable negligibly transmissive units (PNTU)
- negligibly transmissive units (NTU).

The purpose of these definitions is to recognise the relative significance of hydrogeological properties to the response of the hydrogeological system to coal seam gas development, and therefore to ascertain whether a hydrostratigraphic layer may provide a source of groundwater for a GDE.

The hydrostratigraphy is presented in Table 2-5. The principal significant transmissive units within the Groundwater Impact Assessment study area are the Quaternary Narrabri and Gunnedah formations. These units contain a significant resource of readily accessible, good quality groundwater that is heavily utilised for irrigation, public water supply, private water supply and livestock.

Hydrostratigraphic units of the Surat Basin include the Pilliga Sandstone, Purlawaugh Formation and Blythesdale Group (Keelindi Beds). The Pilliga Sandstone is a major regional aquifer and significant transmissive unit. Its lateral equivalent within the Oxley Basin also provides an important water resource within the southern part of the Groundwater Impact Assessment study area.

The Purlawaugh Formation and Blythesdale Group (Keelindi Beds)—composed of the Orallo Formation, Mooga Sandstone and Bungil Formation—contain predominantly fine grained sediments that are considered to be negligibly transmissive units.

The Triassic Deriah Formation, Napperby Formation and Digby Formation are probable negligibly transmissive units and negligibly transmissive units capable of only minor groundwater yields.

Hydrostratigraphic units within the Late-Permian Black Jack Group are predominantly probable negligibly transmissive units. Apart from coal seams, the Clare Sandstone is the only hydrostratigraphic unit with potentially significant transmissivity within the Black Jack Group.

Strata within the lower Black Jack Group (Brothers Sub-group) are considered to be probable negligibly transmissive units due to the combination of mixed lithology and cementation. Middle Permian sediments of the Millie Group (Watermark and Porcupine Formations) are considered to be negligibly transmissive units due to the degree of cementation and their lithological characteristics.

The target coal seams within the Early Permian Maules Creek Formation include the Bohena, Namoi, Rutley and Parkes seams. In this assessment they are referred to collectively as the Early Permian coal seams and are considered to have significant transmissivity within the context of coal seam gas development. They are bounded above and below by the Maules Creek Formation, which is considered to be a negligibly transmissive unit. Interburden strata between the coal seams, consisting predominantly of sandstone, conglomerate and siltstone are thought to be probable negligibly transmissive units. The Goonbri and Leard Formations underlie the Maules Creek Formation and are considered to be negligibly transmissive units.

Table 2-5: Hydrostratigraphy of the study area

Province	Period/ Epoch	Division	Group	Sub-group	Formation	Lithology and Hydrogeological Classification
Namoi Alluvium	Pleistocene				Narrabri fm	Clay and silt with sand lenses
	Pliocene				Gunnedah fm	Gravel and sand with clay lenses
Volcanics	Miocene				Cubbaroo fm	Gravel and sand with clay lenses
					Warrumbungle Vol	Basalt, dolerite
	Eocene				Liverpool Range Vol	Basalt, dolerite
Surat Basin	Cretaceous	Middle	Blythesdale Gp (Keelindi Beds)		Bungil Fm Mooga Ss Orallo Fm	Clayey to Quartzose sandstone, subordinate siltstone and conglomerate
		Early			Pilliga Ss	Fluvial, medium to very coarse grained, quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal.
	Jurassic	Late				
		Middle			Purlawaugh Fm	Fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams
		Early	Garrawilla Volcanics			Dolerite, basalt, trachyte, tuff, breccia
Gunnedah Basin	Triassic	Late				
		Middle			Deriah Fm	Sandstone
					Napperby Fm	Interbedded fine sandstone, claystone and siltstone
						Basal Napperby Shale
		Early			Digby Fm	Quartzose sandstone (Ulinda Ss)
						Lithic sandstone
						Lithic conglomerate (Bomera Conglomerate)
	Permian	Late	Black Jack	Nea	Trinkey Fm	Coal measures - siltstone, fine sandstone, tuffs, stony coal
					Wallala Fm	Conglomerate, sandstone, siltstone, minor coal bands
				Coogal	Breeza Coal	Coal and claystone
					Clare Ss	Medium to coarse-grained quartzose sandstone; quartzose conglomerate
					Hows Hill Coal	Coal
					Benelabri	Claystone, siltstone and sandstone; fining up cycles; more sandy towards top
					Hoskissons Coal	Secondary target coal seam
				Brothers	Brigalow Fm	Fining-up sequence of medium to coarse-grained quartzose sandstone and siltstone
					Arkarula Fm	Sandstone and siltstone
					Melvilles Coal Mb	Coal
					Pamboola Fm	Sandstone, siltstone, minor claystone & coal
		Middle	Millie		Watermark Fm	Marine siltstone, shales and sandstone
					Porcupine Fm	Fining upward sequence of conglomerate and sandstone to mudstone
		Early	Bellata		Upper Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal
					Parkes seam	Target coal seam
					Interburden	Sandstone and conglomerate, siltstone, mudstone
					Rutley seam	Target coal seam
					Interburden	Sandstone and conglomerate, siltstone, mudstone
					Namoi seam	Target coal seam
					Interburden	Sandstone and conglomerate, siltstone, mudstone
					Bohena seam	Target coal seam
					Lower Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal
					Goonbri Fm	Siltstone, sandstone and coal
					Leard Fm	Flinty claystone
Basement			Werrie Basalt and Boggabri Volcanics (Basement)			Rhyolitic to dacitic lavas and ashflow
						Tuffs with interbedded shale. Rare trachyte and andesite. Weathered basic lavas

Colour code key:	
	STU – Significantly Transmissive Unit
	LSTU – Less Significantly Transmissive Unit
	PNTU – Probable Negligibly Transmissive Unit
	NTU – Negligibly Transmissive Unit

The Liverpool Range Volcanics consists predominantly of basalt and is considered to be a probable negligibly transmissive unit.

The Hunter-Mooki Fault system forms the eastern margin of the Gunnedah-Oxley Basin. Small groundwater supplies are drawn from these rocks and the extent of individual water bearing horizons is understood to be limited both structurally and diagenetically.

A summary schematic showing the generalised stratigraphy of the Bohena Trough is presented in Figure 2-2 below. A detailed description of the geological and hydrogeological condition is presented in the Groundwater Impact Assessment (CDM Smith, 2016a) with the hydrostratigraphy presented in Table 2-5.

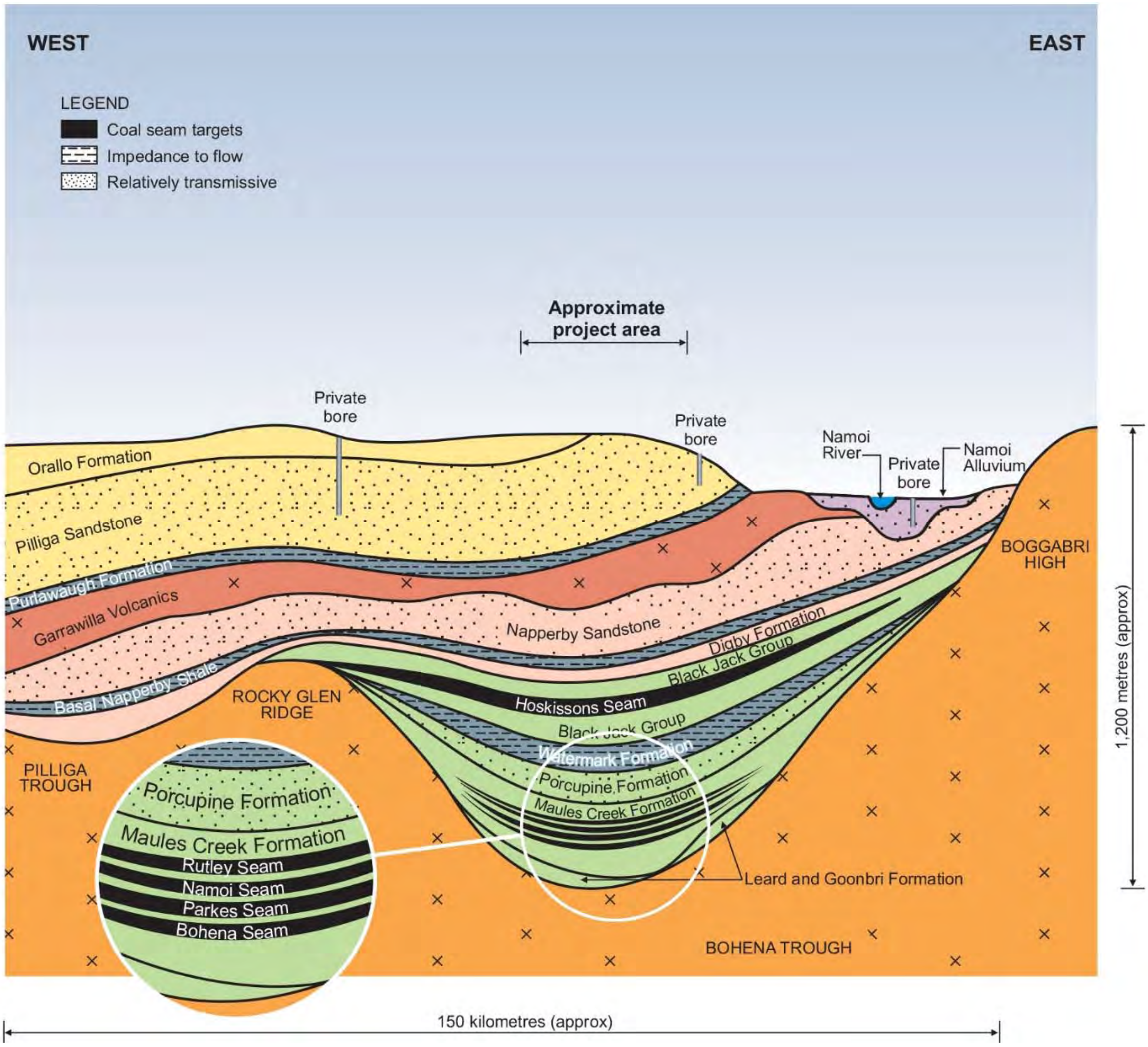


Figure 2-2: Schematic hydrogeological cross section of the Bohena Trough

3 Study methodology

3.1 Study approach

The New South Wales Office of Water (NOW, 2012) (now DPI Water) outlines the approach for the ecological valuation and risk assessment process for identified GDEs, '*Risk assessment guidelines for groundwater dependent ecosystems: Volume 1 – Conceptual framework'.* This is described on the following page (Figure 3-1).

The guideline defines the ecological valuation and risk assessment process for GDEs. The guidelines are based on an assessment of various ecological and risk factors that are considered important to decisions on the implementation and management of a proposed activity of development. The guidelines provide a process by which to identify, characterise and assess potential risks to GDEs. In addition, the guidelines specify management and mitigation measures to be adopted based on the risk category assigned to each GDE.

The ecological valuation and risk assessment process for GDEs specified in the guidelines has been adopted in this study. This has been augmented, where necessary, with additional consideration of the potential for federally listed species, populations or communities to be present at a potential GDE, with a view to assessing the potential for impact to GDE related Matters of National Environmental Significance.

The study has been divided into phases in accordance with the tasks documented in the guidelines.

Phase 1 identifies, via a desktop assessment, the potential type and occurrence of features that may represent groundwater dependent features.

Phase 2 undertakes further detailed desktop characterisation of potential features, and where possible, seeks to validate the characterisation through site reconnaissance, conducted by a hydrogeologist and groundwater ecologist. The findings of this characterisation exercise considers (1) through hydrogeological conceptualisation, whether the feature is likely to be groundwater dependent, and (2) whether there are species or habitats present that may be groundwater dependent.

Phase 3 undertakes a risk assessment, based on the principles and methodology set out in the guidelines, utilising the data obtained in Phase 1 and Phase 2, to ascertain whether the project is likely to have an impact on a GDE.

The output of Phase 3 presents a risk matrix. In Phase 4, this risk matrix is used to provide recommendations for monitoring, mitigation or management actions, depending on the level of risk. This has informed the project Water Monitoring Plan (CDM Smith, 2016b).

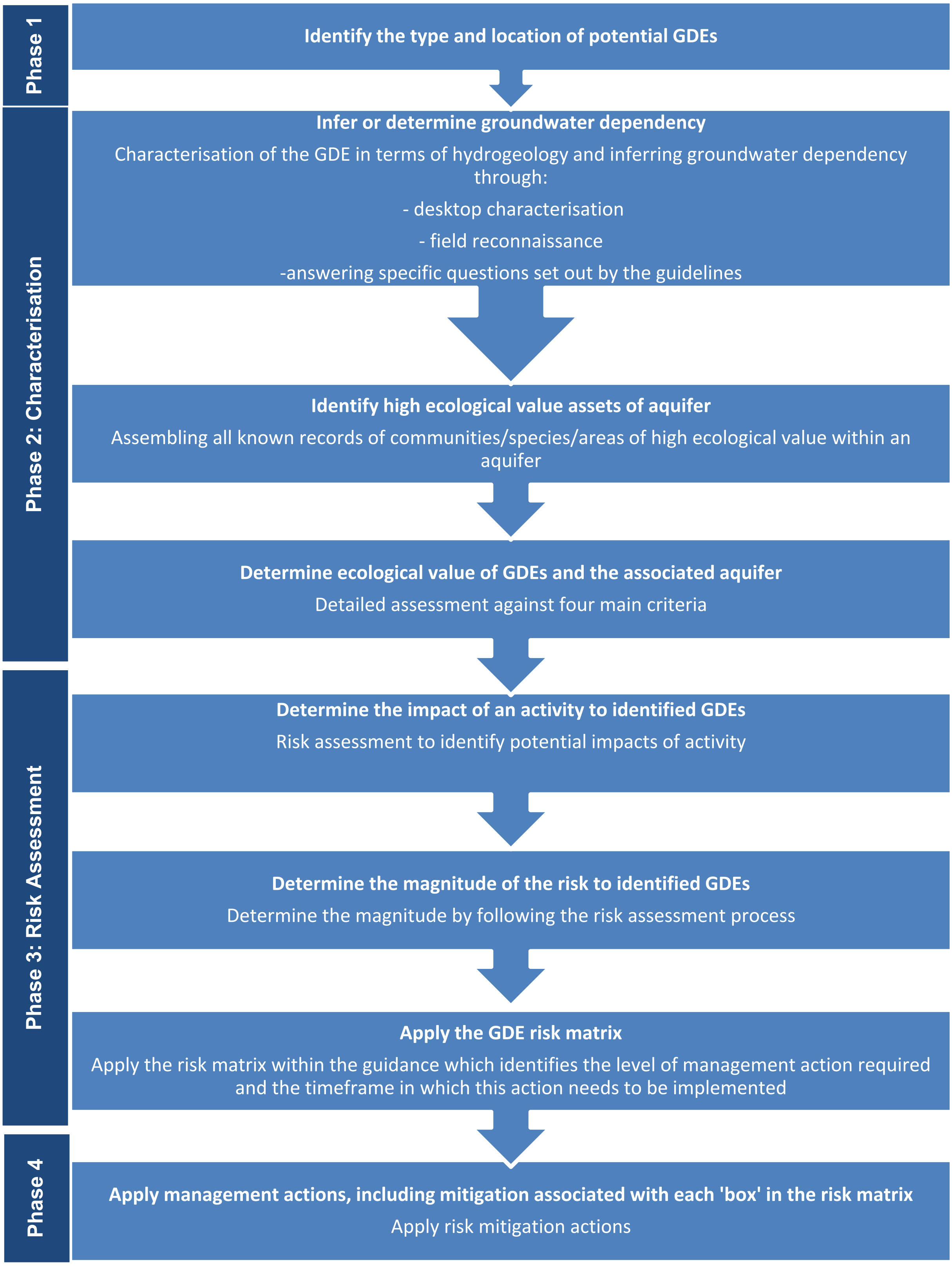


Figure 3-1: Ecological valuation and risk assessment process

3.2 Preliminary Identification of potential GDEs (Phase 1)

Phase 1 comprised the identification of potential GDEs within the study area. Identification of known and potential GDEs was undertaken through the following works:

- literature and database review
- remote sensing techniques
- preliminary assessment of potential GDE locations
- selection of locations for assessment in Phase 2.

3.2.1 Identification of potential GDEs

Features that could potentially be GDEs were identified within the study area through examination of the following sources:

- Conducting a detailed review of available information including:
  - Water Sharing Plans
  - State of the Catchment reports
  - National Atlas of Groundwater Dependent Ecosystems
  - Maps of the study area including the Pilliga Forest and Pilliga State Forests maps
  - The Water Asset Information Tool (WAIT) database
  - Namoi Wetland Assessment and Prioritization Project database.
- Applying remote sensing techniques, principally by using LandSat™ data; and
- Field reconnaissance associated with the Proponents' Groundwater Bore Inventory Baseline Study.

In addition, existing pressures or influences on GDEs previously identified within the study area were noted using the above sources and additional literature (Table 3-1).

3.2.2 Initial assessment of groundwater dependency

An initial assessment of the potential for groundwater dependency has been made. The following criteria were adopted:

- Criteria indicating characteristics of groundwater dependency:
  - well defined drainage channel with pools of 'clear' water at the headwater, or along the channel, though regularly dry in other sections
  - pools of less turbid water (clear or fresh water) which indicate a constant new supply of fresh low-turbidity water
  - ground vegetation appears wet suggesting regular inundation
  - ground vegetation of feature is distinct from surrounding vegetation i.e. significantly more dense or green
  - feature lies within an area known to have high water table
  - feature within an area of distinct geological change (i.e. change in geological formation or presence of fault).
- Criteria indicating surface water dependency (little to no groundwater input):
  - evidence of well-defined drainage channel discharging into the feature
  - pools within low lying areas adjacent to creeks that appear to be inundated by creek overflow

- pools of turbid water suggesting there is no constant fresh flow of water from an aquifer
- registered bore within 50 m which extends to depth suggesting the pool is deliberately maintained by bore water.

The following groundwater dependency confidence scoring was then used based on the criteria above and assigned to each GDE feature listed in Table A3, Appendix A:

- **High** – feature identifiers indicate groundwater dependency.
- **Moderate** – feature identifiers suggest some groundwater dependency but this is not clear from the aerial photography and further assessment is required to identify groundwater dependency.
- **Low** – feature identifiers suggest surface water dependency as per the criteria above.

3.3 Characterisation & methodology (Phase 2)

The desktop assessment has been undertaken in accordance with the *Risk assessment guidelines for groundwater dependent ecosystems* (NOW, 2012), comprising the collection, collation and interrogation of data pertaining to each GDE.

The objectives of the desktop assessment were to:

- conduct a preliminarily characterisation of the hydrogeology of each potential GDE
- conduct a preliminarily identification of the type of potential GDE
- investigate existing geographical impacts within the study area in order to characterise the baseline condition of the potential GDE
- conduct a preliminary characterisation of the ecology of each potential GDE.

The outcomes of the desktop assessment are validated in the field, where possible. The results of the collation and analysis of available information for each potential GDE are presented in characterisation sheets in Appendix B and summarised in Section 5.2 below. The following sections summarise the approach.

3.3.1 Data sources

A number of data sources were reviewed to enable the preliminary characterisation of each potential GDE. Table 3-1 lists the data sources, information gathered from each source and a qualitative assessment of the quality of the data.

3.3.2 Data assessment

The following site elements were assessed and are presented within the characterisation sheets in Appendix B:

Identification of GDE:

- **Data source:** details the source of information for identification of the potential GDE.
- **Feature identifiers:** specifies characteristics which identify the feature as a potential GDE.

Table 3-1: Data availability and information gathered

Data Type		Present in study	Information Gathered	Quality/Usefulness of Data
Literature review	Water Sharing Plans	NOW, 2003, 2008 and 2011a-c	• no available information	Low
	State of the Catchment Reports	DECCW, 2010a and 2010b	• location and type of GDE	Average
	Mapping Groundwater Dependent Ecosystems in the Namoi Catchment	SKM, 2010	• areas of high, medium, low and very low potential groundwater dependency	Average
	National Atlas of Groundwater Dependent Ecosystems	BoM, 2013	• no additional information provided	Low
	Water Asset Information Tool (WAIT) Database	Namoi and Border Rivers-Gwydir CMA, 2012	• location of GDE • field notes on some GDEs	Average
	Namoi Wetlands Assessment and Prioritisation Project database	Eco Logical Australia, 2008	• location of GDE • field notes on some GDEs • regional wetland flora	Average
	Wetland Plants of the Namoi High Country	Bell, 2012	• regional wetland flora	High
	Ephemeral wetlands of the Pilliga Outwash, northwest NSW	Bell et. al., 2012	• regional wetland flora	High
	Wetland Plants of the Namoi Catchment	Namoi CMA, undated	• regional wetland flora	High
Maps and GIS data	Pilliga Forest Map	NSW NPWS, 2008	• locations of springs	Average
	Pilliga State Forests Map	Forestry Commission of NSW, 1989	• locations of springs	Average
	Topographical data	Baan Baa 1:50 000 Sheet Number 8836N 20 m contours (DEM), Geoscience Australia, 2013.	• direction of surface water flow • definition of surface water catchment boundaries	Average
	Aerial photography	Aerial Imagery – Gunnedah Area September 2011 (30 cm Resolution) Santos	• water content of wetland/surface water system • surface water inflow to GDE • vegetation condition	High

Data Type		Present in study	Information Gathered	Quality/Usefulness of Data
			• surrounding land use	
Maps and GIS data	Geological data	Santos_bdmrgeo020625_V2	• surface and bedrock geology • aquifers present in study area	High
	Land use data	NSW Department of Lands, 2008	• surrounding land use	Average
	Surface water systems	Geoscience Australia, 2006	• location of surface water systems with respect to GDE	High
	Groundwater-surface water connectivity map	CSIRO, 2007	• gaining and losing nature of some surface water systems in study area	Low
	Hydrogeological map	Liverpool Plains Hydrogeological Map (WRA 1994)	• surface geology of small portion of study area • average quality and flow rate of surface groundwater formations	Low
	Private groundwater bores and monitoring bores	PINNEENA database (NOW, 2013)	• location of private groundwater supply and monitoring bores relative to each GDE	High
Hydrogeology	Water level data	PINNEENA database (NOW, 2013)	• historical water level data for some groundwater bores in study area	Average
	Hydrostratigraphy table	Santos_bdmrgeo020625_V2	• surface and bedrock geology of study area	High
	Groundwater Impact Assessment	CDM Smith, 2016a	• understanding of geology and hydrogeology of study area	High
	Depth to water table data	Namoi Catchment Management Authority, 2008	• depth to water table for upper and lower Namoi alluvium	Low
	Baseline Study Information	Santos Baseline Assessments	• identification of established wetland feature created under artesian conditions	High
Ecology	Threatened species list	PlantNET, 2013	• threatened wetland species in the Northwest Slopes and Plains bioregions	High

- **General site characterisation:**
  - **Site description:** general site descriptions were derived from interrogation of topographical data and aerial photography.
  - **Surrounding land use:** land use of the GDE and surrounding locations was identified through aerial photography and land use maps.
  - **Hydrology:** watercourses were identified through aerial photography and surface water mapping.
  - **Local groundwater dependency:** local groundwater dependency within the vicinity of the GDE was identified from available information sources.
  - **Catchment area:** the surface water catchment area of each GDE was estimated from Digital Elevation Models (DEM) within ArcGIS following identification of surface water flow directions and watersheds.

- **Geology and hydrogeology**
  - **Surface geology:** surface geology was identified through 1:1,250 digital geological mapping provided by the Proponent (surface geology is defined as the geology directly beneath the GDE).
  - **Solid geology:** where the surface geology consisted of quaternary sediments such as alluvium, the underlying solid geology was inferred from the digital geological mapping**.**
  - **Initial hydrogeological assessment:** preliminary hydrogeological characterisation was undertaken to aid in the identification of the source aquifer of each potential GDE. Geological and hydrogeological data was interrogated to identify aquifers present within the study area; define the surface and bedrock geology of each potential GDE; identify the water table level within the study area and at each potential GDE and assess the target aquifer of neighbouring groundwater bores.
  - **Preliminary GDE type:** geological data, topographical maps and aerial photography were interrogated to answer questions aiding in the preliminary identification of GDE types, as follows:
    - **Base flow streams**
      - Is there visible water in pools or consistent flow within surface water systems during prolonged dry conditions, indicating base flow contribution from groundwater?
      - Is the stream or sections of the stream known to be gaining?
    - **Groundwater dependent terrestrial vegetation**
      - Is the water table level near or at the surface or within the root zone of the surrounding vegetation?
      - Is the vegetation community composed of species known to require permanent saturation?
      - During extended dry periods, does a significant proportion of the vegetation remain green and physiologically active?
      - Is the vegetation distinct from surrounding vegetation?
    - **Groundwater dependent wetlands**
      - Is there visible water in the wetland and does the wetland lack surface inflow?
      - Does the wetland occur at a break in the slope?

  - Does the wetland intersect a confined aquifer with a slope?
  - Does the wetland occur at a point of stratigraphic change?
  - Is the wetland considered seasonal?
- **Initial assessment of the potential source aquifer:** based on the aquifers present at the potential GDE location and the preliminary assessment of the type of GDE, a potential source aquifer was assigned to each potential Type 2 GDE.
- **Potential existing geographical impacts:** potential existing geographical impacts to each potential Type 2 GDE were investigated through literature review, identification of land uses within the vicinity of each potential GDE and review of available water level data recorded in neighbouring groundwater bores.

3.3.3 Ecology

- **Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:** ecological characterisation of the study area and potential Type 2 GDEs was undertaken through the interrogation of flora and fauna maps, literature review and threatened species searches.
- **Lists of plant species likely at each potential GDE were compiled from regional lists of wetland flora**. Plant species lists take into consideration the habitat available at the potential Type 2 GDE and the ecological requirements of each species. A focus was given to threatened and listed species.

3.3.4 Existing geographical impacts

There are a variety of ‘pressures’ or disturbances that may adversely impact on GDEs and ultimately affect the overall condition rating. The *State of the catchments 2010 – Wetlands Namoi region* (DECCW, 2010a) identifies three main indicators of pressure to wetland ecosystems in the Namoi catchment, as follows:

- **Catchment disturbance** – modification or changes to the catchment structure or processes that affect the wetland; includes urbanisation, agriculture and infrastructure.
- **Hydrological disturbance** – the levels of nutrients entering a wetland, water and soil chemistry, vegetation patterns, the biota present and the wetlands productivity; includes drainage, damming, extraction and river regulation.
- **Habitat disturbance** – both the direct removal of wetland habitat and activities that modify, damage or disturb wetland habitat areas; includes construction work, urban development, clearing for agriculture and recreational uses.

The baseline condition of the potential GDEs was preliminarily assessed with respect to the above indicators of pressure and a level of potential impact was allocated as follows:

- **Nil impact** – no evident catchment, hydrological or habitat disturbance i.e. GDE within forested area with no nearby registered groundwater abstraction bores.
- **Minor impact** – evidence of catchment disturbance though no evidence of hydrological or habitat disturbance i.e. GDE within forested area with nearby registered groundwater abstraction bores.
- **Moderate impact** – evidence of catchment and hydrological disturbance though no evidence of habitat disturbance i.e. GDE within agricultural area with nearby registered abstraction bores though no evidence of disturbance to wetland/water body vegetation.
- **high impact** – evidence of catchment, hydrological and habitat disturbance i.e. GDE within agricultural area, nearby registered abstraction bores and used for recreational purposes.

3.3.5 Data analysis and characterisation finalisation

Post completion of the field reconnaissance (Section 3.4 below), the following was undertaken:

- Confirmation of groundwater dependency and source aquifer through the review of collated information including analysis of water quality data collated.
- Determination of the ecological value of the aquifer and associated potential GDEs and an assessment of the significance of the flora and fauna present at each site.
- Identification of the existing values and disturbance tolerances / sensitivities of the ecosystems being assessed.

3.3.6 Groundwater dependency and source aquifer

Groundwater dependency was confirmed through the following:

- Observations made through field reconnaissance including water turbidity; observations of seepage into the wetland from the ground; and interactions with nearby surface water systems; the modified nature of the wetland; presence of nearby groundwater bores.
- The type of plant species present indicating the degree and duration of inundation, groundwater systems are more likely to be permanent inundations than surface water wetlands.
- Water quality observations made on site through field parameters, and the analysis of water samples taken from pools.

3.4 Field reconnaissance methodology

The purpose of the field reconnaissance was to further characterise the hydrogeological and ecological systems identified during the screening exercise. A sampling and analysis plan was produced to guide and inform the field work. The following was undertaken during the field reconnaissance:

- Confirmation of the presence of the potential Type 2 GDE:
    - visual confirmation that a potential Type 2 GDE is present
    - confirmation of the number, type and location of potential Type 2 GDEs (e.g. creek bed, mound springs etc.).
- Hydrogeological characterisation:
    - field observations such as surroundings, topography, water table characteristics, potential GDE extent measured
    - water quality samples from the groundwater flow or pool (if appropriate)
    - geology – description of nearby rock outcrops
    - Type 2 GDE type – identification of water table or discharge spring;
    - estimation of groundwater flow.
- Ecological characterisation:
    - potential Type 2 GDE status (active or inactive)
    - potential Type 2 GDE area measured
    - frequency of inundation
    - presence of flora and fauna and invasive species.
- GDE condition assessment based on pig damage, stock damage, excavation damage.

3.5 Determination of groundwater dependency

The NSW Risk Assessment Guidelines suggest that the importance of groundwater to an ecosystem can be determined through a series of general questions. The list of questions (presented in Appendix C), are answered ‘yes’, ‘no’ or ‘unknown’, and the answers can infer the dependency on the groundwater system. The questions are divided into general questions for all types of GDEs and more specific questions for each potential GDE type.

These questions were answered for all 21 potential Type 2 GDE sites (including the 12 which were visited and the nine which were not) utilizing the information collated in the desktop assessment and field reconnaissance summarized in the potential GDE characterisation sheets (Appendix B). The reasons that some sites were not visited is documented in Section 5. The results of the determination of groundwater dependency for all sites are presented in Appendix C.

3.6 Determination of ecological value of GDEs

3.6.1 Methodology

Following the determination of the dependency on groundwater of a site, the ecological value of the ecosystem must be determined. The methodology is described in the NSW Risk Assessment Guidelines (NOW, 2012) and includes the following stages:

- Stage 1 – general aquifer ecological valuation and identification of high ecological value assets.
- Stage 2 – detailed ecological valuation of an aquifer and GDE.

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

This stage is a rapid identification of high ecological value assets of the source aquifer by answering three questions. This is a broad scale assessment that aims to identify if an aquifer has environmental assets that have been previously identified as having important conservation significance, allowing for the initial protection of a GDE. This is the initial process for listing High Priority GDEs within the water sharing plan process.

The following questions must be answered ‘yes’ or ‘no’:

- Does the aquifer or portion of it occur within a state reserve or support GDEs with a sub-catchment identified as High Conservation Value?
- Does the aquifer support obligate/entirely dependent GDEs including: karsts, springs, mound springs, subterranean aquifer ecosystems and some wetlands such as hanging swamps?
- Does the aquifer support GDEs that have endemic, rare or endangered biota populations?

If a yes is answered to any of these questions then they are assigned ‘High Ecological Value’. The aquifer as a whole is therefore considered to have ecological value. In order to determine the final ecological value Stage 2 must be followed.

3.6.3 Stage 2 - Detailed ecological valuation of an aquifer and GDE

The stage 2 ecological valuation process assesses those potential or known GDEs as well as their associated aquifers using a detailed ecological assessment. The process follows two steps:

- Step 1: identification of the ecological value of individual GDEs within an aquifer.
- Step 2: identification of the ecological value of the aquifer.

The following criteria are assessed:

- GDE environment
- rarity of dependent biota or physical features with the catchment
- diversity within the catchment and/or hydrological unit (as appropriate)
- special features.

A number of questions are answered to determine 1) the ecological value of the individual potential GDE, and 2) the ecological value of the aquifer. These questions are detailed in the guidance and presented as part of the assessment in Appendix C.

The questions must be answered under the criteria 'high', 'moderate' and 'low' based on the criteria provided. The overall value for the potential GDE or aquifer is the category of value (H, M or Low) that has the most attributes assigned to it.

3.7 Risk assessment methodology (Phase 3)

A risk assessment has been undertaken in accordance with the *Risk assessment guidelines for groundwater dependent ecosystems* (NOW, 2012) and comprised the following tasks:

- Identification of proposed activities associated with the development of the project and location of proposed activity with respect to each potential GDE.
- Assessment of the potential impact of the proposed activity on the aquifer and associated potential GDE; and
- Estimation of the magnitude of risk from the proposed activity on the ecological value of the potential GDE and aquifer.

3.7.1 Determine impact of activity to aquifer and associated GDEs

The impacts of the project were assessed with respect four main aquifer assets as follows:

- Water quantity impacts:
  - o Will there be an alteration to the water table levels, aquifer flow paths, aquifer discharge volume, and frequency/timing of water table level fluctuations?
  - o Will there be an alteration of river base flow?
  - o Will there be a reduction in artesian/spring water pressure?
- Water quality impacts:
  - o Will there be an alteration to the natural groundwater chemistry and/or chemical gradients?
  - o Will there be an alteration in nutrient loads, sediment loads, salinity levels, groundwater temperatures or heavy metals?
- Aquifer integrity impacts
  - o Will substrate alteration occur through compaction?
  - o Will cracking or fracturing of bedrock occur?
- Biological integrity impacts
  - o Will there be an alteration to the number or composition of native species within the groundwater dependent communities?
- Exotic flora or fauna impacts
  - o Will there be removal or alteration of a GDE type/subtype habitat

When assessing potential impacts of the project on aquifer assets, the impact of existing disturbances was taken into consideration such that the level of anticipated impact was a direct comparison of the degree of change relative to the ecological values being affected.

3.7.2 Determining the magnitude of potential risk from activity

The magnitude of the risk to each aquifer and potential Type 2 GDE was assessed through consideration of the characteristics of the GDE and the impacts to the potential GDE as a result of the project. The likelihood and degree of threat to each aquifer and potential Type 2 GDE was assessed and potential impacts ranked based on a high, medium or low rating.

The risk assessment guidelines for groundwater dependent ecosystems (NOW, 2012) specifies that if the risk rating is unable to be quantified for greater than 50% of the potential impacts, the risk is to be considered as high until proven otherwise. This requirement has been adopted within this assessment.

3.7.3 Risk matrix

The NOW (2012) guidelines provide a risk matrix which identifies both the level of management required and the timeframe in which this action needs to be implemented. This matrix is utilised to determine the level of risk, and therefore the type of response required. The matrix compares the sensitivity of the GDE, depending on ecological value to the magnitude of the risk, as presented in Figure 3-2 below.

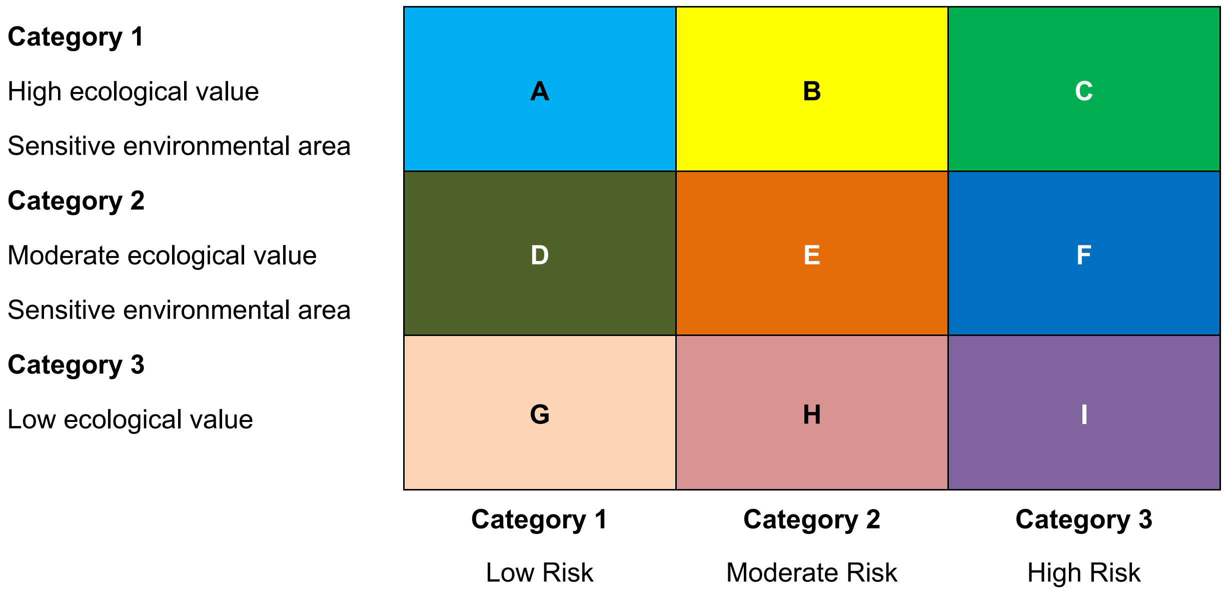


Figure 3-2: Risk matrix (from NOW, 2012)

The outcome of the risk scoring is reflected in a risk matrix score. This is translated into recommended management actions with timeframes, as shown in Table 3-2 below.

Table 3-2: Recommended management actions & timeframes

Risk Matrix Box	Management action short term	Management action mid term	Management action long term
A	Protection measures for aquifer and GDEs. Baseline risk monitoring	Continue protection measures for aquifers and GDEs. Periodic monitoring and assessment.	Adaptive management. Continue monitoring.
B	Protection measures for aquifer and GDEs. Baseline risk monitoring. Mitigation action.	Protection measures for aquifer and GDEs Monitoring and periodic assessment of mitigation	Adaptive management. Continue monitoring.
C	Protection measures for aquifer and GDEs Baseline risk monitoring. Mitigation	Protection measures for aquifer and GDEs Monitoring and annual assessment of mitigation	Adaptive management. Continue monitoring.
D	Protection of hotspots Baseline risk monitoring	Protection of hotspots Baseline risk monitoring	Adaptive management. Continue monitoring.
E	Protection of hotspots Baseline risk monitoring Mitigation action	Protection of hotspots monitoring and periodic assessment of mitigation	Adaptive management. Continue monitoring.
F	Protect hotspots Baseline risk monitoring. Mitigation action	Protect hotspots Monitoring and annual assessment of mitigation	Adaptive management. Continue monitoring.
G	Protect hotspots (if any) Baseline risk monitoring	Protect hotspots (if any) Baseline risk monitoring	Adaptive management. Continue monitoring.
H	Protect hotspots (if any) Baseline risk monitoring, mitigation action	Protect hotspots (if any) Monitoring and periodic assessment of mitigation	Adaptive management. Continue monitoring.
I	Protect hotspots (if any)	Protect hotspots (if any)	Adaptive management. Continue monitoring.

4 Phase 1: Identification of type and location of potential GDEs

4.1 Identification of potential GDE locations

4.1.1 Literature and database review

A review of available information relating to GDEs from literature and database searches was undertaken. Further to this, available data from other sources, such as the Proponents' Baseline Assessment

Water Sharing Plans (NOW, 2003, 2008 and 2011)

The *Water Management Act 2000* is the key piece of legislation for the management of water in NSW. Under the Act, Water Sharing Plans (WSPs) are the main tool under the act for managing the State's water resources, setting out rules for the sharing of water and the protection of high priority GDEs. High priority GDEs are GDEs of High Ecological Value (HEV) and are considered a high priority for management action.

Water Sharing Plans may also provide additional information on the ecological value of an aquifer and associated GDEs. The assignment of ecological value at the aquifer and individual GDE scale is essential in identifying management actions. The following Water Sharing Plans, relevant to the study area, were examined:

- NSW Great Artesian Basin Groundwater Sources 2008.
- Upper and Lower Namoi Groundwater Sources 2003.
- NSW Murray Darling Basin Porous Rock Groundwater Sources 2011.

The Water Sharing Plans do not specify high priority GDEs in the study area.

State of the Catchment Reports (DECCW, 2010a and 2010b)

The 2010 State of the Catchment (SoC) reports document the condition and pressures on natural resources and community targets at the regional scale. The State of the Catchment reports for the Namoi region have been compiled from the NSW Natural Resources Monitoring, Evaluation and Reporting Program undertaken 2010 – 2015 (DECCW, 2010c). The Namoi Region State of the Catchment reports provide information on the biodiversity, community, land and water resources, including details of GDEs and wetland communities.

The following features were identified in the study area from the State of the Catchment report:

- Springs: Two springs (Eather and Hardy's) were identified at the interface of the Purlawaugh Formation and Garrawilla Volcanics.
- Wetlands: Four wetlands (Round Swamp, Reedy Lagoon, Yarrie Lake and Narrabri Lagoon) were identified though their groundwater dependency is not specified.

The spring features (Eather and Hardy's) were originally identified and assessed within a desktop assessment by the former Department of Water and Energy (DWE, 2008) and their groundwater dependency and ecological features are understood not to have been ground-truthed by the Department. These features are not listed in the relevant Water Sharing Plans as they were not identified as existing at the time of implementation of the plan, however they remain protected under the *Water Management Act 2000*.

The two springs and four wetlands identified from the State of the Catchment reports are presented in Appendix A Table A1.

National Atlas of Groundwater Dependent Ecosystems (Bureau of Meteorology, 2013)

The National Atlas of Groundwater Dependent Ecosystems presents an assimilation of knowledge of GDEs across Australia. The Atlas displays ecological and hydrogeological information on known and potential GDEs. The online component of the Atlas shows ecosystems including springs, wetlands, rivers and vegetation that interact with:

- subsurface groundwater
- the surface expression of groundwater.

The GDE Atlas has provided details on the Eco-Hydrogeological Zones (EHZ), Groundwater Management Areas (GMA) and spatial connectivity between the ecosystem and groundwater, confirming the presence of Eather and Hardy's springs (identified previously through the Namoi Region State of the Catchment reports). A section of the Namoi River which runs parallel to the Kamilaroi Highway towards the township of Baan Baa has been identified through previous fieldwork and desktop assessments to have a high potential of groundwater dependency.

Pilliga Forest Map (NSW NPWS, 2008), Pilliga State Forests Map (Forestry Commission of NSW, 1989), Baan Baa 1:50 000 Topographic Map (Sheet Number 8836N)

The Pilliga Forest Map and the Pilliga State Forests Maps indicate the location of potential springs. The maps differentiate between bores and springs, though it is likely that some features listed as a spring may in fact be a bore. As an example, the so-named Garlands Dam implies that it is a constructed feature, but on both maps it is given the symbol for a spring. Where apparent contradictions such as these occur, a conservative approach has been adopted and the feature in question has been assigned as a spring in the initial list but later discarded if it was found to it occur close to a registered bore (Lucky Flat Bore and Top Well).

Between the two maps, eleven springs were identified in the study area and an additional fifteen were found that occurred just outside the boundary of the study area. The maps also show the locations of Spring Creek, Yellow Spring Creek, and other drainage lines originating at the junction of the Pilliga Sandstone and Purlawaugh Formation in the Pilliga East State Forest. Springs occurring at this geological interface are likely to be recharge-rejection springs.

The features identified in the study area are listed in Table A1 in Appendix A.

The Water Asset Information Tool (WAIT) Database (Namoi and Border Rivers-Gwydir CMA, 2012)

The Namoi and Border Rivers-Gwydir Catchment Management Authority (CMA) has commenced a bioregional assessment involving the identification and compilation of all available water asset data. In conjunction with the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) the Water Asset Information Tool (WAIT) database and associated geodatabase were developed.

The WAIT database is designed to store data about a catchment's water assets and allows a broad rating of vulnerability to be entered in relation to the potential impact of major land use activities on flow pattern, habitat, and water quality and water quantity. The database includes information on streams, rivers, waterholes, waterfalls, wetlands, groundwater dependent ecosystems and other aquatic features in the Namoi and Border Rivers-Gwydir Catchments. Two springs were identified in the WAIT database as present within the study area, though both had been identified previously within this investigation - these were Eather Spring and Hardy's Spring.

Namoi Wetlands Assessment and Prioritisation Project database (Eco Logical Australia, 2008)

The Namoi Wetlands Assessment and Prioritisation Project database was developed by Eco Logical Australia (ELA) for the Namoi CMA in 2008 using a combination of remotely sensed and ground-truthed data. This project identified and mapped 2,766 wetlands in the Namoi catchment, then ranked them on their ecological value and perceived level of threat (ELA, 2008).

To identify potential GDEs in the study area, the database was scrutinized for all wetlands whose water source was listed as groundwater. This provided an additional nine potential GDEs, which included apparent spring-fed dams, swamps and perennial wetlands. The GDEs in this database were unnamed, but were assigned a number between 979 and 1679.

Ecological and Hydrogeological survey of the Great Artesian Basin springs – Volume 1&2 (Commonwealth of Australia, 2014)

This survey considers the potential impacts, mainly from coal seam gas projects in the Surat Cumulative Management Area in Queensland, to springs of the Great Artesian Basin. The report considers the findings of surveys of 848 springs in four Great Artesian Basin supergroups, the nearest being in the Bogan River Supergroup, situated over 100 km to the west of the study area. The Bogan River Supergroup includes the outcrop of the Pilliga Sandstone, for which the recharge beds are located in the study area. The outcome of the survey was that there are no active springs in the Bogan River Supergroup, and, given the distance, was not considered further.

Potential GDEs Identified Through the Literature and Database Review

Table A1, Appendix A lists potential GDEs identified through the literature and database review process located in the study area (Twenty potential GDEs).

4.1.2 Additional baseline study information

Baseline information for a survey of registered bores within the study area identified a wetland feature with potential groundwater dependency.

A recent registered bore survey visit to a groundwater bore (GW020506) identified a wetland feature created under artesian conditions of an old exploration well. It is assumed that upon completion of the well the bore was plugged above producing formations and screened within a water bearing unit of economical supply.

The artesian bore has effectively established a wetland feature that may be of ecological significance and identified one additional potential GDE within the study area. The wetland feature has been assessed in more detail and provided with a confidence score in Section 4.4.

Table A1, Appendix A lists a total of twenty-one potential GDEs located within the study area.

4.1.3 Remote sensing

Characteristics of known GDEs were used as reference characteristics to identify additional potential GDE features from satellite and aerial images. Imagery from dry periods (October 2002, October 2006, and

September 2009) was used to enhance the contrast between GDEs and other features in the landscape. The spectral signatures of 24 reference GDEs (identified during the literature review both inside and outside of the study area) were collected to train supervised classification techniques and to evaluate unsupervised classification outputs. These processes were refined to enhance detection of known GDEs and limit the inclusion of non-groundwater fed wetlands. Classified images were overlaid on higher resolution aerial imagery to guide investigation and identification of potential GDEs.

Once the potential GDEs were mapped by this technique, each was assigned a confidence rating to indicate the likelihood of groundwater connection. This included assessments of wetland morphology, local surface flow patterns, vegetation and proximity to infrastructure. A total of 40 potential GDEs were identified in this way.

4.2 Preliminary assessment of potential GDEs

Potential GDE features identified in the study area through the literature and database review, remote sensing exercises and additional baseline study information are illustrated on Figure 4-1 and listed in Table A3, Appendix A (54 potential GDEs in total). One location identified during remote sensing was duplicated in the literature review.

These features were subject to an initial screening exercise in order to identify with medium to high confidence that potential GDEs warranted further assessment.

The location, topography, geology, hydrogeology and surface drainage was assessed for each potential GDE, and the list was refined to identify the highest potential GDE sites. This process of refinement is described below. Full details of this preliminary assessment for all identified potential GDEs are presented in Table A-3, in Appendix A, and summarised below.

4.2.1 Groundwater dependency initial assessment

The outcomes of the preliminary assessment were used to identify locations for assessment in Phase 2. Where low groundwater dependency was indicated (i.e. source of water is considered to be surface water and not groundwater) the site was removed from the assessment. If the groundwater dependency of the site could not be determined and the site appeared to have little to no ecological value, the site was removed from further assessment.

Two preliminary GDEs (Reedy Lagoon and Narrabri Lagoon) were identified as having a low groundwater dependency and predominant surface water dependency. A further two preliminary GDEs (Lucky Flat Bore and Top Well) were identified as having low groundwater dependency and low ecological value. Both are located within 10 m of a registered bore and their feature-identifiers suggest that the wetland is caused by the historical construction of agriculture dams. These four features were removed from further assessment.

4.2.2 Ecological valuation initial assessment

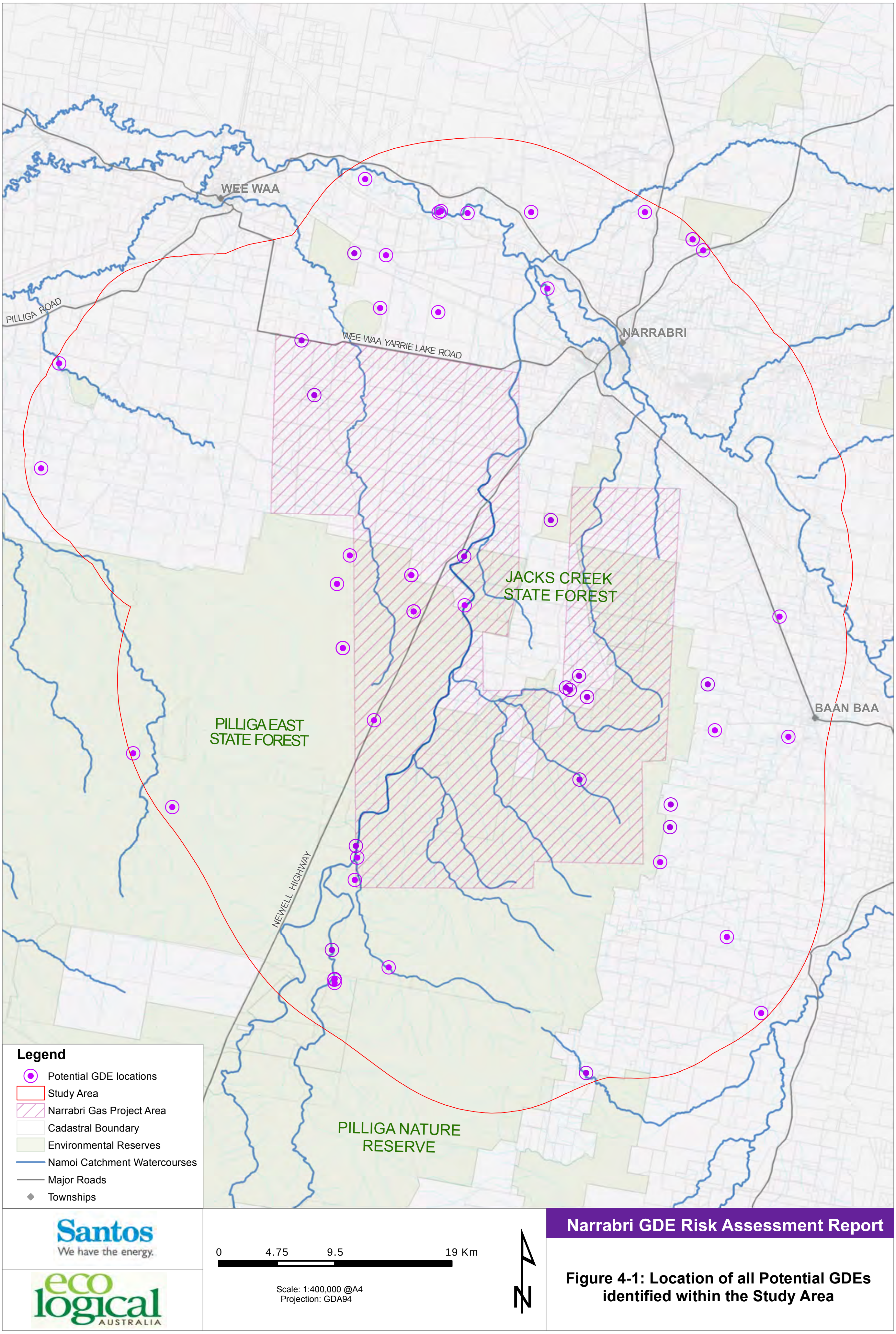
A number of the wetlands identified during the desktop assessment have already received some level of assessment. These include some wetlands from the *Namoi Wetlands Assessment and Prioritisation Project* database (e.g. 1200), which was designated as ‘artificial but with ecological significance’. These assessments are considered in this valuation. For those wetlands for which little or no information was available, assessment of the wetland value was based on the appearance of the wetland in satellite images.

Wetlands were assigned an initially high ecological value if they appeared to be unmodified by human activity, were surrounded by a broad band of native vegetation, contained water with low turbidity and/or were close to other wetlands. Wetlands in cleared agricultural land, or with stock access to the water were rated as being indicative of poor ecological condition. Turbid water was also taken as an indicator of poor ecological condition for potential GDEs as, in the absence of stock disturbance, it indicates dominant contributions from overland flow.

Although most GDE wetlands will receive some overland flow during wet periods, when rainfall is scarce, low turbidity groundwater will be the principal source of water.

4.3 Selection of locations for assessment in Phase 2

A total of 21 potential GDEs located in the study area, illustrated in Figure 4-2 were taken forward to Phase 2.



Narrabri GDE Risk Assessment Report

Figure 4-1: Location of all Potential GDEs identified within the Study Area

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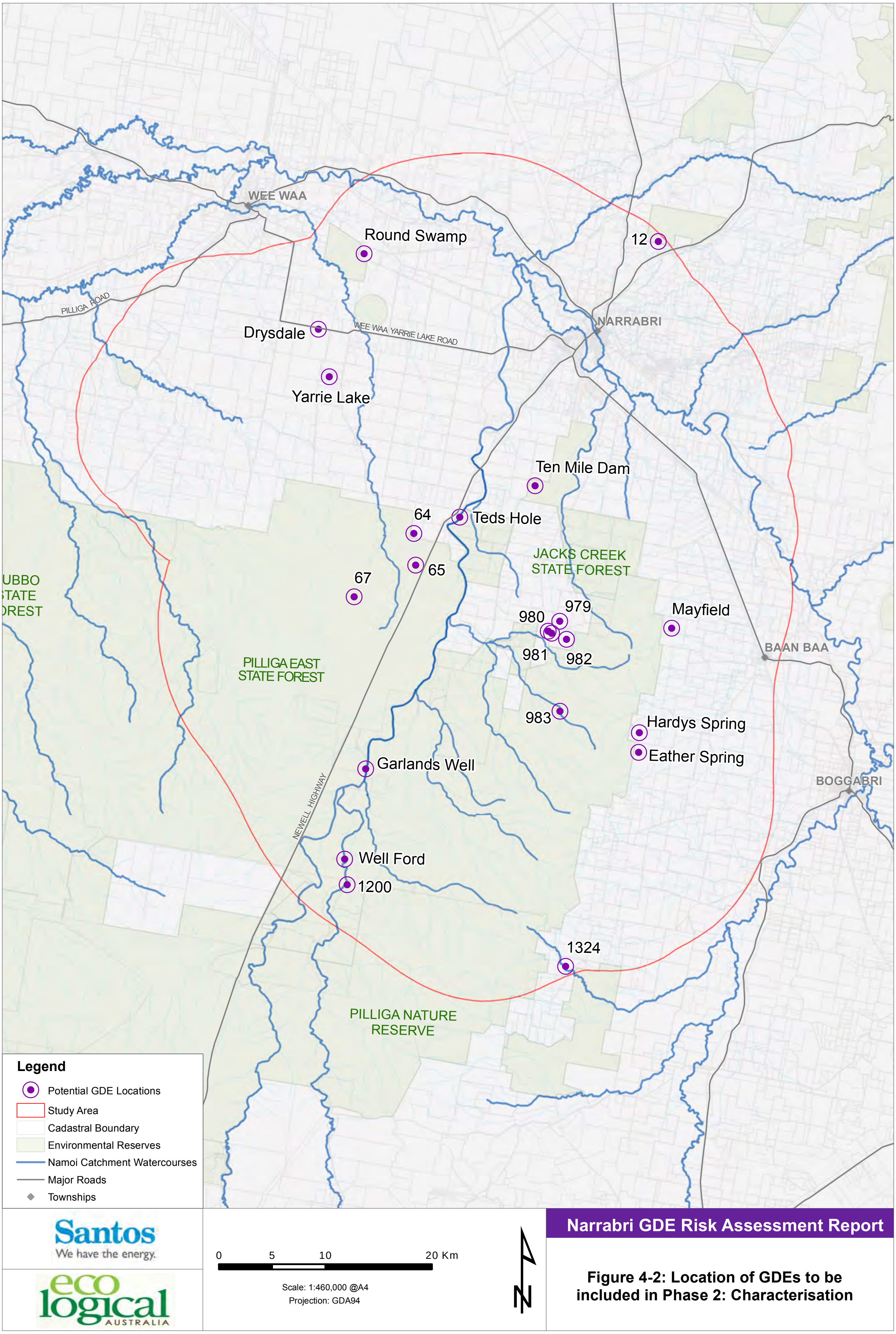

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Figure 4-2: Location of GDEs to be included in Phase 2: Characterisation

5 Phase 2: GDE characterisation & assessment

Phase 2 provides detailed characterisation of each of the potential GDEs, with the aim of providing sufficient evidence to determine the level of groundwater dependency and the ecological dependency.

Summary characterisation sheets are presented in Appendix B documenting the evidence collected during this phase. The outcome of the assessment is the determination of whether or not a potential GDE exhibits evidence of groundwater dependency, and the ecological value of the potential GDE, both aspects of which are taken forward into the risk assessment in Phase 3.

The following sections summarise the findings of Phase 2.

5.1 Field reconnaissance

Field reconnaissance was undertaken at thirteen potential GDEs (Table 5-1). One further potential GDE was observed during a baseline bore assessment visit.

Table 5-1: Site visits completed & samples taken

GDE Reference	Date Visited	Laboratory Sample Work-order Reference	Water Sample Reference
10 Mile Dam	21/10/2013	ES1322981	7561_WSURF_201310211440
Ten Hole	21/10/2013	ES1322981	7551_WSURF_201310211650
12	22/10/2013	No sample	No sample
67	24/10/2013	No sample	No sample
65	24/10/2013	ES1323117	7555_WSURF_201310240840
1324	04/11/2013	ES1324014	7563_WSURF_201311041640
Yarrie Lake	05/11/2013	ES1324014	7550_WSURF_201311050730
Garlands Dam	05/11/2013	ES1324038	7507_WSURF_201311051345
981	06/11/2013	ES1324201	7567_WSURF_201311060945
982	06/11/2013	No sample	No sample
983	06/11/2013	ES1324202	7557_WSURF_201311061355
Drysdale	22/06/2014	ES1404180	7789_WG_201422060900
Mayfield Spring	30/10/2015 and 25/11/2015	No sample	No sample

It was not possible to complete site visits at all sites. Unvisited sites, and the reasons they weren't visited, are presented in

Table 5-2. These included:

- two landowners refused access to their properties
- the Proponent was not able to identify land owners through the Narrabri Shire Council, so had no authority to access the land; and
- property owners were not contactable to gain permission.

Table 5-2: Potential GDEs not visited

GDE Reference	Reason not visited
979	Landholder refused access
Eather Spring	Landholder refused access
Hardy's Spring	Unable to identify property owner
Well Ford	Unable to make contact with property owner
980	Not accessible
Drysdale	Not accessible
64	Unable to complete field visit within appropriate timeframes
Round swamp	Unable to identify property owner

Where potential GDEs were not visited, additional desktop characterisation was undertaken specifically as part of the ecological assessment to determine the potential for MNES to be present.

5.2 Hydrogeological characterisation

The outcome of this initial desktop characterisation and subsequent field reconnaissance is included in the summary characterisation sheets presented in Appendix B.

5.2.1 Review of geology & hydrogeology

An assessment of surface geology was undertaken at each location. This is shown on Figure 5-1, and presented in greater detail on the site summary characterisation sheets in Appendix B.

5.2.2 Water quality analysis

Water quality samples were taken at potential GDEs where a representative sample could be taken. Table 5-1 presents where a sample was taken and the laboratory reference. All data has been incorporated into the Proponents' surface water quality monitoring program and held within their EQUIS database.

Interpretation of the water quality analysis has been undertaken, with the following findings:

- Water samples obtained from sites were sampled for chemical and isotopic analysis. This information has been used to characterise the water quality of the potential GDEs, to inform the conceptual model for each location, and therefore to assist with the determination of groundwater dependency.
- All C^{13} ratios analysed under show negative values and therefore do not indicate a linkage between surface water features and coal seam formations.

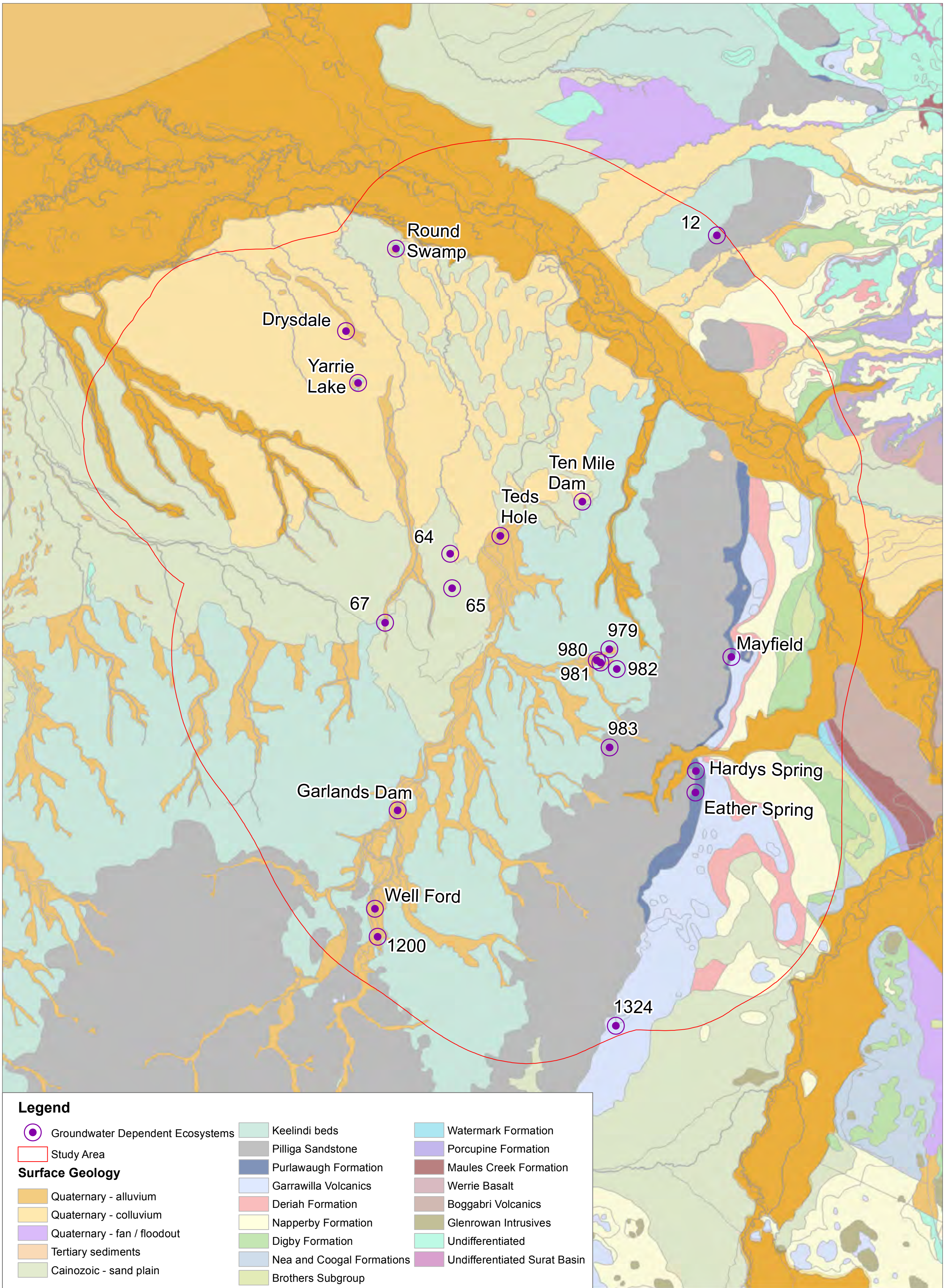

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Figure 5-1: Geological Summary Map of the Study Area

5.3 Assessment of groundwater dependency

Of the 21 sites, nine were determined to be potentially groundwater dependent and are summarised in Table 5-3 below. Of these nine, four of them were visited.

Table 5-3: Determination of groundwater dependency

Site	Rationale & GDE Type
12*	Located on the Pilliga Sandstone, small ecological community with no signs of surface water inputs, therefore assumed to be groundwater dependent. This site is considered to be a water table spring, and potentially a 'window into the water table'
65*	Located at a former gas well (Bohena 1) which sources water from the Pilliga Sandstone, it is assumed that the wetland is directly dependent on the water flowing from the bore located at the base of the pool.
980	Aerial photography suggests that this site may be groundwater dependent because the site appears to contain fresh (not turbid) water, there is potentially a water table spring located to the south-east of the site, and the naming of 'Spring Creek' located in proximity to the site suggests springs occur in the area.
Eather Spring	This site has been recognized by NOW as a high priority GDE. Given proximity to the interface between the Pilliga Sandstone and the Purlawaugh Formation this is considered to be a water table spring (contact spring). This is a farm dam and is highly modified through excavation and damming of drainage lines, and through stock access.
Hardy's Spring	This site has been recognized by NOW as a high priority GDE. Given proximity to the interface between the Pilliga Sandstone and the Purlawaugh Formation this is considered to be a water table spring (contact spring). This is a farm dam and is highly modified through excavation and damming of drainage lines, and through stock access
Mayfield Spring*	Identified as a spring in other studies. Given proximity to the interface between the Pilliga Sandstone and the Purlawaugh Formation this is considered to be a water table spring. A highly modified environment. Potentially fed by a diffuse soak in the upstream channel. If a spring site exists, it has probably been enlarged by excavation and damming of the downstream edge of the drainage line, which leads west-east.
Teds Hole*	This site is a permanent waterhole which is relatively fresh with no obvious surface water input. The GDE is likely to represent a perched feature, occupying a depression in an Orallo sandstone member, perched on an Orallo shale bed, well above the Pilliga Sandstone. The evidence suggest that the site is at least partially dependent on groundwater.
Well Ford	Considered to be located at a former gas well (Galloway 1) which is currently assumed to supply water to the feature from the Pilliga Sandstone. High resolution aerial photography of the site does not clearly show a wetland feature, the area surrounding the location is in part densely forested.
Drysdale	Located immediately adjacent to the Wee Waa 1 bore which the borehole log indicates sources water from the Pilliga Sandstone. Artificial wetland with a dependence on groundwater upwelling from an open bore.

*Visited during field reconnaissance

The remaining sites have been ruled as unlikely to be groundwater dependent on the basis of the evidence obtained during Phase 2. The rationale for this is presented in the individual summary characterisation sheets (Appendix B) and presented in summary in Table 5-4 below.

Table 5-4: Site determined to not be groundwater dependent

Site	Rationale for not being groundwater dependent
64	Unlikely to be groundwater dependent as the aerial photography suggests the site to be a man-made dam sourced by surface water, the water is turbid suggesting a lack of fresh groundwater input.
67*	The site was dry when visited with little vegetation, there was no evidence of seepages, water pools or vegetation. The feature is likely to have been formed through surface runoff.
979	Aerial photography suggests that the site is a man-made damming of a natural drainage line likely sourced by surface run off. In addition the water within the feature appears to be turbid which suggests a lack of fresh groundwater input.
981*	The site visit confirmed that the site is a surface water dam, the water within the dam was receding and turbid suggesting no fresh groundwater input.
982*	It was confirmed through site visit as a surface water dam, the site was dry at the time of visit and did not support vegetation suggesting that the site is forms a temporary store of surface water during wet periods.
983*	This site was confirmed in the location of Yellow Spring Creek as a man-made dam with inputs from Yellow Spring Creek, fairly turbid water suggests a lack of fresh groundwater input.
1200*	On the occasion of the site visit, the site was dry and confirmed as a surface water dam, a shallow drainage line was observed entering the feature to the south. It is very unlikely that groundwater feeds this feature when water is present.
1324*	The site visit confirmed that the site is a surface water dam, man-made, located in the Bara Creek and designed to capture surface water inputs such as runoff. The high turbidity of the water suggests a lack of freshwater input.
Garlands Dam*	The site visit confirmed that this feature is an artificial dam fed by surface water runoff. The turbid nature of the dam suggests a lack of fresh groundwater input.
Round Swamp	This site is very similar to Yarrie Lake, high resolution photography suggests that this location is sourced by a surface water channel and its colour suggests that it is turbid with a lack of fresh groundwater input.
Ten mile Dam*	The site visit confirmed that this site is a surface water dam which is not considered to be dependent on groundwater, dried surface water run-off channels were observed, the water level was receding and turbid with no evidence of fresh input.
Yarrie Lake*	Yarrie Lake was confirmed as a natural surface catchment lake which is not dependent on groundwater. The high turbidity of the lake suggests little fresh groundwater input which is supported by the lake being dry at the time of the reporting.

*Visited during field reconnaissance

Sites that are determined to not be groundwater dependent are not considered further in this study.

5.4 Ecological characterisation

5.4.1 Desktop assessment

While the establishment of groundwater dependence is of defining importance in classifying springs, the relevance of the spring type needs to be considered when assessing for Matters of National Environmental Significance. As an ecosystem type, the GDEs need to fit the definition of the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin to be considered a Matters of National Environmental Significance.

Endangered Ecological Communities are defined by the assemblage of species that are associated with a particular area (i.e. the habitat present). Many of the species required to meet the definition of the Great Artesian Basin discharge springs are absent from the potential wetlands assessed during this study. Therefore, the potential GDEs considered during this assessment are not considered to be communities of national significance because they are in the wrong geographical location and they do not have the correct species assemblages.

Other factors that could result in the springs being of national significance is whether they support species of national significance. To determine whether this is the case without a site visit, a threatened species search was conducted for an area of approximately 20 km around each of the spring locations. This resulted in a list of 13 threatened fauna five threatened flora species.

Of these 18 species, only the Australasian Bittern (*Botaurus poiciloptilus*) and Australian Painted Snipe (*Rostratula australis*) have affiliation with GDEs. Therefore, the only factors that need to be considered in an assessment of Matters of National Environmental Significance is whether there is suitable habitat for these two species. Both species require wetlands with dense vegetation. Australasian Bittern require permanent wetlands with tall, dense vegetation, particularly *Typha spp.* and *Eleocharis spp*. Painted Snipe prefer marshy areas beside swamps and dams, where there are mudflats for foraging. These required habitat features are relatively common in the study area, though most are associated with surface wetlands that have not been identified as having potential for groundwater dependence.

Appendix D presents a list of flora species which may be present within the study area.

The aquatic fauna at potential GDEs in the study area were considered to be dominated by invertebrates, of which only *Notopala sublineata* (River Snail) is listed as a threatened species. Three threatened species of fish are found within the study area, as shown in Table 5-5 though within the Namoi River only. *Crinea sloanei* (Sloanes Froglet) may be found in GDEs with inundated grassy areas.

Table 5-5: Expected threatened aquatic fauna in study area

Species	Common Name	Habitat	Conservation status	Location
Crinia sloanei	Sloane's Froglet	Periodically inundated areas of grassland, woodland, and disturbed habitats	Vulnerable	Predicted to be in study area
Maccullochella peelii	Murray Cod	Deep pools, slow-flowing water in turbid lowland rivers	Vulnerable	In Namoi River, not in springs
Tandanas tandanas	Freshwater Catfish	Slow-flowing or still water with deep pools	Endangered population	In Namoi River, not in springs
Bidyanus bidyanus	Silver Perch	Deep pools, slow-flowing water in turbid lowland rivers	Vulnerable	In Namoi River, not in springs
Notopalaz sublineata	River Snail	Slow-flowing water with hard substrate	Endangered	Possibly extinct though may be present in study area

5.5 Extended review of aerial photography

High resolution aerial photos were examined for each of the unvisited sites. Two images per site are provided in each Site Summary Sheet, but additional images were also viewed using Google Earth©. The additional images allowed a more detailed assessment temporal variation, as well as an indication of site context at the broader scale.

Observations of each potential wetland are summarised in the Table 5-6. There were two sites where groundwater dependence was possible, one where it was likely, and another where it was certain. The latter wetland is the shallow depression on ‘Drysdale’, which is fed by an uncapped bore. Wetland vegetation is present, but this is unlikely to contain GDE species. As the potential GDE is essentially an artificial wetland, the vegetation community that preceded the bore will have resembled that of the surrounding landscape. Wetland species are likely to have arrived either via wind, birds and other animals, or overland flow during periods of high rainfall. This potential Type 2 GDE may be suitable for Australian Painted Snipe, although it is close to a road. It is also likely to be accessed by stock and feral animals such as foxes and cats. It is unlikely that the wetland is large enough to support Australasian Bittern, which are wary of predators.

Both Eather and Hardy’s springs have a dependence on groundwater that is implied by their name. However, if there is a connection, the wetlands appear to have been altered substantially. Both are used for watering stock, appear to have been excavated, and have had embankments raised around them to increase their water-holding capacity. Excavation of the potential GDE probably removed most of the original soil, and consequently also removed the seedbank that soil contained. None of the wetlands indicate sufficient fringing aquatic vegetation to favour Australasian Bittern or Australian Painted Snipe, so both of these species are unlikely to occur. These sites, while potentially groundwater dependent, are unlikely to contain Matters of National Environmental Significance. Further disturbance from stock, which appear to have access the springs, trample the shoreline and shallow underwater habitat, and enrich the nutrient content of the water.

Nearly all of the potential wetlands (apart from Drysdale and 65), occur in drainage channels. This suggests that, periodically, water flows through the wetlands, linking them to other wetland systems further downstream and potentially distributing reproductive material along the channel. It is likely that seeds will germinate in the channel and persist for as long as water remains, regardless of whether the water is of subterranean or terrestrial origin. There are unlikely to be threatened wetland plant species present at the study sites. If they were, then these species are likely present because of surface runoff, rather than groundwater.

Table 5-6: Summary of aerial photo inspections for potential GDEs not visited.

Site name	Notes from aerial/satellite images	Likelihood of Matters of National Environmental Signifiance
Eather Spring	Circular body of water in a vegetated drainage line. Contour banks north and south to channel runoff into channel. Surrounded by tilled grazing land.	Very unlikely because of high level of disturbance. Habitat unsuitable for Australasian Bittern or Australian Painted Snipe because of insufficient wetland vegetation.
Hardy's Spring	Three isolated water bodies in a shallow drainage channel. Surrounded by bare ground. Contour banks funnel overland flow to dams.	Very unlikely because of the high level of disturbance and apparent access to water by stock. Habitat unsuitable for Australasian Bittern or Australian Painted Snipe because of insufficient wetland vegetation.
64	Rectangular dam of water similar in colour to the surrounding earth. No apparent fringing vegetation. Stock trails leading to water.	Very unlikely because of the high level of disturbance and absence of wetland vegetation.
979	Clear embankments created along southern and western sides to create damming of a drainage line. Stock access trails. Green tinge in north western end of dam in 2010 may be a thin band of wetland vegetation, but this is absent in 2014. In 2014 there is a fringe of vegetation around part of the dam between water and embankment.	None, given the high level of disturbance in the surrounding area. Habitat unsuitable for Australasian Bittern or Australian Painted Snipe wetland vegetation is sparse and not permanent.
980	Long, thin wetland in forest south of buildings that retreated to a small waterhole in 2014. Possible embankment at the western end. Vehicular tracks provide access. Green tinge on dry bed to east of water in 2014 - likely to be herbaceous vegetation on moist soil.	Although surrounded by treed vegetation, the presence of wetland Matters of National Environmental Significance is unlikely.

Site name	Notes from aerial/satellite images	Likelihood of Matters of National Environmental Signifiance
Round Swamp	Large round water body, probably of similar origin as Yarrie Lake. Heavy sediment load and drainage channel entering from south-east.	Matters of National Environmental Significance very unlikely. Habitat unsuitable for Australasian Bittern or Australian Painted Snipe because wetland vegetation is sparse.
Well Ford	No apparent water in 2010, although there is a bare patch beside Borah Creek that may hold water after prolonged rain.	Very unlikely that aquatic Matters of National Environmental Significance are present as there is no permanent water.
Drysdale	Shallow wetland formed in a depression that ponds water from flowing artesian bore. Wetland plants present, but unlikely to be endemic because the wetland is artificial.	Unlikely because the wetland is present only because of bore. If threatened species are present, they are likely also to be present in wetlands nearby. Habitat unsuitable for Australasian Bittern and likely too disturbed for Painted Snipe.

5.5.1 Existing geographical impacts

There are a variety of 'pressures' or disturbances that may adversely impact on wetlands and ultimately affect the overall condition rating. These are considered important when assessing the current ecological value of the site.

Geographical impacts evident at the location of the potential GDEs identified during characterisation include:

- extraction of groundwater locally from nearby registered bores
- location of grazing land nearby which results in damage from stock
- damage from wildlife such as wild pigs
- location of agricultural land nearby which could have impacts on the groundwater quality of the GDE
- location of the GDE with respect to homesteads resulting in some human impact such as the removal of water
- evident damming of the GDE for water supply purposes
- occurrence of recreational activities such as jet skiing or boating which could result in degradation or pollution.

5.6 Ecological field survey findings

The findings of the field survey are presented on the GDE characterisation sheets for both sites confirmed as likely to be GDEs and those confirmed as unlikely to be GDEs, included in Appendix B.

5.7 Ecological value of GDEs

5.7.1 Stage 1 General aquifer ecological valuation and identification of High Ecological Value assets

The Stage 1 assessment undertaken in accordance with the NSW Risk Assessment Guidelines (NOW, 2012) presents a high level review of the overall aquifer ecological value. The assessment determined that all the aquifers present at the potential GDE sites are all classed as having high ecological value. This is because the Pilliga Sandstone, Cainozoic sand plain and Quaternary alluvium all support obligate/entirely dependent GDEs including springs.

5.7.2 Stage 2 Detailed ecological valuation of the GDEs

The detailed Stage 2 assessment was conducted for sites confirmed as groundwater dependent in accordance with the NSW Risk Assessment Guidelines (NOW, 2012). The full assessment is presented in Appendix D, with a summary provided in Table 5-7 below. The overall valuation score for each GDE takes the most frequently occurring ranking score from each question through the assessment as per the guideline methodology.

Table 5-7: Ecological valuation of GDEs

Site	Summary of Ecological Valuation	Valuation Score
12*	Likely sourced from the Pilliga sandstone. Generally considered to be of low value, except for likely good water quality and limited contamination. Absence of rare, threatened or endangered species.	Low
65*	Likely sourced from a bore in the Pilliga Sandstone issuing freely at surface. Generally considered to be of low value, except for likely good water quality and limited contamination. Absence of rare, threatened or endangered species.	Low
980	Unclear as to whether source aquifer is alluvial aquifer or Pilliga sandstone. Existing pressures on groundwater unknown. Greater number of unknowns but majority of ecological valuation indicates low value.	Low
Eather Spring	Likely sourced from Pilliga Sandstone at interface with Purlawaugh Formation on eastern flank. Major modifications to GDE have occurred, including excavation, damming and stock access. May be impacts on groundwater quantity from local uses. Groundwater quality generally high. Low ecological value based on species population but reasonable size feature within the landscape. Identified by the NSW Office of Water as having high ecological value but unlikely to support any Matters of National Environmental Significance.	Low
Hardy's Spring	Likely sourced from Pilliga Sandstone at interface with Purlawaugh Formation on eastern flank. Major modifications to GDE have occurred, including excavation, damming and stock access. May be impacts on groundwater quantity from local uses. Groundwater quality generally high. Low ecological value based on species population but reasonable size feature within the landscape. Identified by NSW Office of Water as having high ecological value, but unlikely to support any Matters of National Environmental Significance.	Low
Mayfield Spring*	Likely sourced from Pilliga Sandstone at interface with Purlawaugh Formation on eastern flank. Major modifications to GDE have occurred, including excavation, damming and stock access. May be impacts on groundwater quantity from local uses. Groundwater quality generally high. Low ecological value based on species population but reasonable size feature within the landscape.	Low
Teds Hole*	Likely sourced from Bohena Creek alluvium (Quaternary alluvium) within or immediately adjacent to Bohena Creek. Minor modifications to GDE have occurred. May be impacts	Low

Site	Summary of Ecological Valuation	Valuation Score
	on groundwater quantity from local uses. Groundwater quality generally high. Low ecological value based on species population	
Well Ford	Likely sourced form Pilliga Sandstone. Generally low ecological value with small number of unknowns. Water quality considered to be high value.	Low
Drysdale	Bore fed wetland sourcing water from Pilliga Sandstone under artesian conditions. Generally considered to be of low ecological value with few unknowns. Water quality considered to be high value however dependent species have low value.	Low
*Visited during field reconnaissance.		

5.8 Summary of Phase 2

Figure 5-2 presents a flow diagram representing the outcome of Phase 1 and Phase 2 of this assessment. It displays how the initial high number of potential GDEs have been reduced down to a shortened list of sites that have a high likelihood of groundwater dependence.

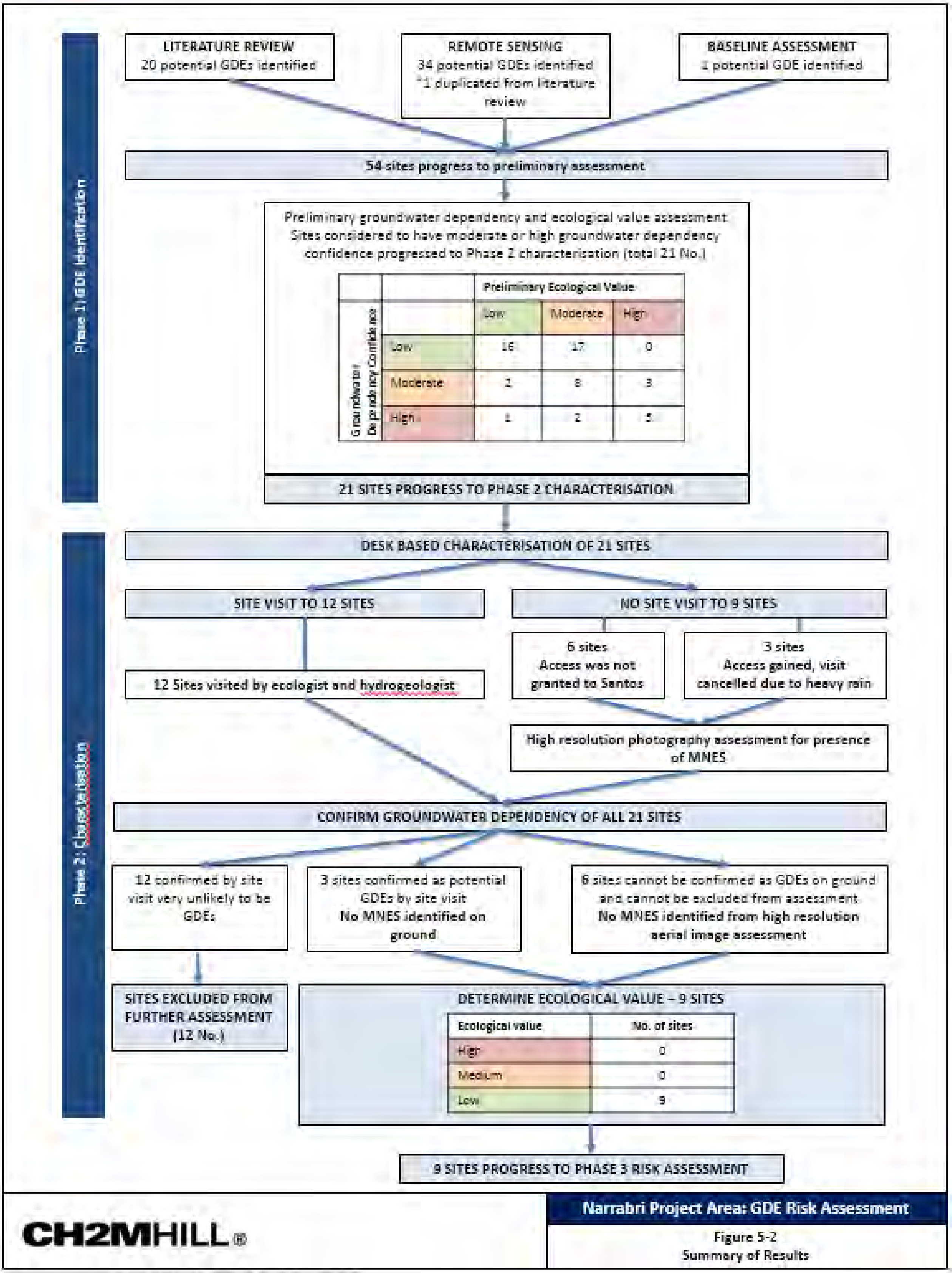

Figure 5-2: Summary of Phase 2 assessment

6 Phase 3: Risk assessment

A risk assessment has been undertaken based on the methodology suggested in the guidelines (NOW, 2012). A summary of this methodology is presented in Section 3, with the detailed risk assessment tables in Appendix E. A summary of the risk assessment is presented in this section.

6.1 Likelihood of impact of activity

Section 5 presents the results of GDE characterisation including both a description of the hydrogeological conceptual model on site, and an assessment of the ecological value. The second component to the risk assessment is to assess the nature of the impact of the project on groundwater, in particular the source aquifer. The description of risk factors for each type of asset are presented in Appendix E alongside the risk assessment.

6.1.1 Predicted impact of activity to potential GDEs

The Proponent has developed a regional groundwater flow model to assess the potential impact of gas development on the groundwater and surface water resources of the region. The model was developed utilising data collected by the Proponent (and other parties) within the region and is based on detailed conceptualisation of the regional hydrostratigraphy. Detail on the conceptualisation and construction of the model is presented in the Groundwater Impact Assessment (CDM Smith, 2016a).

Potential impacts that may affect GDEs include:

- change in the availability of groundwater
- change in the quality of groundwater due to induced interaction of groundwater between formations
- changes in water levels in watercourses, (gaining stream to a losing stream);
- concentration of mobilised chemicals in the surface water system through loss of available dilution
- siting of project infrastructure such as pipelines, well pads, access roads, workers camp and water treatment facilities.

The NSW Office of Water guidelines present an assessment matrix that assists with the prediction of the likelihood of impact to the aquifer asset for each identified potential GDE. This is important step in understanding the impact of existing disturbances, as well as predicting the changes likely through a series of questions which are asked with a choice of likely, unlikely or insufficient data.

The full breakdown of assessment is presented in Appendix E. The results are summarised in Table 6-1 below for each potential GDE.

Table 6-1: Summary of likelihood of impact

Site	Summary of predicted likelihood of impact	Valuation score
12	Potential for alteration to water levels in the Pilliga Sandstone, although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely
65	Potentially for some reduction in artesian pressure within the Pilliga Sandstone although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other impacts are considered unlikely.	Unlikely
980	Predicted impacts to the Quaternary alluvial source are considered to be negligible.	Unlikely
Eather Spring	Potential for alteration to water levels in the Pilliga Sandstone, although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely
Hardy's Spring	Potential for alteration to water levels in the Pilliga Sandstone, although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely
Mayfield Spring	Potential for alteration to water levels in the Pilliga Sandstone, although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely
Teds Hole	GDE may be impacted upon by changes to natural groundwater chemistry and/or chemical gradients due to proximity to the proposed Bohena Creek managed release scheme, although discharges are limited to minimise impact through releasing to a creek flowing at > 100 ML/day (Eco Logical Australia, 2016a). This may affect groundwater salinity levels in the Bohena Creek alluvium. All other risks are considered unlikely.	Unlikely
Well Ford	Potentially for some reduction in artesian pressure, or alterations to water levels within the Pilliga Sandstone although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely
Drysdale	Potential for alteration to water levels in the Pilliga Sandstone, although this is predicted to be less than 0.5m of drawdown over the life of the project which corresponds to the probable minimum threshold for model prediction. All other risks are considered unlikely.	Unlikely

Based on the evidence collated for this study, and conclusions drawn, impacts of the project on potential GDEs associated with the Pilliga Sandstone or Quaternary alluvium are considered to be unlikely. This consideration of likelihood of impact has been taken forward into the risk assessment.

6.1.2 Assessment against requirements of the Aquifer Interference Policy

The NSW Aquifer Interference Policy sets out the water licensing and approval processes and requirements for aquifer interference activities under the *Water Management Act 2000* (Act). Water Sharing Plans are statutory documents currently used to manage water resources under the Act. The framework for making an assessment of potential aquifer interference is prescribed by NOW (2012). For GDEs, the minimal impact considerations are related to impacts from changes in water pressure or level within 40 m from high priority GDEs. A high priority groundwater dependent ecosystem is defined as having high ecological value and being considered a priority for management action.

Eather and Hardy’s springs have been identified as High Priority GDEs by the State of the Catchment Report (DECCW, 2010b). This is understood to be on the basis of a Stage 1 – General aquifer ecological valuation and identification of high ecological value assets, an initial desktop approach based on aquifer qualities (DWE, 2008) and is understood not to have included field based assessments.

This study has assessed in detail the ecological value (Section 5.7.2) of all nine potential GDEs in the study area following the valuation method presented in the guidelines. The findings indicate that all nine potential GDEs are considered to have low ecological value, including Eather and Hardy’s springs (note: as Eather, Hardy’s springs have not been visited during this study they are still regarded as being ‘potential’ GDEs but for the purpose of this discussion are grouped within the nine potential GDEs despite a high chance that they are now more dependent on channelled overland flow rather than groundwater).

The nine potential GDEs do not meet the definition of a high priority GDE due to their low ecological value. Therefore the Proponent is not required to assess these features under the Minimal Impact Consideration criteria of the Aquifer Interference Policy.

Eather and Hardy’s springs are also not considered to be high priority GDEs based on their current ecological status following the procedures and assessments outlined in the risk assessment guidelines (NOW, 2012). It is feasible that the species assemblage and abundance could have changed since 2008, and that these changes are likely to be due to the modified nature of the water features noted during the review of high definition aerial photography. However, the springs are in a highly modified state and are likely to have been in poor ecological condition for many years.

6.2 Outcome of risk assessment

6.2.1 Overall risk score

The GDE risk assessment has been undertaken for sites confirmed as being groundwater dependent. As with previous assessments, a series of questions are asked relating to the level of impact to the following GDE attribute:

- water quantity
- water quality
- aquifer integrity
- biological Integrity.

A score of high, moderate, low or insufficient data/unknown is assigned, with the highest risk score taken as the overall risk to the individual GDE. The outcome of the assessment is presented in Table 6-2.

Table 6-2: Results of risk assessment

Site	Risk Assessment Comments	Overall Risk Score
12	Predicted impacts to the Pilliga Sandstone aquifer are demonstrated in the Groundwater Impact Assessment to be less than seasonal variations. All criteria are scored as low risk.	Low
65	Predicted impacts to groundwater pressure in Pilliga Sandstone aquifer are considered to be less than seasonal variations. All criteria are scored as low risk.	Low
980	Predicted impacts to the Quaternary alluvium are considered to be significantly less than seasonal variation.	Low
Eather Spring	Predicted impacts to the Pilliga Sandstone aquifer are demonstrated in the Groundwater Impact Assessment to be less than seasonal variations. All criteria are scored as low risk.	Low
Hardy’s Spring	Predicted impacts to the Pilliga Sandstone aquifer are demonstrated in the Groundwater Impact Assessment to be less than seasonal variations. All criteria are scored as low risk.	Low
Mayfield Spring	Predicted impacts to the Pilliga Sandstone aquifer are demonstrated in the Groundwater Impact Assessment to be less than seasonal variations. All criteria are scored as low risk.	Low
Teds Hole	There may be negligible changes to the groundwater quality at Teds Hole downstream of the proposed Bohena Creek managed release site. The Managed Release Study - Bohena Creek (Eco Logical Australia, 2016a) provides a detailed assessment of risk associated with the managed release scheme indicating impacts are considered to be negligible.	Low
Well Ford	Predicted impacts to the Pilliga Sandstone aquifer are considered to be less than seasonal variations in the Groundwater Impact Assessment. All criteria are scored as low risk.	Low
Drysdale	Predicted impacts to groundwater pressure in Pilliga Sandstone aquifer are considered to be less than seasonal variations in the Groundwater Impact Assessment. All criteria are scored as low risk.	Low

The results of the risk assessment indicate that there is a low risk to each of the nine identified potential GDEs within the study area.

7 Phase 4: Identification of management and mitigation measures

The *NSW Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (NOW, 2012) specifies that management strategies are required to maintain and/or improve the ecological value of a GDE and reduce the level of risk to the aquifer and associated GDE.

The management measures recommended for each potential GDE were identified through comparison of the ecological value of the aquifer and associated potential GDE and the potential risk to the aquifer and potential GDE as a result of the project.

Mitigation measures are additional measures for management of short term or localised impacts (NOW, 2012). Mitigation measures may be required dependent on the risk category of a GDE or when an activity has had a notable impact and requires immediate action.

Adaptive management needs to be implemented for all GDEs regardless of their ecological value or risk rating. Changes to the monitoring actions and management and mitigation measures for each GDE may be required as a result of observed GDE responses to development activities once implemented.

Where a GDE is defined as a High Priority GDE within a Water Sharing Plan, the Water Sharing Plan rules for protecting the High Priority GDE must be adhered to.

7.1 Risk categorisation

A risk matrix is presented in Figure 3-2 to outline the most appropriate management response for a given environmental value under a particular activity. The management strategies are based on comparison of the ecological value of the potential GDE to the risk proposed by the project, based on the impacts predicted in the Groundwater Impact Assessment (CDM Smith, 2016a). The outcome of the risk categorisation therefore defines an appropriate management action required.

Each of the nine potential GDEs was assessed as Category 3 – Low Ecological Value, and as Category 1 – Low Risk. The assigned risk category is therefore “G” which is classed as low value/low risk. Low risk indicates that there is minor to no discernible predicted impact resulting in no change or minor change to the aquifer and/or associated potential GDEs.

7.2 Recommended management strategy

Under the risk category G (Table 3-2) the short term management action recommended by NOW (2012) is to protect hotspots (if any) and undertake baseline risk monitoring. Long term management is recommended to include adaptive management and continued monitoring; however, no mitigation is required at this stage.

7.3 GDE monitoring network

7.3.1 Integrated groundwater monitoring system

The Proponent has designed an integrated groundwater monitoring network that includes monitoring of the GDE source aquifers as a key feature. Given the low risk identified in this study monitoring at any specific GDE is not required.

Monitoring of groundwater level will be undertaken at a number of locations targeting the Quaternary alluvium and Pilliga Sandstone aquifers, identified as the sources of the water table springs and artesian discharge springs in this study.

The project operational monitoring plan is presented in the Water Monitoring Plan (CDM Smith, 2016b).

7.3.2 Early detection system & threshold criteria

The proposed groundwater monitoring network is designed to provide an early detection system to identify whether there is unforeseen manifestation of depressurisation from coal seam gas activities within the Pilliga Sandstone, before impacts are evident at specific environmental values including potenital GDEs.

Such effects could potentially be manifested in the Pilliga Sandstone as a diminishing volume of water within the recharge spring, or reduced artesian pressure driving lessor volume discharges at a discharge spring. However, for the effects of depressurisation to be expressed in the Pilliga Sandstone, the Purlawaugh Formation would have to exhibit significant transmissivity, but it is due to low transmissivity that the Purlawaugh acts as a perching layer, giving rise to the three recharge rejection springs.

Targeted monitoring in the Pilliga Sandstone across the study area would be undertaken to validate this inference. If proven, appropriate exceedance criteria based on the NSW Aquifer Interference Policy will be applied.

8 Conclusions

An assessment has been made under the framework of the *NSW Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (NOW, 2012). The potential for GDEs to be present within the study area has been considered. The study area is defined by the maximum extent of potential depressurisation of groundwater head caused by the operation of the project. Where potential GDEs have been identified, a risk assessment has been undertaken to qualitatively assess the potential impact, with management measures and monitoring based on the outcome of the risk assessment.

The following conclusions are drawn:

- There are no known groundwater dependent protected species or habitats in the study area.
- Nine out the 21 potential GDEs were considered likely to be groundwater dependent – with the conceptual understanding of each site's hydrogeology typically indicating water table springs to be present. At least two potential GDEs source water from pre-existing landholder bores flowing freely under artesian pressure.
- Of the 21 potential GDEs identified, there were no confirmed classifications of GDEs having Matters of National Environmental Significance present.
- Nine of the potential GDEs were confirmed as being potentially groundwater dependent, either defined as water table springs or as artesian discharge springs. The source aquifer for all nine potential GDEs was determined as either the Pilliga Sandstone or the Quaternary alluvium.
- All nine potential GDEs were estimated to have low ecological value, mainly due to the absence of protected or important wetland species, and due to the general heavily or moderately modified nature of the sites. It was concluded that none of the nine potential GDEs meet the definition of a high priority GDE, and therefore fall outside the assessment requirements of the NSW Aquifer Interference Policy Minimal Impact Consideration Criteria.
- An assessment of the likelihood of potential impact as a result of the project was undertaken based on the findings of the Groundwater Impact Assessment (CDM Smith 2016a). Impacts in the identified source aquifers are predicted to be less than 0.5 m which corresponds to the probable minimum threshold for model prediction, and therefore the impact to all nine potential GDEs was confirmed as low.
- The overall risk assessment score for each potential GDE corresponded to low value and low risk features.
- No mitigation or specific management measures are required based on the outcome of the risk assessment. Adopting the principle of adaptive management, the conceptual hydrogeology at each potential GDE would be reviewed should additional relevant data become available through monitoring or drilling, or other non-project related means.
- Given the low risk and low ecological value of the potential GDEs, the guidelines recommend continued long-term monitoring. The Proponent is committed to monitoring groundwater level and pressure within its groundwater monitoring network, as set out in the Water Monitoring Plan (CDM Smith, 2016b).

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Water Resources Authority, Liverpool Plains Land Management Committee, Salt Action, TCM, Land and Water Resources, CSIRO and Murray Darling Basin Commission, 1994. Hydrogeological Map of the Liverpool Plains Catchment 1:250,000 scale

Appendix A – Potential GDE reference tables

Table A1: Potential GDEs identified within the study area (literature and database review)

ELA Reference Number/GDE Name	Latitude	Longitude	Data Source	Description
Reedy Lagoon	-30.24	149.67	State of the Catchment (SoC) Report (DECCW, 2010)	Defined as a wetland through State of the Catchment Report
Round Swamp	-30.26	149.54		Wetland
Yarrie Lake	-30.37	149.51		Wetland
Narrabri Lagoon	-30.32	149.75		Defined as a wetland through State of the Catchment Report
Ten Mile Dam	-30.45	149.72	The Pilliga Forest Map (NSW NPWS, 2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50,000 topographic map (sheet No. 8836N)	Spring
Teds Hole	-30.48	149.65		Spring
Mayfield Spring	-30.57	149.87		Spring
Hardy's Spring	-30.66	149.84		Spring
Eather Spring	-30.67	149.84		Spring
Garlands Dam	-30.70	149.56		Spring
Well Ford	-30.77	149.55		Spring
Lucky Flat Bore	-30.54	149.47		Defined as a spring on Pilliga Forest Map
Top Well	-30.64	149.43		Defined as a spring on Pilliga Forest Map
979	-30.57	149.75	Namoi Wetland Assessment and Prioritisation Project (ELA, 2008)	Wetland
980	-30.58	149.74		Wetland
981	-30.58	149.75		Wetland
982	-30.59	149.76		Wetland
983	-30.65	149.76		Wetland
1200	-30.80	149.55		Artificial with potential ecological significance
1324	-30.86	149.77		Artificial with potential ecological significance
Drysdale	-30.32	149.51	Santos Registered Bore Survey	Identified as a wetland feature during field survey to property

Table A2: Potential GDEs identified through remote sensing

ELA Reference Number	Latitude	Longitude	Wetland Confidence	Spring Confidence	Feature Descriptions	Landscape	Modified Feature?
4	-30.21	149.56	High	Low	Ponded water, marsh	Adjacent to drainage	Yes
5	-30.23	149.62	High	High	Marsh, moist or distinct ground cover	Adjacent to drainage	Yes
6	-30.23	149.62	High	High	Marsh, ponded water	Adjacent to drainage	Yes
8	-30.23	149.70	Moderate	Low	Flow paths, wet soil	Open floodplain	Yes
11	-30.22	149.8	High	Low	Ponded water	Open floodplain	Yes
12	-30.24	149.84	High	Low	Moist or distinct ground cover	Low rises or hills	Yes
13	-30.25	149.85	High	Low	Ponded water, marsh, wet soil	Open floodplain	Yes
15	-30.23	149.64	High	Low	Ponded water, marsh	Adjacent to drainage	Yes
16	-30.26	149.58	High	Moderate	Ponded water, marsh, moist or distinct ground cover	Wooded floodplain	Yes
17	-30.30	149.62	Moderate	Moderate	Wet soil	Open floodplain	Yes
18	-30.30	149.57	High	Low	Ponded water	Open floodplain	Yes
38	-30.80	149.55	Moderate	Moderate	Moist or distinct ground cover	Low rises or hills	No
39	-30.79	149.55	High	Moderate	Ponded water, marsh	Low rises or hills	No

ELA Reference Number	Latitude	Longitude	Wetland Confidence	Spring Confidence	Feature Descriptions	Landscape	Modified Feature?
41	-30.79	149.59	Moderate	Moderate	Marsh, Wet soil	Within drainage	No
48	-30.72	149.56	Moderate	Moderate	Marsh	Low rises or hills	No
49	-30.81	149.91	High	Low	Ponded water	Open floodplain	Yes
51	-30.63	149.37	Moderate	Moderate	Ponded water, wet Soil	Low rises or hills	No
52	-30.67	149.40	Moderate	Moderate	Wet soil, marsh	Adjacent to drainage	No
53	-30.70	149.56	High	Low	Ponded water	Adjacent to drainage	No
54	-30.76	149.88	High	Low	Ponded water	Open floodplain	Yes
56	-30.60	149.58	High	Low	Ponded water, wet Soil	Low rises or hills	Yes
57	-30.61	149.87	High	Low	Ponded water, wet Soil	Low rises or hills	Yes
58	-30.61	149.93	High	Low	Marsh, wet Soil	Within drainage	No
61	-30.52	149.92	High	Low	Ponded water, wet Soil	Open floodplain	Yes
62	-30.48	149.55	High	Moderate	Ponded water	Wooded floodplain	No
63	-30.50	149.54	Moderate	Moderate	Wet Soil	Wooded floodplain	No

ELA Reference Number	Latitude	Longitude	Wetland Confidence	Spring Confidence	Feature Descriptions	Landscape	Modified Feature?
64	-30.50	149.60	High	Moderate	Wet Soil, ponded water	Wooded floodplain	Yes
65	-30.52	149.61	High	Low	Ponded Water, wet Soil	Wooded floodplain	Yes
66	-30.52	149.65	High	Low	Ponded Water, wet Soil	Within drainage	No
67	-30.55	149.55	Moderate	Low	Marsh, wet Soil	Within drainage	No
68	-30.70	149.82	High	Low	Ponded water, wet Soil	Open floodplain	Yes
69	-30.28	149.71	High	Moderate	Marsh, wet soil	Adjacent to drainage	No
72	-30.43	149.29	Moderate	Moderate	Marsh	Open Floodplain	No
73	-30.35	149.31	High	Moderate	Marsh; Wetted soil	Adjacent to drainage	Probable

** Potential GDEs located in the study area identified by remote sensing*

Table A3: Assessment of likelihood of feature being a GDE and decision to proceed to next stage of works

ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
Hardy's Spring	Known spring GDE, and protected, groundwater dependence is thought to be high, but most water is likely from surface runoff.	MODERATE	Farm dam fringed with aquatic vegetation, possibly a dammed spring, cattle access	MODERATE	Y
Eather Spring	Known spring GDE, and protected, groundwater dependence is thought to be high, but most water likely comes from surface runoff.	MODERATE	This is a farm dam that has little significance as an ecological habitat.	MODERATE	Y
Mayfield Spring	Known spring GDE, and protected, groundwater dependence is thought to be high, but most water is likely from surface runoff.	MODERATE	This is a farm dam that has little significance as an ecological habitat	MODERATE	Y
Round Swamp	Isolated from drainage, heavily vegetated, potential overflow from pool suggests source rather than sink - needs to be confirmed on site through topography	MODERATE	Large body of water surrounded by vegetation	HIGH	Y
Reedy Lagoon	Pools within low lying areas adjacent to creeks that are evident to be inundated by creek overflow, murky water	LOW	Lagoon in field on floodplain of Namoi, lots of other small lagoons nearby, possibly riverine, but also potentially fed by alluvial groundwater	MODERATE	N
Yarrie Lake	GDE atlas suggests some groundwater dependency, potential overflow to south	MODERATE	Large, shallow circular lake surrounded by trees	MODERATE	Y

ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
Narrabri Lagoon	Linked to drainage ditch, therefore unlikely to have groundwater dependency	LOW	Floodplain lagoon, no marginal vegetation	MODERATE	N
Ten Mile Dam	Isolated from drainage, heavily vegetated, water is not murky or brown, potential for some groundwater dependency	MODERATE	Dam with dark water, access by roads, surrounded by wooded vegetation	MODERATE	Y
Teds Hole	Discharging Bohena Creek, potential for spring	MODERATE	Waterhole on Bohena Creek, riparian vegetation, sand bed	MODERATE	Y
Garlands Dam	Discharging Bohena Creek, potential for spring	MODERATE	Waterhole on Bohena Creek, riparian vegetation, sand bed, near road crossing	MODERATE	Y
Well Ford	Discharging into Borah Creek, distinct vegetation	MODERATE	Discrete area of low vegetation next to Borah Creek	MODERATE	Y
Top Well	Within 10 m of a registered bore	LOW	Turbid dam, fed by bore	LOW	N
Lucky Flat Bore	Within 10 m of a registered bore	LOW	No wetland visible in satellite image, site is within 10 m of registered bore	LOW	N
Drysdale	Isolated from drainage. Water is not murky or brown. Within 10 m of a registered bore – under artesian conditions. Potential habitat for potentially threatened ecological species	HIGH	To be confirmed	TBC	Y
4	Floodplain ponding area	LOW	Ponding on floodplain	MODERATE	N

ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
5	Floodplain ponding area	LOW	Large wetland near Namoi, aquatic and fringing vegetation.	MODERATE TO HIGH	N
6	Floodplain ponding area	LOW	Smaller water body near 6	MODERATE	N
8	Surface water collated in depression, no evidence of permanent water feature	LOW	Marsh field	MODERATE	N
11	Isolated from drainage, water looks turbid	LOW	Turbid dam	LOW	N
12	Distinct from surface water, looks natural	MODERATE	Long dam	LOW	N
13	Man-made, very turbid water, flooded low ground	LOW	Flooded low ground	LOW	N
15	Floodplain ponding area	LOW	Floodplain wetland	MODERATE	N
16	Water is green and murky most likely flooded low	LOW	Dry marsh nr drainage line	MODERATE	N
17	Isolated feature, dry - not permanent	LOW	Dry marsh in field of crops	LOW	N
18	Potential gilgai, water is green and murky	LOW	Possibly a temporary gilgai wetland	LOW	N
38	Feature likely associated with ephemeral creek	LOW	Ephemeral wetland in forest	LOW	N
39	Next to Borah Creek (dry in the aerial), water looks fresh with groundwater inputs	HIGH	Appears as ephemeral wetland near Borah Creek, tree vegetation on east and west banks, north and south may be extended wetland	MODERATE	Y

ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
			vegetation, same as GIS wetland 1200		
41	Pool is located in watercourse, water is very murky which suggests it is surface water	LOW	Along drainage in forest with good riparian vegetation	MODERATE	N
48	Little visible in aerial photos, likely roadside drainage	LOW	Small roadside wetland	LOW	N
49	Man-made dam, water is very murky	LOW	Farm dam	LOW	N
51	Located between two creeks, likely surface water feature	LOW	Bare ground beside waterway, surrounded by trees	MODERATE	N
52	Located on a creek line, likely to be surface water fed, no feature visible in aerial	LOW	Bare ground beside waterway, surrounded by trees	MODERATE	N
53	Dammed water, possibly sourced from Bohena Creek	LOW	Circular dam	LOW	N
54	Man-made circular dam, very close to creek line, water is murky and dam is partially dry	LOW	Farm dam in field	LOW	N
56	Dark murky water suggests no groundwater influence	LOW	pale grey water surrounded by bare earth	MODERATE	N
57	Small man-made dam in woodland, most likely associated with the surface water drainage	LOW	Dam	LOW	N
58	Wetland vegetation but most likely pooled surface water	LOW	Small area of wetland vegetation in forest near river	LOW	N

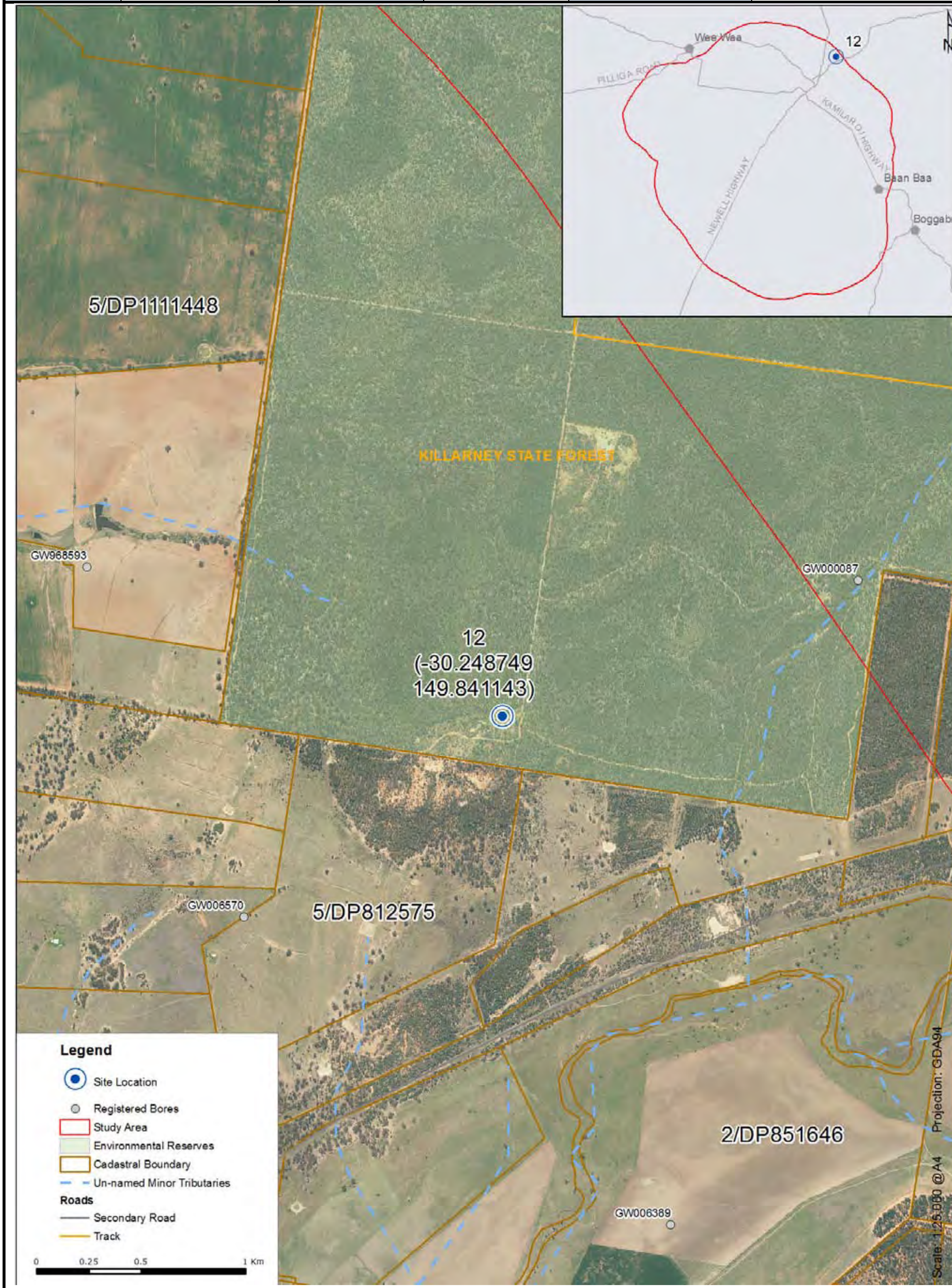
ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
61	Dam located next to ephemeral creek, most likely surface water	LOW	Dam in agricultural land, lots of bare ground	LOW	N
62	Man-made but isolated from surface drainage Water looks turbid, likely surface water	LOW	Square turbid dam in forest	LOW	N
63	No water evident, clearing	LOW	Low vegetation in forest	MODERATE	N
64	Interesting green feature, water looks fresh	MODERATE	Circular dam on Leewood, probably surface-fed but may be fed by groundwater from bore, aquatic vegetation	MODERATE	Y
65	Small pool with very dark water suggests groundwater influence	MODERATE	Turbid dam in forest surrounded by bare ground	LOW	N
66	Isolated pool of water in Bohena Creek, water is murky suggesting remnant surface water	LOW	Waterhole on Bohena Creek with riparian vegetation on one side, wetland now possibly covered by sand	MODERATE	N
67	Dark water suggests possible groundwater influence, on a drainage line	HIGH	Drainage line	LOW	Y
68	Man-made dam, very close to creek line, surface water drainage	LOW	Square dam in drainage line, beside agricultural land	LOW	N
69	Marshy ground Most likely associated with surrounding surface water system (Namoi River)	LOW	Marshy area near Namoi River east of Bohena Creek	MODERATE	N

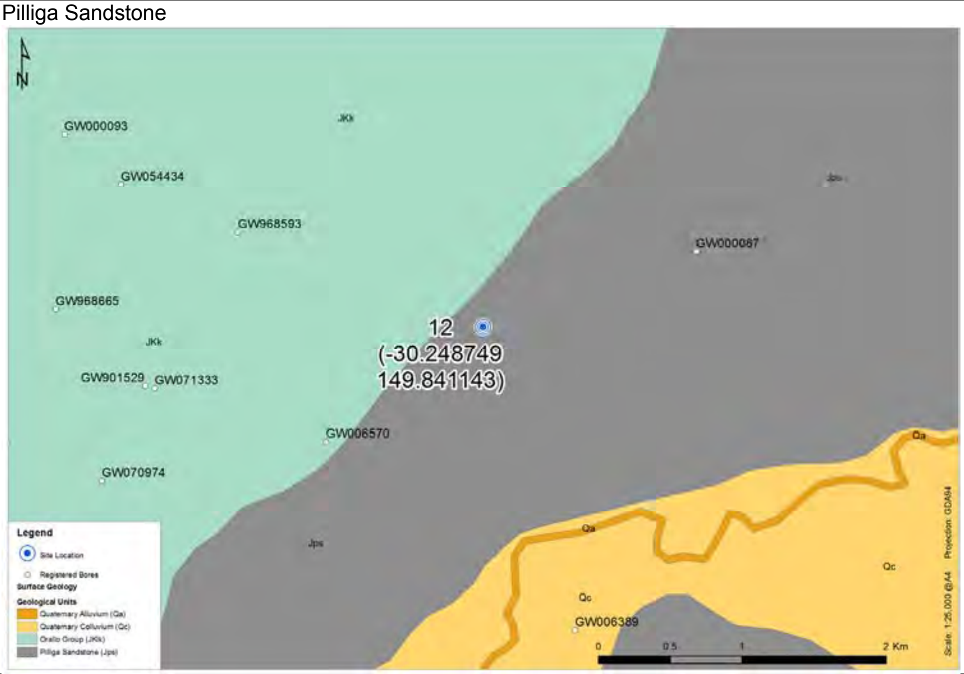
ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
72	Isolated vegetation, noticeable drainage line indicates extension of surface water drainage. Cluster of such features in the area	LOW	Dam in mid-field island of vegetation, fed by contours	MODERATE	N
73	Surface water collated in depression, 50m east of Brigalow Creek	LOW	Along drainage in forest with good riparian vegetation	MODERATE	N
979	Dammed water source, but could be potential groundwater source to the north east	MODERATE	Large dark water body, surrounded by cleared land	MODERATE	Y
980	Dark isolated pool of water surrounded by woodland	HIGH	Long wetland, good riparian and aquatic vegetation, south of buildings	HIGH	Y
981	Dark isolated pool of water surrounded by woodland	HIGH	Wetland, good riparian and aquatic vegetation, near road	HIGH	Y
982	Potential for some groundwater inputs, isolated from drainage, although slightly murky looking	MODERATE	Circular wetland surrounded by good forest vegetation	HIGH	Y
983	Potential for groundwater connection	MODERATE	Shown on map as Yellow Spring Creek Dam, good forested vegetation, aquatic vegetation present, probably artificial	HIGH	Y
1200	Next to Borah Creek (dry in the aerial), water looks fresh with groundwater inputs	HIGH	Appears as ephemeral wetland near Borah Creek, tree	MODERATE	Y

ELA Reference Number/GDE Name	Hydrogeological Comment	Groundwater Dependency Confidence	Ecological Comment	Ecological Value	Proceed to Next Stage (Y/N)
			vegetation on east and west banks, north and south may be extended wetland vegetation, same as GIS wetland 39		
1324	Wetland on Bara Creek. Water looks fresh and potentially groundwater fed, however could be drainage from the surrounding land	MODERATE	Looks like a dammed drainage line, which could be spring-fed because it drains eastward from the outcropping Pilliga Sandstone, surrounded by forest	MODERATE	Y

Appendix B – GDE characterisation sheets

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		12		DATE OF SITE VISIT:	22/10/13
LATITUDE:	-30.248749	LONGITUDE:	149.841143	ELEVATION:	276 mAHD



CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Ecological Australia Remote Sensing; SKM Report – Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Long water body disconnected from drainage system, apparently low turbidity in satellite image.
GENERAL SITE CHARACTERISATION	
Site description:	The site comprises a dammed area of approximately 90 m (east-west) by 30 m (north-south), surrounded by native forest. There are vehicle tracks adjacent to the site. The dam appears to have been excavated along a natural drainage line with at least partially constructed embankments to increase the water holding capacity. The dam was dry at the time of site visit (22/10/13). At the time of visit, the western bank of the dam was approximately 2.5 m height and extended southwards to a shallow gully of exposed sandstone bedrock beyond the site. The sandstone offsite was covered by approximately 150 mm to 200 mm of sandy soil which may have channeled water into the dam. Sandstone outcrops were present along sections of the southern bank of the dam. Two patches of healthy green vegetation (*Schoenoplectus mucronatus* and *Juncus* sp.) were present at either end of the dam with an area of dried brown grass in the centre. The soil was moist approximately 20 mm below surface in the location of the fresh grasses.
Surrounding land use:	The site is located in Killarney State Forest. Ironbark and native Pine surround the site. Aerial imagery shows soil terraces and a dam to the west of the site.
Hydrology:	There are no major watercourses proximal to the site. Two ephemeral creeks were identified on aerial imagery, located 0.8 km west and 1.0 km east of the site.
Catchment area:	0.87 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Pilliga Sandstone 
Solid geology from geological mapping:	Pilliga Sandstone (Late Jurassic - Early Cretaceous) – fluvial, medium to very coarse grained, quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone, fine grained sandstone and coal.
Onsite geological observations:	Pilliga Sandstone confirmed at surface. Sandstone observed outcropping around the edge of site (on the dam banks) and beyond the site. Sandstone observed was orange/reddish brown medium to coarse grained with some rounded gravel and pebbles (Photograph 4). Sandy soil.
Initial hydrogeological assessment:	The site is located on an outcrop of Pilliga Sandstone which is considered a significant transmissive unit within the region. There are five registered bores within a 3 km radius of the site. The source of the bores is not confirmed from available bore logs but it is considered likely they target the Pilliga Sandstone. Reported groundwater levels of the identified bores range between 261 and 243 mAHD. Ground surface at the site is 276 mAHD which suggests there is no hydraulic connection between the bores and the site. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced from the Pilliga Sandstone.
Existing features with potential to impact the site:	There are two bores reported used for stock and domestic purposes, located within 3 km of the site. The source or abstraction rate of the bores are not known. Abstraction from these bores is assumed to have negligible effect on a potential GDE at this location.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eleocaris blakeana.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	Vegetation around the site was dominated by *Eucalyptus creba*, *Angophora leiocarpa* and *Acacia cheelii*.
Observed plant species:	Three aquatic plant species were present at the site: *Eleocaris plana*, *Juncus* sp., *Schoenoplectus mucronatus*. Dead algae formed a crust on the soil surface at the lower sections of the dam where the last of the surface water had pooled. The wetland was surrounded by bare ground, beyond which grew *Eucalyptus creba*, *Angophora leiocarpa* and *Acacia cheelii*.
EPBC Species or community observed?	None observed.
Observed site condition:	Evidence of pig rooting at the western edge of the wetland where the last of the receding water would have lain. There was also evidence of stock access, and beer bottles indicated that the site is used by humans.
Significance of the flora and fauna present:	None of the plant or animal species seen at this site were of conservation significance. When water is present, the site is potentially an important source of drinking water for the vertebrate animals present.
Predicted ecological value of the aquifer and site:	While this wetland occurs on a natural drainage line and may have a prolonged hydroperiod that is due to the subsurface channeling of water, it appears to be largely constructed and is of very little ecological value apart from its role as a water source when saturated.
Predicted sensitivity of the ecosystem:	This wetland is likely to be very tolerant to wetting and drying regimes.

HYDROCHEMISTRY					
Water quality sample taken?	No		**Santos sample reference:**	-	
Sample location and description:	Site dry at time of visit (22/10/13). No sample possible.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	-	-	-	-	-

FINAL CONCLUSIONS

- This site is **considered to be partially supported by groundwater** because:
  - The site was observed to be dry at the time of visit but supports a healthy growth of *Schoenoplectus mucronatus* and *Juncus* sp. in discrete areas;
  - No evidence of surface water input observed during the site visit (22/10/13);
  - The site is likely sourced from the Pilliga Sandstone which was confirmed to outcrop at the surface.
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

Photograph 1: Site 12 facing west. Patch of *Eleocaris plana* in the foreground approximately 6 m by 2 m. The green patch in the background is a crescent-shaped sward of *Schoenoplectus mucronatus* in the western end of the site.

Photograph 2: Western half of site 12 facing north towards crescent-shaped patch of *Schoenoplectus mucronatus*.

Photograph 3: Close up of *Schoenoplectus mucronatus* in western half of site. The brown area in front of sedges is a crust formed by the remnants of Characeae algae. Beneath the algal crust, the ground was moist though not saturated. Pig rooting is evident as the pale patch in the centre right of the photo.

Photograph 4: Pilliga sandstone outcropping at the perimeter of the site.

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		65		DATE OF SITE VISIT:	24/10/15
LATITUDE:	-30.527675	LONGITUDE:	149.611707	ELEVATION:	254 mAHD

<table>
<tr><th colspan="2">CHARACTERISATION SUMMARY</th></tr>
<tr><th colspan="2">INITIAL IDENTIFICATION OF SITE</th></tr>
<tr><td>Data source(s):</td><td>Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment</td></tr>
<tr><td>Feature identifiers:</td><td>Small pool of water, water appears dark in satellite imagery, suggesting low turbidity and potential groundwater influence. Disconnected from drainage system.</td></tr>
<tr><th colspan="2">GENERAL SITE CHARACTERISATION</th></tr>
<tr><td>Site description:</td><td>Excavated dam, approximately 12 m by 22 m, oval in shape with low mounded banks. Water is turbid. Surrounding topography is flat. The site is located adjacent to Pilliga Forest Way. A sign identifies the location as ‘Bohena Bore’ and cautions of deep water (Photograph 3). No evidence of a bore in the area surrounding the pool was observed during the site visit (bore could potentially be within the dam). Total water depth of the dam is unconfirmed. The majority of the dam banks and surrounding area was sparsely vegetated at time of visit (24/10/13). Three areas of grasses/reeds (Typha orientalis and Juncus sp.) were present around the perimeter of the dam.</td></tr>
<tr><td>Surrounding land use:</td><td>The site is located within Pilliga East State Forest. Relatively flat topography with dense forest surround. The main track (Pilliga Forest Way) is approximately 160 m to the west of dam, the road is well used. Tanks and cleared forest area approximately 160 m east from the dam.</td></tr>
<tr><td>Hydrology:</td><td>Bundock Creek (likely intermittent) 1.71 km to the west and Bohena Creek (ephemeral) 4.0 km to the east.</td></tr>
<tr><td>Catchment area:</td><td>0.11 ha</td></tr>
<tr><th colspan="2">GEOLOGY AND HYDROGEOLOGY</th></tr>
<tr><td>Surface geology from geological mapping:</td><td>Cainozoic Sand Plain

</td></tr>
<tr><td>Solid geology from geological mapping:</td><td>Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate</td></tr>
<tr><td>Onsite geological observations:</td><td>No surface outcrops. Sandy soil.</td></tr>
<tr><td>Initial hydrogeological assessment:</td><td>The site is located on a Cainozoic sand plain which is considered a significant transmissive unit within the region. No registered bores are located within a 3 km radius of the site. A historic exploration bore, Bohena-1, is located at the site and could be a potential source of groundwater. The Bohena-1 bore was drilled in 1963 to a total depth of 1646 m then plugged to 165 m and screened within the Pilliga Sandstone.

From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced from the Cainozoic Sand or an artificial GDE sourced from the Bohena-1 bore.</td></tr>
<tr><td>Existing features with potential to impact the site:</td><td>Three registered bores are located between 3 and 5 km of the site, all are used for stock and domestic purposes (abstraction rates unknown). Given the distance from the iste and the highly transmissive nature of the Cainozoic Sand It is unlikely that these bores will have any impact on a potential GDE at this location.</td></tr>
</table>

ECOLOGY			
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eleocaris blakeana.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.		
Ecological environment observations:	This wetland is a small artificial dam beside Pilliga Forest Way. The dam is surrounded by bare ground with sparse *Eucalyptus creba.* Three clumps of vegetation dominated by *Typha orientalis* and *Juncus sp.* grow around the water margin. Water was turbid and only had a small surface area.		
Observed plant species:	*Cyperus betchei*, *Typha orientalis*, *Juncus sp.*		
EPBC Species or community observed?	None observed		
Observed site condition:	Excavation damage adjacent (dammed). Area around dam is cleared.		
Significance of the flora and fauna present:	No species of conservation significance were present at the site.		
Predicted ecological value of the aquifer and site:	This wetland has a low ecological value as an aquatic ecosystem, but is potentially important as a watering source for terrestrial fauna. There were 13 aquatic invertebrate taxa present in the dam. The only fish present were the pest species *Gambusia hollbrookii* and native carp gudgeon (*Hypseleotris* sp.)		
Predicted sensitivity of the ecosystem:	Low		

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7555_WSURF_201310240840	
Sample location and description:	Latitude: -30.5192, Longitude: 149.6007 Sample taken on the eastern edge of the pool. Water turbid with brown colour. Water depth less than 100 mm at sample point.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	8.53	151.0	4.01	69.3	21.0

FINAL CONCLUSIONS

- This site is **considered to be an artificial groundwater dependent ecosystem** potentially sourced from historic exploration bore, Bohena-1 with an excavated dam surrounding;
- Exploration bore Bohena-1 is sourced from the Pilliga Sandstone;
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

Photograph 1: Site 65 facing east. Regular shape of pool suggests it was excavated. Water turbid.

Photograph 2: Site 65 facing south from sample point.

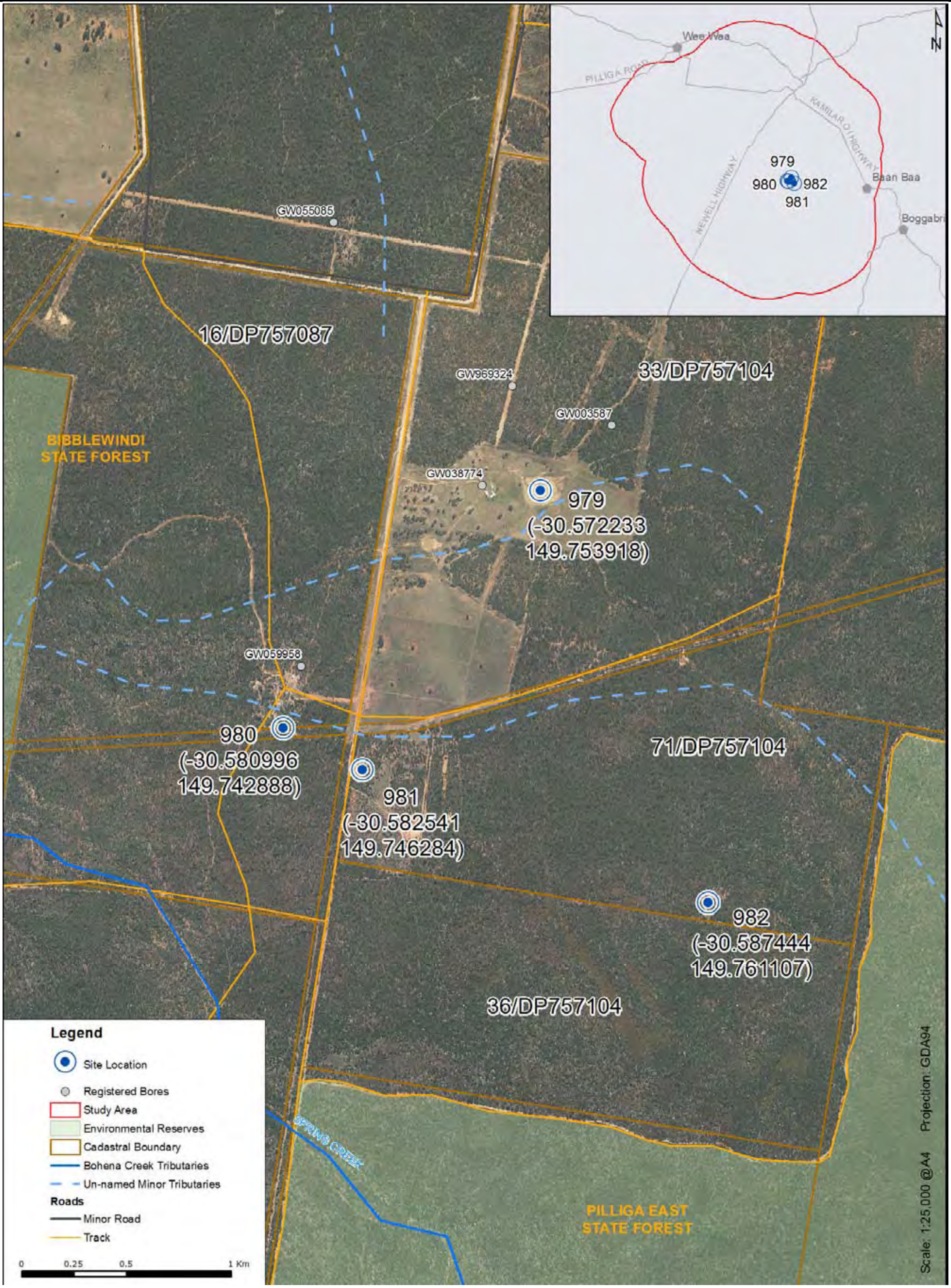
Photograph 3: Sign indicating wetland name and warning of deep water.

Photograph 4: Tanks and forest clearing area approximately 160 m east of Site 65.

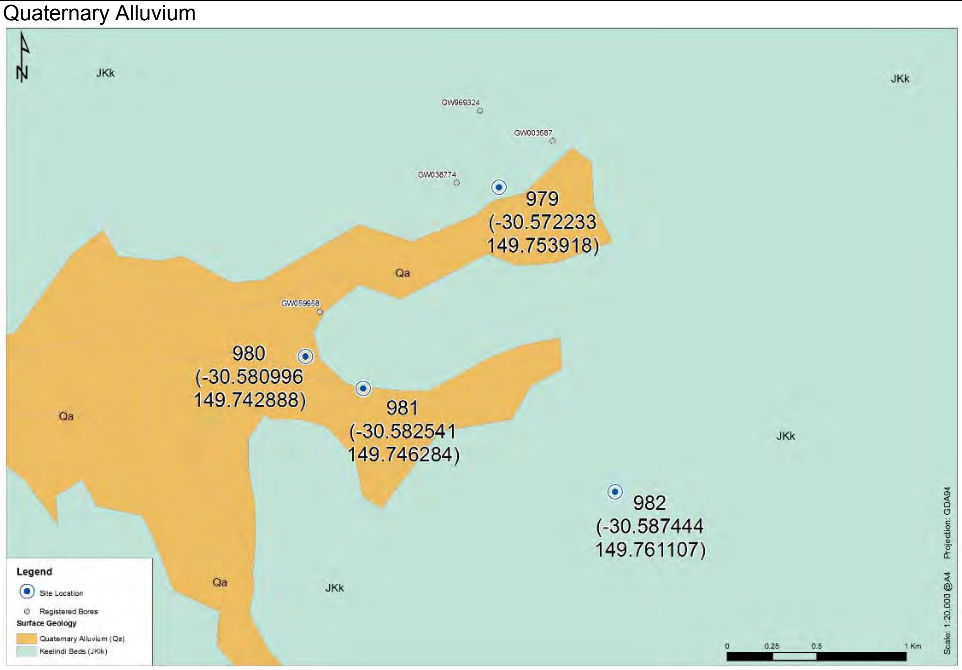
PRELIMINARY CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:	980	DATE OF SITE VISIT:	NOT VISITED

LATITUDE:	-30.580996	LONGITUDE:	149.742888	ELEVATION:	285 mAHD



PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Long wetland on an unnamed tributary of Spring Creek (likely ephemeral), low-turbidity appearance and surrounded by woodland.
GENERAL SITE CHARACTERISATION	
Site description from desk study:	High resolution aerial imagery shows the site to comprise a long, thin pool of seemingly fresh water (not turbid) surrounded by relatively dense forest. The pool has receded between 2014 and 2010 and vehicular tracks have become more prominent. Buildings are located north of the pool. The pool appears to have been dammed on the western edge. Aerial suggests the site is located in an area of remnant vegetation, good riparian and aquatic vegetation is identified.
Surrounding land use from aerial photography:	The site is located within the Bibblewindi State Forest. Pilliga East State Forest is located south east of the site.
Hydrology from aerial photography:	The site is located on an un-named tributary of Spring Creek. Spring Creek (ephemeral) itself is located 0.85 km south-west of the site.
Catchment Area:	0.17 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Alluvium



Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate
Desk top hydrogeological assessment:	The site is underlain by the Quaternary Alluvium which is considered a significant transmissive unit in the region and the most likely source of groundwater to a potential GDE at this location. There are eight registered bores located within 1.7 km of the site. A hydraulic connection between the site and the bores could not be proven due to a lack of information. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring likely sourced by the Quaternary Alluvium. Further assessment of high resolution aerial photography did not provide enough evidence to rule out groundwater dependence. The aerial photographs show the site to potentially contain fresh (not turbid) water and potentially be sourced by a spring to the south east. Additionally, the site is located proximal to Spring Creek, the name of which suggests groundwater influence.
Existing features with potential to impact the site:	The site is located to the south of buildings (0.11 km). It is unlikely that nearby abstraction bores will be impacting a potential GDE at this location (not confirmed as aquifer source for these bores is unknown).

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	2010 aerial imagery shows the site to comprise a long, thin wetland located south of some buildings and surrounded by forest. The wetland retreated to a small waterhole by the image taken in 2014. The green tinge on the dry bed to east of water in 2014 is likely to be herbaceous vegetation taking advantage of moist soil.
Matters of National Environmental Significance present?	High resolution photography show the site to be surrounded by treed vegetation, however, the presence of wetland Matters of Environmental Significance is considered unlikely. None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.
Site condition:	The site appears to have an impoundment wall to the west, forming an in-channel dam. Numerous vehicle and/or cattle tracks nearby suggests this may be a stock watering point.
Significance of the flora and fauna present:	Species likely to occur would be tolerant of fluctuating water levels and stock disturbance. These hardy species are common in the region and unlikely to be threatened.
Predicted ecological value of the site:	This site is in moderate ecological condition as a wetland.
Predicted sensitivity of the ecosystem:	Probably a dammed and deepened section of a drainage channel and therefore not a highly sensitive ecosystem.

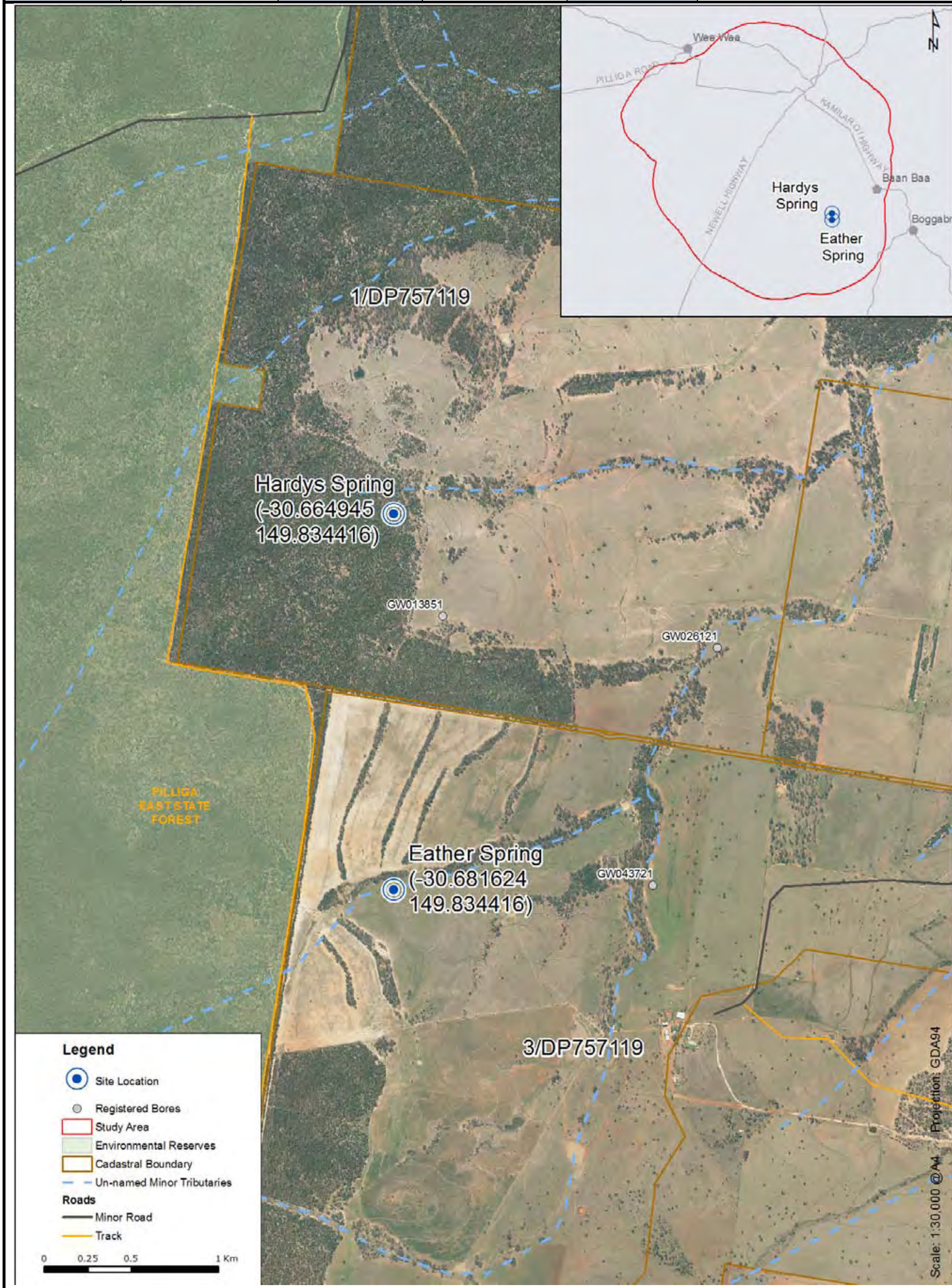
FINAL CONCLUSIONS

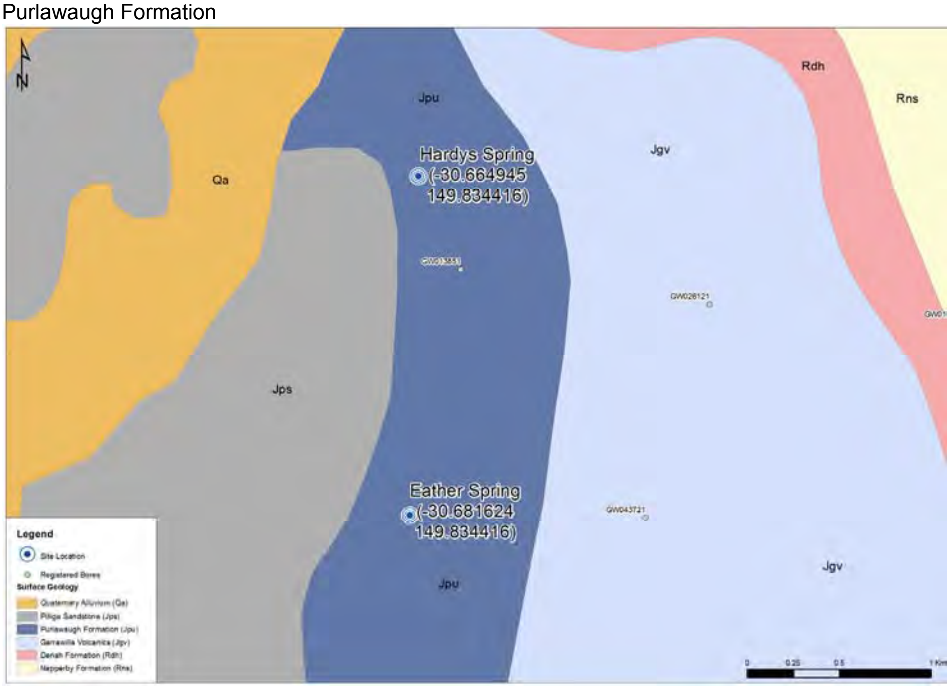
- This site is **considered to be potentially sourced by groundwater** because:
  - Aerial photography suggests the site to contain fresh (not turbid) water;
  - Aerial photography suggests the wetland may potentially be sourced from a spring south-east of the site;
  - Naming of 'Spring Creek' located proximal to the site suggests springs occur in the area; and
  - There is not enough evidence to rule out groundwater input at this stage, a site visit is required.
- The site is considered to have moderate ecological value.
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - The site experiences fluctuating water levels meaning species present are likely to be tolerant of change and not threatened;
  - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

PRELIMINARY CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		Eather Spring		DATE OF SITE VISIT:	NOT VISITED
LATITUDE:	-30.681624	LONGITUDE:	149.834416	ELEVATION:	335 mAHD



PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Namoi State of the Catchment Report - Groundwater; Narrabri Coal Mine Stage 2 Longwall Project - Hydrogeological Assessment; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; Eco Logical Australia Remote Sensing; The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50000 Topographic Map (Sheet Number 8836N).
Feature identifiers:	A known GDE identified in the Namoi State of the catchment report. Located within an un-named ephemeral creek. Actual location of feature will need to be confirmed by landholder.
GENERAL SITE CHARACTERISATION	
Site description from desk study:	The site is identified in the Namoi state of the catchment report as a high priority groundwater dependent ecosystem. Aerial imagery suggests the site to be in low lying topography surrounded by grassland and pastures with some vegetation. The site is located within terraced, agricultural land, cattle access is visible from aerial imagery. Dams are located 0.2 km to the west and 0.7 km to the east and are assumed to form part of the feature. Actual location of the spring site will need to be confirmed by landholder.
Surrounding land use from aerial photography:	Dominant grassland and pastures State Forest - Pilliga Nature Reserve to the west
Hydrology from aerial photography:	Ephemeral drainage line, Sandy Creek (ephemeral) 2.4 km to the west
Catchment area:	0.60 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Purlawaugh Formation 
Solid geology from geological mapping:	Purlawaugh Formation (Jurassic) – fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams
Desk top hydrogeological assessment:	The site is located on the Purlawaugh Formation which is a less transmissive unit within the region. The interface between the Pilliga Sandstone and the Purlawaugh Formation is located to the west of the site. The Pilliga Sandstone is considered a significant transmissive unit within the region and is the most likely source of a potential GDE at this location. Four registered bores are located within a 3.4 km radius of the site, the source of these bores is unknown. A hydraulic connection between the site and the bores could not be proven due to a lack of data. Desktop assessment classified the site as a known high priority GDE, likely to be a groundwater dependent wetland supported water table spring. However, aerial imagery could not confirm exact location of the feature.
Existing features with potential to impact the site:	The four registered bores proximal to the site (within 3.4 km) are reported as used primarily for stock and domestic purposes. Abstraction from these bores is unlikely to have an impact on a potential GDE at this location. The aerial photography suggests some cattle access, damming and large areas of grazing land surrounding the site.

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eriochaulon australasicum.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Phragmites australis, Vallisnaria* sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	From assessment of high resolution photography the circular body of water in a vegetated drainage line is assumed the most likely location of the spring. This body of water is approximately 200 m west of the plotted coordinates. The water body appears to have dammed edges. Trees surround all sides of the waterbody, though only in a thin band to north. Contour banks north and south of the wetland runoff into the drainage line. The feature is surrounded by tilled grazing land with strips of remnant vegetation.
Matters of National Environmental Significance present?	From assessment of high resolution aerial photography it is considered very unlikely the site will support Matters of National Environmental Significance because of high level of disturbance to the surrounding landscape, and because of the potential for stock to access the dam. Genetic isolation is considered unlikely because of potential for semi-regular hydrological connectivity to the Namoi during periods of high rainfall. If the dam has been deepened by excavation, seedbank potentially removed. None of the threatened species listed under the EPBC Act for this area are wetland dependent.
Site condition:	Turbid water and visible cattle tracks along riparian corridor. Likely to capture high nutrient and sediment loads from disturbed catchment via overland flow.
Significance of the flora and fauna present:	No visible macrophytes on aerial images. Cattle trampling would limit plant establishment, and historical excavation to shape the dam would have removed much of the seedbank. Only hardy, common species likely to tolerate disturbed conditions are therefore likely. The site is unlikely to support threatened flora.
Predicted ecological value of the site:	The site has low ecological value. This site was recognised as a high priority GDE in the Namoi State of the Catchment Report. The exact location of the GDE feature has not been confirmed, assessment has focused on the dammed water bodies identified on aerial images. Aerial imagery indicates that this wetland, while potentially fed by groundwater, appears typical of agricultural stock dams in the area and is unlikely to have any significant ecological components that distinguish it from other water sources in the surrounding landscape.
Predicted sensitivity of the ecosystem:	The water bodies visible on aerial imagery appear to be have been excavated and dammed, the environment is therefore already highly disturbed/modified and not sensitive to change.

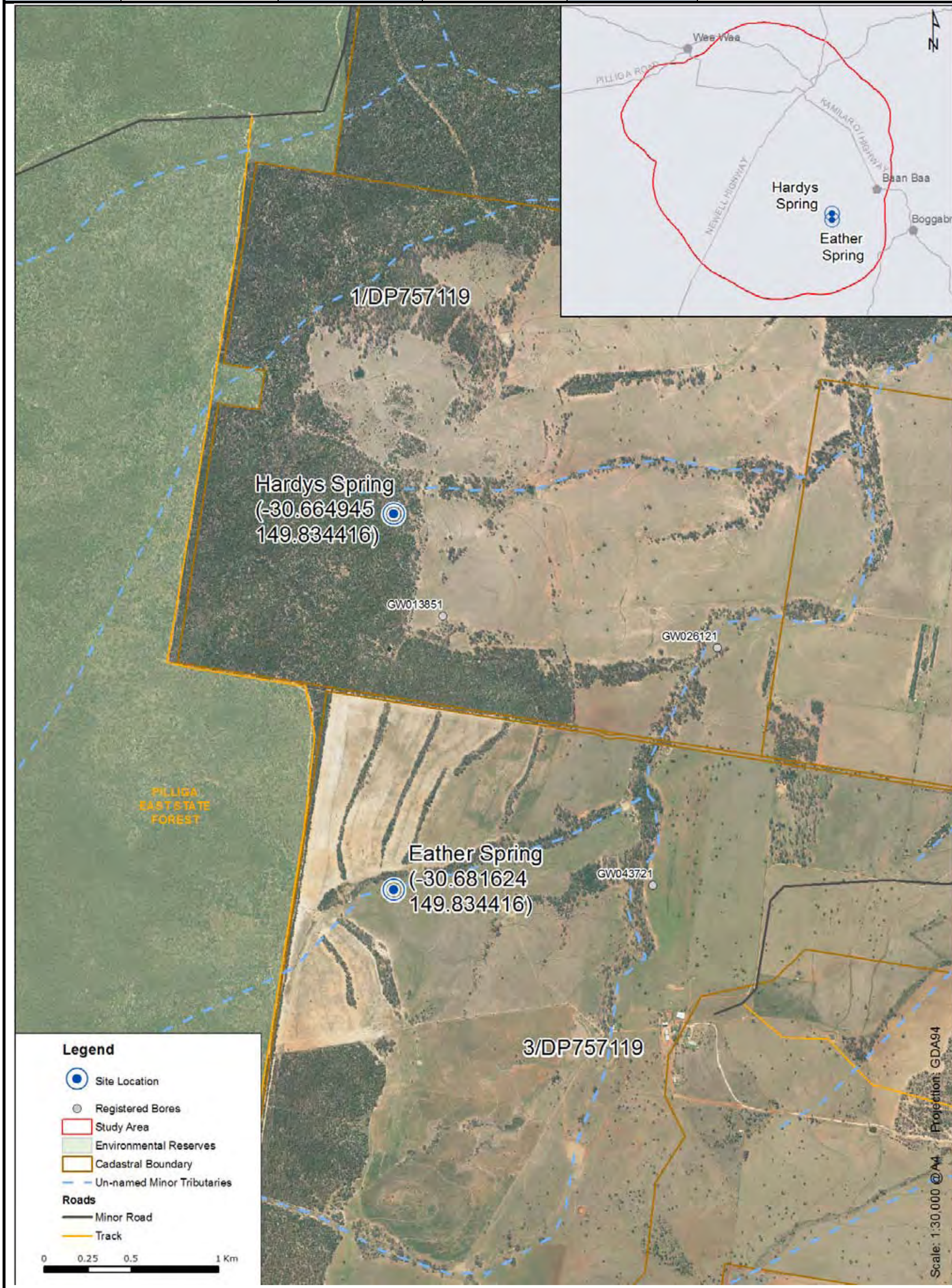
FINAL CONCLUSIONS

- This site is **considered to be a groundwater dependent ecosystem** because:
  - The site was identified as a high priority GDE in the Namoi State of Catchment Report; and
  - The site is located proximal to the interface between the Pilliga Sandstone and the Purlawaugh Formation which is a hydrogeologically likely place for springs to occur.
- This site is considered **very unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography suggest the habitat to be unsuitable for threatened species (disturbed);
  - Aerial photography suggest the site to be in poor ecological condition; and
  - None of the threatened species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

PRELIMINARY CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		Hardys Spring		**DATE OF SITE VISIT:**	**NOT VISITED**
LATITUDE:	-30.664945	**LONGITUDE:**	149.834416	**ELEVATION:**	345 mAHD



PRELIMINARY CHARACTERISATION SUMMARY

INITIAL IDENTIFICATION OF SITE

Data source(s):	Namoi State of the Catchment Report – Groundwater; Narrabri Coal Mine Stage 2 Longwall Project – Hydrogeological Assessment; SKM Report – Mapping Groundwater Dependent Ecosystems in the Namoi Catchment;The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50 000 Topographic Map (Sheet Number 8836N).
Feature identifiers:	A known GDE identified in the Namoi State of the catchment report. Disconnected from existing drainage. Water body recognised 0.8 km northeast of spring location, potentially a dam. Actual location of the feature will need to be confirmed by landholder.

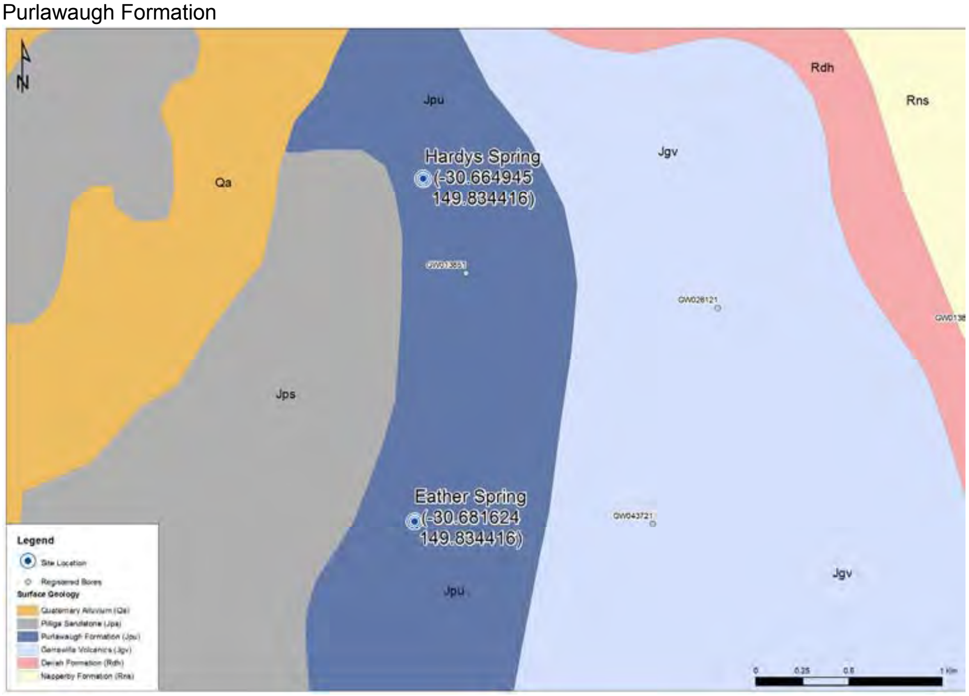
GENERAL SITE CHARACTERISATION

Site description from desk study:	The site is identified in the Namoi state of the catchment report as a high priority groundwater dependent ecosystem. Aerial suggests low lying topography surrounded by grasslands and state forest to the west. Visible cattle access and contoured banks. Prominent vegetation surrounding site. Three water holes that appear to be dammed are present in the location and assumed to be part of the feature. Actual location of the spring will need to be confirmed by the landholder.
Surrounding land use from aerial photography:	Surrounding land use is dominated by grassland and pasture. There are visible soil terraces and cattle access tracks. Pilliga East Nature Reserve is located to the west of the site.
Hydrology from aerial photography:	Sandy Creek 1.3 km west of spring location, ephemeral creek 0.14 km to the north
Catchment Area:	0.30 ha

GEOLOGY AND HYDROGEOLOGY

Surface geology from geological mapping:

Purlawaugh Formation



Solid geology from geological mapping:	Purlawaugh Formation (Jurassic) – fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams.
Desk top hydrogeological assessment:	The site is located on the Purlawaugh Formation which is a less transmissive unit within the region. The interface between the Pilliga Sandstone and the Purlawaugh Formation is located to the west of the site. The Pilliga Sandstone is considered a significant transmissive unit within the region and is the most likely source of a potential GDE at this location. There are four registered bores within a 3.4 km radius of the site, the source of the bores is unknown. A hydraulic connection between the bores and the site could not be proven due to a lack of information. Desktop assessment classified the site as a known high priority GDE, likely to be a groundwater dependent wetland supported water table spring sourced by the Pilliga Sandstone. However, aerial imagery could not confirm exact location of the feature.
Existing features with potential to impact the site:	The four registered bores proximal to the site (within 3.4 km) are reported as used primarily for stock and domestic purposes. Abstraction from these bores is unlikely to have an impact on a potential GDE at this location. Aerial photography shows the site to be surrounded by grazing suggesting there may be some impact by cattle. Visible soil terraces and cattle access tracks.

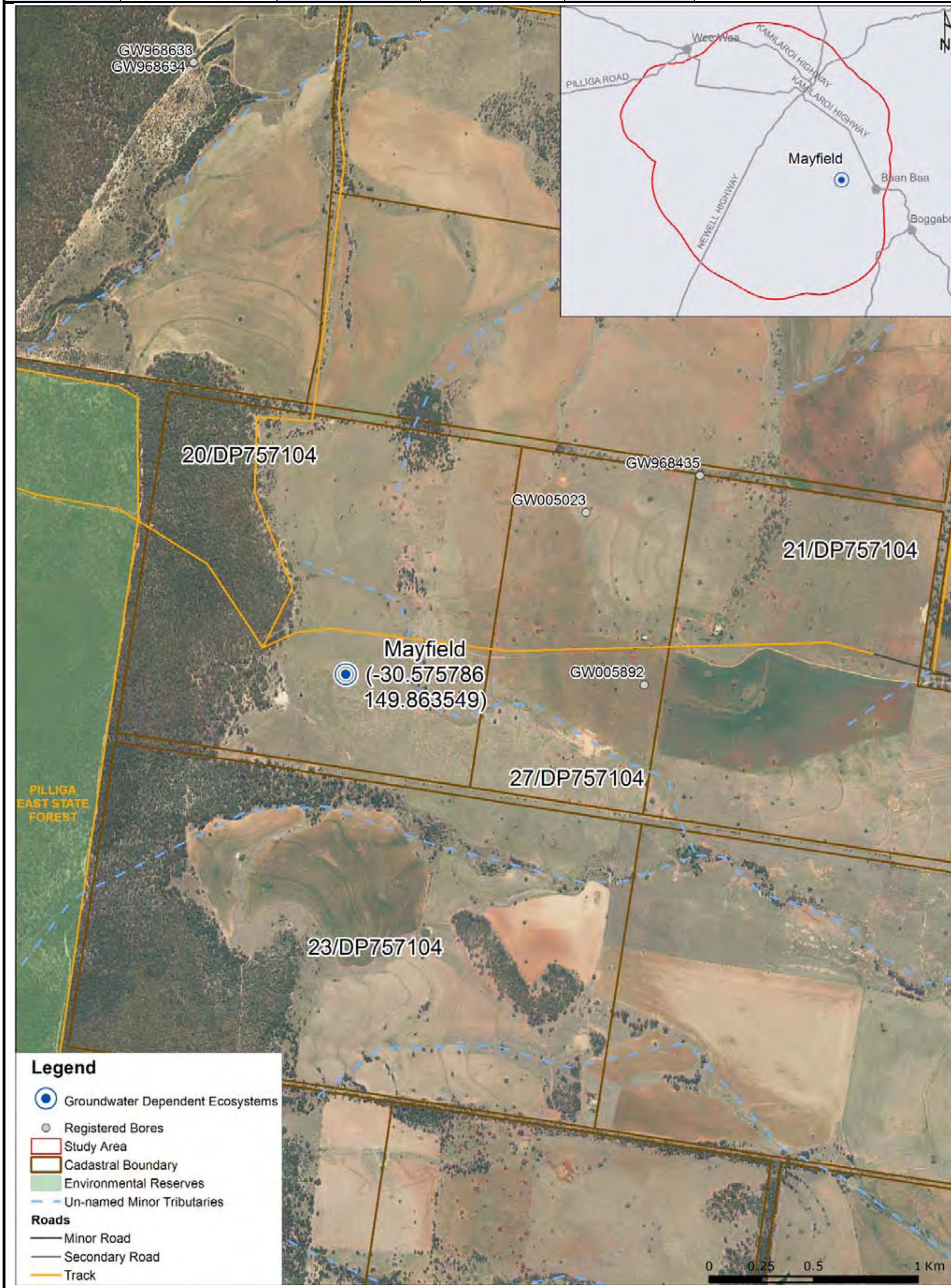
ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eriochaulon australasicum*. **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis*, *Vallisnaria* sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	From assessment of high resolution photography the triangular body of water east of the plotted point is assumed the most likley location of the spring. The triangular water body appears to have a large dam wall and two small ponds forming an overflow channel to creek. Visible contoured bunds across the paddocks may influence catchment runoff. There is possible fringing vegetation. Google Earth Image from 2010 shows dark water, while in 2007 and 2013 it is brown and indicative of surface runoff.
Matters of National Environmental Significance present?	From assessment of high resolution aerial photography it is considered unlikely the site will support Matters of Environmental Significance because of the high level of disturbance and apparent access to water by stock. Any species present are unlikely to be genetically isolated from conspecifics further down in the drainage channel because hydrological connection is likely to occur infrequently during periods of high rainfall. None of the threatened species listed under the EPBC Act for this area are wetland dependent.
Site condition:	The site appears to be modified and heavily impacted by cattle watering and catchment clearing. Contour ripping appears to direct some water to the dams, and would transport sediment and nutrients from cleared catchment. Upper catchment densely forested.
Significance of the flora and fauna present:	Fringing flora visible in some aerial images, likely dense macrophytes growing in deep edges where cattle don't access, or mats of algae in shallow, nutrient-rich water. Highly disturbed lower catchment with increased sediment and nutrients inflows. Only hardy, common species likely to be tolerant of disturbed conditions, therefore, site is unlikely to have threatened flora. None of the species listed in threatened species searches are wetland-dependent.
Predicted ecological value of the site:	Listed as a high priority GDE in the Namoi State of the Catchment Report. The exact location of the GDE feature has not been confirmed, assessment has focused on the dammed water bodies identified on aerial images. The site appears to be in poor condition as wetland. It is possibly connected to groundwater, either through a spring or an upslope soak, and that water has been trapped by a dam wall and an excavation. The surrounding landscape has been heavily modified by agricultural activities. None of the species listed in threatened species searches are wetland-dependent.
Predicted sensitivity of the ecosystem:	The water bodies visible on aerial imagery appear to be have been excavated and dammed, the environment is therefore already highly disturbed/modified and not sensitive to change.

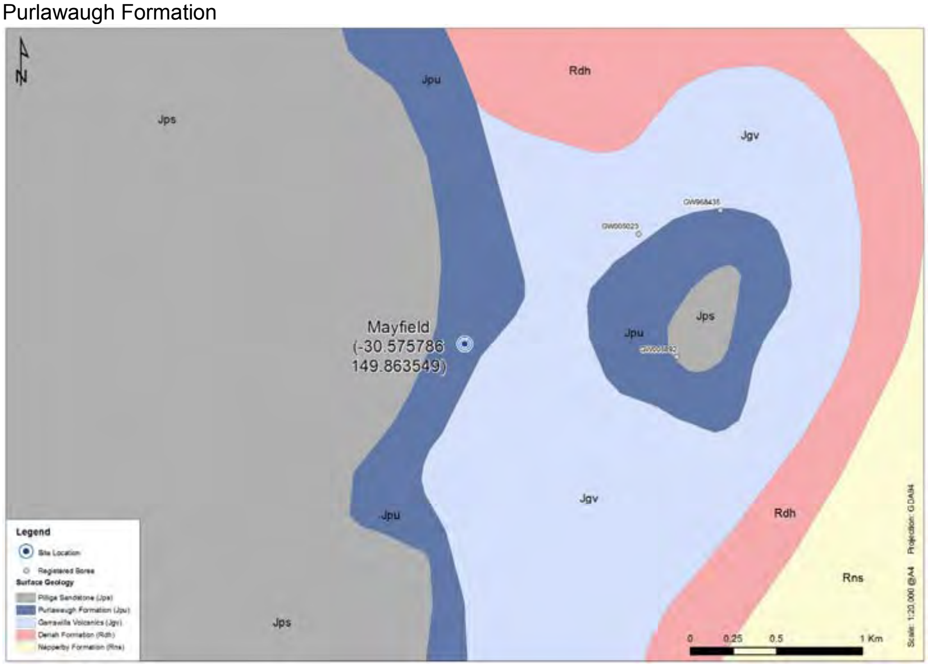
FINAL CONCLUSIONS

- This site is **considered to be a groundwater dependent ecosystem** because:
    - The site was identified as a high priority GDE in the Namoi State of Catchment Report; and
    - The site is located proximal to the interface between the Pilliga Sandstone and the Purlawaugh Formation which is a hydrogeologically likely place for springs to occur.
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
    - Aerial photography suggest the site to be highly modified and unsuitable for threatened species;
    - Aerial photography suggest the site to be in poor ecological condition; and
    - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

PRELIMINARY CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Mayfield		DATE OF SITE VISIT:	NOT VISITED
LATITUDE:	-30.575786	LONGITUDE:	149.863549	ELEVATION:	314 mAHD



PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Narrabri Coal Mine Stage 2 Longwall Project - Hydrogeological Assessment; Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Water body directly to the east of site with drainage to secondary body of water further south-east (visible on aerial imagery)
GENERAL SITE CHARACTERISATION	
Site description from desk study:	The site was identified as a spring in the Narrabri Coal Mine Stage 2 Longwall Project. Aerial imagery shows the site to comprise a regular shaped farm dam fringed with aquatic vegetation, possibly a dammed seep. Cattle access is visible from aerial imagery. Aerial suggests low lying topography dominated by grassland and pasture surround the site.
Surrounding land use from aerial photography:	Cropping land surrounded feature, soil terraces and dams evident. Pilliga Nature Reserve is located west of the site.
Hydrology from aerial photography:	Within or adjacent to drainage line
Catchment Area:	0.16 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Purlawaugh Formation 
Solid geology from geological mapping:	Purlawaugh Formation (Jurassic) – fine to medium grained sandstone thinly interbedded with siltstone, mudstone and thin coal seams
Desk top hydrogeological assessment:	The site is located on the Purlawaugh Formation which is a less transmissive unit within the region. The interface between the Pilliga Sandstone and the Purlawaugh Formation is located to the west of the site. The Pilliga Sandstone is considered a significant transmissive unit within the region and is the most likely source of a potential GDE at this location. There are six registered bores located within a 3 km radius of the site. The source of the bores is unknown. A hydraulic connection between the bores and the site could not be proven due to a lack of data. Initial desktop assessment classified the site as a potential groundwater dependent wetland supported by a water table spring sourced by the Pilliga Sandstone. Anecdotal information for this site suggests the landholder has dammed the spring source for farming use, and that the site has a constant input of groundwater.
Existing features with potential to impact the site:	There are six registered bores located within a 3 km radius of the site. Source of the bores is unknown. Abstraction from the bores is unlikely to impact a potential GDE at this location. The site is known to have been dammed. The site is surrounded by cropping land and is likely to be accessed and therefore impacted by cattle.

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eriochaulon australasicum*. **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis*, *Vallisnaria* sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	High resolution aerial photography shows the site to comprise a dark-coloured dam with stock trails leading to the water. The aerial photo taken in 2014 shows a band of apparently floating vegetation around the outside edge of the dam. This is also visible in 2010 when the water is greener, although is narrower.
Matters of National Environmental Significance present?	From assessment of high resolution aerial photography it is considered unlikely the site will support Matters of National Environmental Significance because of high level of disturbance to the spring (it has been dammed) and the surrounding land. There is no fringing vegetation to provide habitat for Australasian Bittern or Painted Snipe. None of the threatened plant species listed for the area under the EPBC Act are aquatic.
Site condition:	Poor quality due to modified dam structure and cattle trampling. Cleared catchment would increase sediment and nutrient loads entering waterbody.
Significance of the flora and fauna present:	Possible floating vegetation or emergent growing in deep edges where cattle don't access. Only hardy, common species likely to be tolerant of disturbed conditions, therefore, site is unlikely to have threatened flora.
Predicted ecological value of the site:	This site is in poor ecological condition as a wetland. It is possible this dam is a connected to groundwater.
Predicted sensitivity of the ecosystem:	The site has been highly modified and dammed around a potential spring source. The environment is therefore already highly disturbed/modified and not sensitive to change.

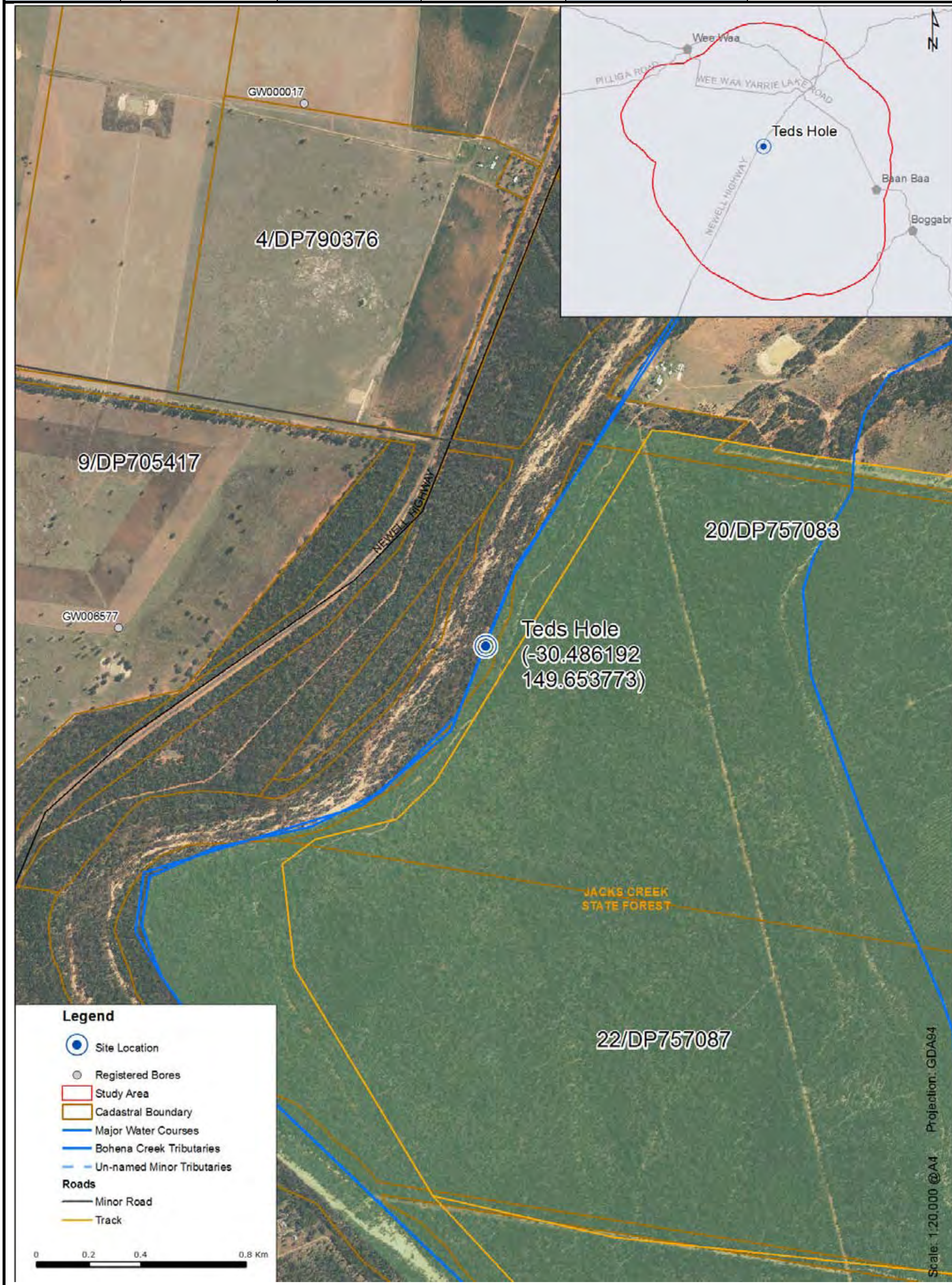
FINAL CONCLUSIONS

- This site is **considered to be a groundwater dependent ecosystem** because:
  - The site was previously identified as a spring in the Narrabri Coal Mine Stage 2 Longwall Project – Hydrogeological Assessment.
  - Anecdotal information identified the site as being a dammed spring with permanent water supply;
  - The water in most recent aerial imagery (2014) looks to be fresh, indicative of groundwater input rather than surface run-off; and
  - The site is located proximal to the interface between the Pilliga Sandstone and the Purlawaugh Formation which is a hydrogeologically likely place for springs to occur.

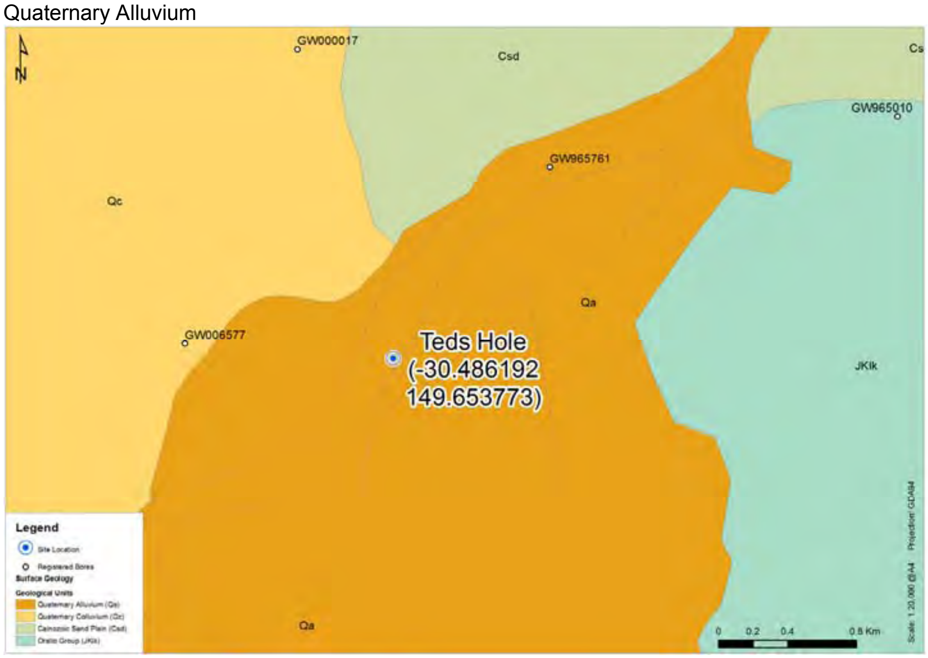
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography suggest the site to be highly modified and unsuitable for threatened species;
  - Aerial photography suggest the site to be in poor ecological condition with no fringing vegetation for threatened bird species; and
  - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Teds Hole		DATE OF SITE VISIT:	21/10/13
LATITUDE:	-30.486192	LONGITUDE:	149.653773	ELEVATION:	237 mAHD



<table>
<tr><th colspan="2">CHARACTERISATION SUMMARY</th></tr>
<tr><th colspan="2">INITIAL IDENTIFICATION OF SITE</th></tr>
<tr><td>Data source(s):</td><td>Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50 000 Topographic Map (Sheet Number 8836N)</td></tr>
<tr><td>Feature identifiers:</td><td>Waterhole adjacent to Bohena Creek</td></tr>
<tr><th colspan="2">GENERAL SITE CHARACTERISATION</th></tr>
<tr><td>Site description:</td><td>Teds Hole is a well established and signposted pool of water approximately 55 m by 7 m, located on Bohena Creek (ephemeral). The pool is approximately 1.5 m deep with sandstone outcropping on the base. The eastern and western banks of the pool were densely vegetated and fairly steep rising to approximately 1 m on both sides. The Bohena Creek channel leads north and south from Ted's Hole. At the time of visit (21/10/13), the remainder of the creek bed was dry, flat and sandy. A fallen tree bridged the north of the pool. The water was turbid with a slight sheen at the time of visit.</td></tr>
<tr><td>Surrounding land use:</td><td>Teds Hole is located in the Pilliga Nature Reserve. Surrounding land is relatively flat with dense forest. An access track is located approximately 15 m to the west of the site.</td></tr>
<tr><td>Hydrology:</td><td>Located on drainage channel of Bohena Creek (ephemeral)</td></tr>
<tr><td>Catchment area:</td><td>43.30 ha</td></tr>
<tr><th colspan="2">GEOLOGY AND HYDROGEOLOGY</th></tr>
<tr><td>Surface geology from geological mapping:</td><td>Quaternary Alluvium



</td></tr>
<tr><td>Solid geology from geological mapping:</td><td>Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate</td></tr>
<tr><td>Onsite geological observations:</td><td>No visible surface outcrops. Rock substrate at base of pool, likely to be sandstone, covered largely by loose sand and detritus. Sandstone gravel and cobbles observed around the pool sides and along the track. Track has sand covering.</td></tr>
<tr><td>Initial hydrogeological assessment:</td><td>Teds Hole is located on the Quaternary Alluvium which is considered a significant transmissive unit in the region. There are six registered bores located within a 3 km radius of the site, source of the bores is unknown. Reported groundwater levels of the bores are between 228.5 and 177.9 mAHD. Ground surface at the site is 237 mAHD.

From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring (watercourse spring) sourced by the Quaternary Alluvium.

No seepages or flow was observed during the site visit (23/1013) but the banks were obscured by dense vegetation.</td></tr>
<tr><td>Existing features with potential to impact the site:</td><td>The remote location of the site in the Pilliga Forest suggests that there are likely to be few existing features that may impact the site. The closest registered bore reported as used for irrigation and stock (GW965057) is located 3.0 km from spring location and is unlikely to impact the site.</td></tr>
</table>

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	Teds Hole is a 55 m long pool in Bohena Creek that is 1.5 m deep. Both sides of the pool rose steeply from the water for approximately 1.0 m. Vegetation atop the bank was dominated by Blakeley's Red Gum (*Eucalyptus blakelyi)* with an understory of *Juncus* sp. *Callistemon linearus* and *Leptospermum polygalifolium* made up the shrub layer at the upstream and downstream ends of the pool. Iron stained the sand at the northern (upstream) end of the pool and a slight sheen partially covered the water surface. Water in the pool is sustained by alluvial groundwater from the alluvium of Bohena Creek.
Observed plant species:	*Juncus* sp., *Callistemon linearus*, *Leptospermum polygalifolium, Glandularia aristigera, Lomandra confertifolia* ssp *palida, Schoenoplectus mucronatans.*
EPBC Species or community observed?	None observed
Observed site condition:	Teds Hole is in a relatively good ecological condition. Eleven aquatic invertebrate families were present at the time of sampling, and all had low to medium levels of tolerance to disturbance. The wetland had three species of fish comprising native carp gudgeon (*Hypseleotris* sp.) and the pest species carp (*Cyprinus carpio*) and mosquitofish (*Gambusia holbrooki*). Water was turbid, EC was low (250.4 µS/cm), and pH was slightly above neutral (7.95). Dissolved oxygen concentration was 4.25 mg/L, which is moderate for an isolated, lentic wetland.
Significance of the flora and fauna present:	None of the species present in the wetland are of conservation significance.
Predicted ecological value of the aquifer and site:	The wetland is an important component of the Bohena Creek aquatic ecosystem. As a permanent body of water, it acts as a colonizing source for the creek when it is flowing. It is also an important source of drinking water for terrestrial fauna. Although the wetland contains exotic species (carp and mosquitofish), it is an important refuge for aquatic species. There are no evident geomorphological reasons why this deepened hole occurs where it does on Bohena Creek. The waterhole may have been deepened by mechanical excavation in the past, as there are sandstone fragments on the ground next to the entrance track.
Predicted sensitivity of the ecosystem:	The ecosystem appears fairly robust, although may be threatened by activities that lead to drawdown in the Bohena Creek alluvium of more than 2 m, or lead to a change in water quality.

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7551_WSURF_201310211650	
Sample location and description:	Latitude: -30.4835 Longitude: 149.6517 Sample taken on shallow bank at the south of the pool. Brown colour to the water. Water depth approximately 150 mm at sample point.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	7.95	250.4	4.25	31.0	23.1

FINAL CONCLUSIONS

- This is **considered to be dependent on groundwater sourced from the Bohena Creek Alluvium because:**
  - The site is a permanent waterhole with no obvious surface water input; and
  - Sandstone is known to outcrop at the base of the pool.
- **This site has high ecological value as a permanent waterhole;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

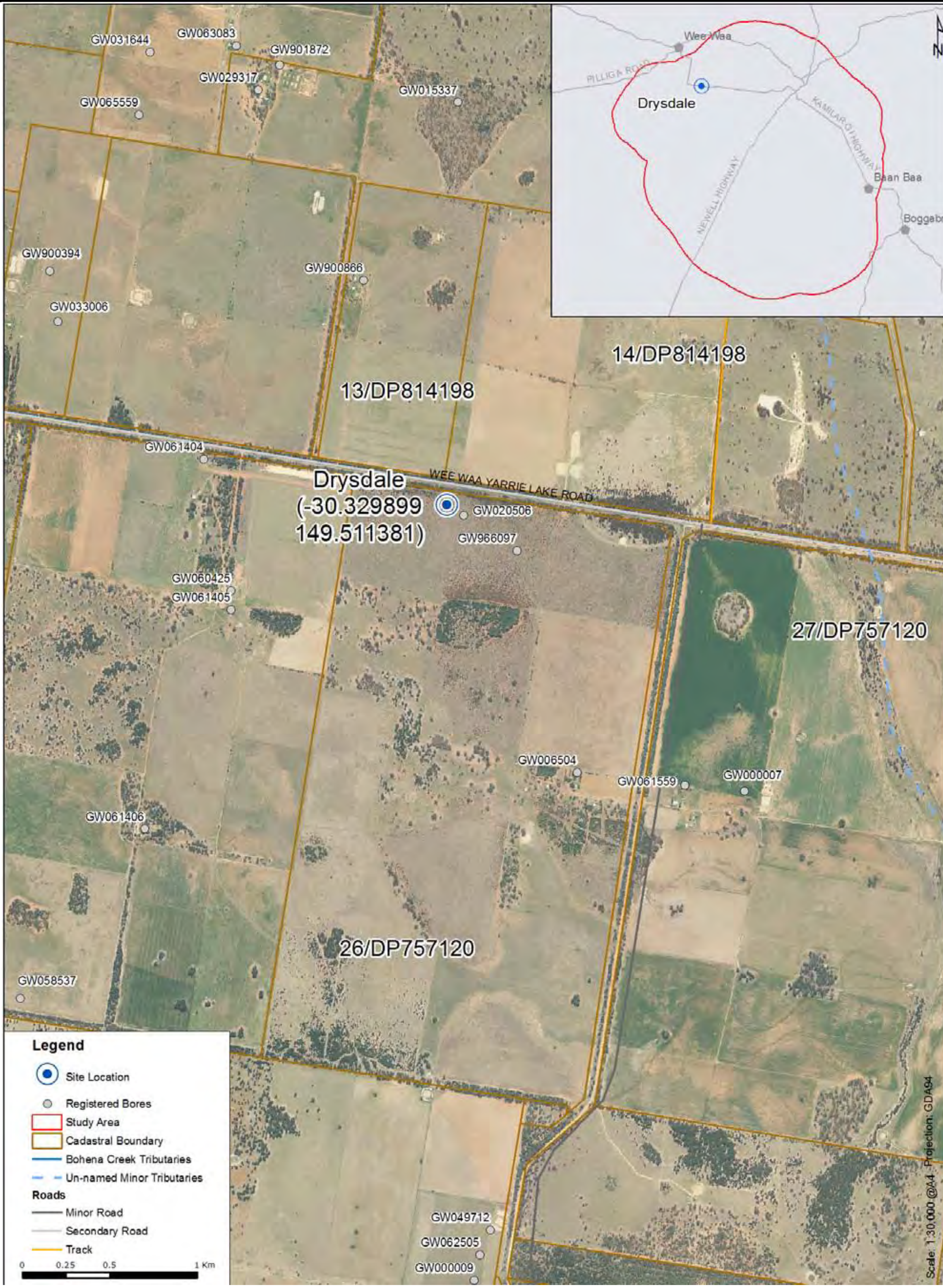
FIELD RECONNAISSANCE PHOTOGRAPHS

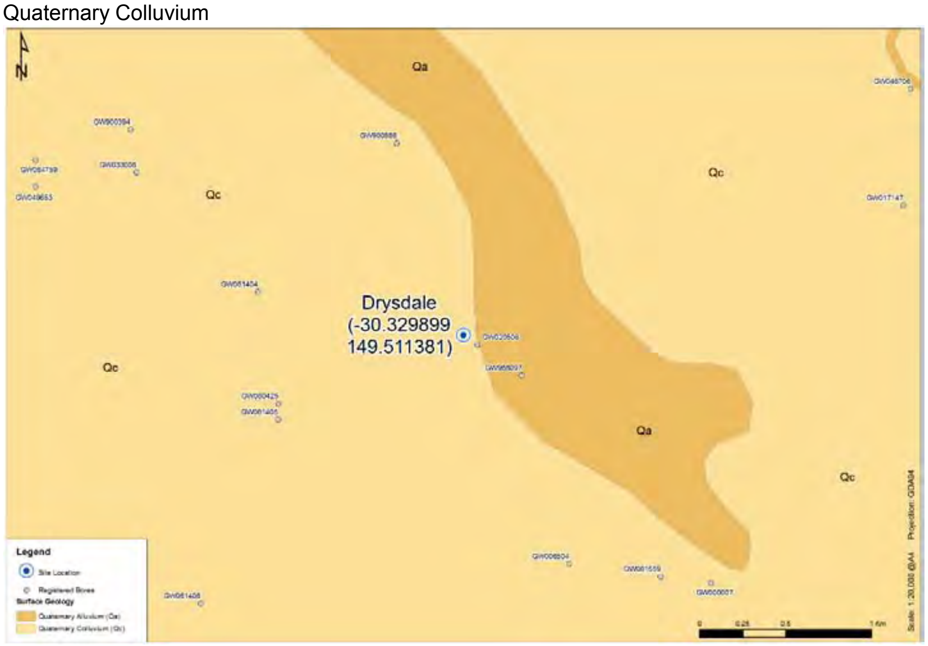
	
Photograph 1: Teds Hole facing north. Water is turbid. Densely vegetated, grassed banks.	Photograph 2: Teds Hole facing south. Fallen tree bridging pool in the foreground. Sample point taken on furthest bank.
	
Photograph 3: Eastern bank of Teds Hole. Steep banks which drop straight to water.	Photograph 4: Dry drainage channel leading from the northern edge of Teds Hole. Sand base. Densely vegetated.

PRELIMINARY CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:	Drysdale	DATE OF SITE VISIT:	26/02/14 (No Ecological Assessment)

LATITUDE:	-30.329899	LONGITUDE:	149.511381	ELEVATION:	280 mAHD



PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	CH2M HILL Registered Bore Inventory - identified during field survey to property
Feature identifiers:	Water body disconnected from drainage system, low turbidity appearance. Associated with old exploration well (GW020506).
GENERAL SITE CHARACTERISATION	
Site description:	The site is a flat pasture adjacent to a main road (Yarrie Lake Road). An old oil exploration well (registered bore number: GW020506 / Exploration bore name: Wee-Waa 1), advanced to 824.8 m and plugged to 338.6 m was drilled at the site in 1963. The well has been allowing groundwater under artesian conditions to seep to the surface forming large pools of water around the location of the well. The bore cap is inaccessible, underlying approximately 200 mm of water in an area of thick bull rushes. There is some salt crusting around the perimeter of the pools.
Surrounding land use from aerial photography:	Surrounding land appears to be low lying and used for pasture and cattle grazing. Agricultural dams, either side of the site are recognised on aerial imagery (elongate dam 1.0 km west and dam 1.7 km east)
Hydrology from aerial photography:	No major watercourses are nearby the site. An ephemeral creek is located approximately 4.1 km to the east.
Catchment Area:	0.02 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Colluvium 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Desk top hydrogeological assessment:	The wetland feature has formed under artesian conditions of an old exploration well (registered bore number: GW020506 / Exploration bore name: Wee Waa 1). The well was drilled to 824.8 m and intercepts a number of formations. The bore was plugged to 338.6 m, it is assumed that the well is screened in the Pilliga Sandstone. The Pilliga Sandstone is considered a significant transmissive unit in the area and is the most likely source of groundwater to the wetland feature. Twenty-four registered bores are located within a 3 km radius. A hydraulic connection between the site and the bores could not be proven due to a lack of information.
Existing features with potential to impact the site:	Four bores, located within 2 km of the wetland feature, are reported as used for stock, domestic and irrigation purposes. The source of the bores is unconfirmed. If the registered bores are abstracting from the Pilliga Sandstone some effect on the wetland feature is assumed.

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* **Threatened wetland fauna:** Australasian Bittern (*Botaurus poiciloptilus*), Australian Painted Snipe (*Rostratula australis*)
Ecological environment observations:	Shallow wetland formed in a depression that ponds water from flowing artesian bore. Wetland plants present, but unlikely to be any endemic species. Potential suitable habitat for Australian Painted Snipe, but this is made less likely by the apparent level of disturbance from stock and predators.
Matters of National Environmental Significance present?	No wetland plant species are listed for this site. Two significant wetland bird species may occur in the area but high resolution aerial imagery suggest the habitat is not suitable for either as the area appears to be too disturbed.
Site condition:	Poor ecological condition. Wetland is artificially wet. Low ecological value.
Significance of the flora and fauna present:	No wetland plant species are listed for this site. Two significant wetland bird species may occur in the area but high resolution aerial imagery suggest the habitat is not suitable for either as the area appears to be too disturbed.
Predicted ecological value of the site:	This wetland is likely to have significance as an area of permanent water, but does not support nationally significant species. The wetland ecological community will have developed only in the period since the bore was drilled.
Predicted sensitivity of the ecosystem:	The wetland sourced by groundwater from the old exploration bore located at the site (registered bore number: GW020506 / Exploration bore name: Wee Waa 1). The groundwater is assumed to be sourced from the Pilliga Sandstone. The wetland will be sensitive to changes in water levels of the Pilliga Sandstone.

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7789_WG_201402260900	
Sample location and description:	Grab water sample collected (26/02/14) from pooled water, approximately 200 mm depth overlying the bore cap.				
Geochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	8.27	1287	1.62	-188.4	23.5

FINAL CONCLUSIONS

- This site **is considered dependent on groundwater** because:
  - Water of the wetland is sourced from an old exploration well (registered bore number: GW020506 / Exploration bore name: Wee Waa 1) under artesian conditions; and
  - The bore is assumed to be sourced from the Pilliga Sandstone
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography suggest the habitat to be too disturbed by stock and predators to support threatened bird species;
  - Aerial photography suggest the site to be in poor ecological condition; and
  - None of the threatened species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

FIELD RECONNAISSANCE PHOTOGRAPHS

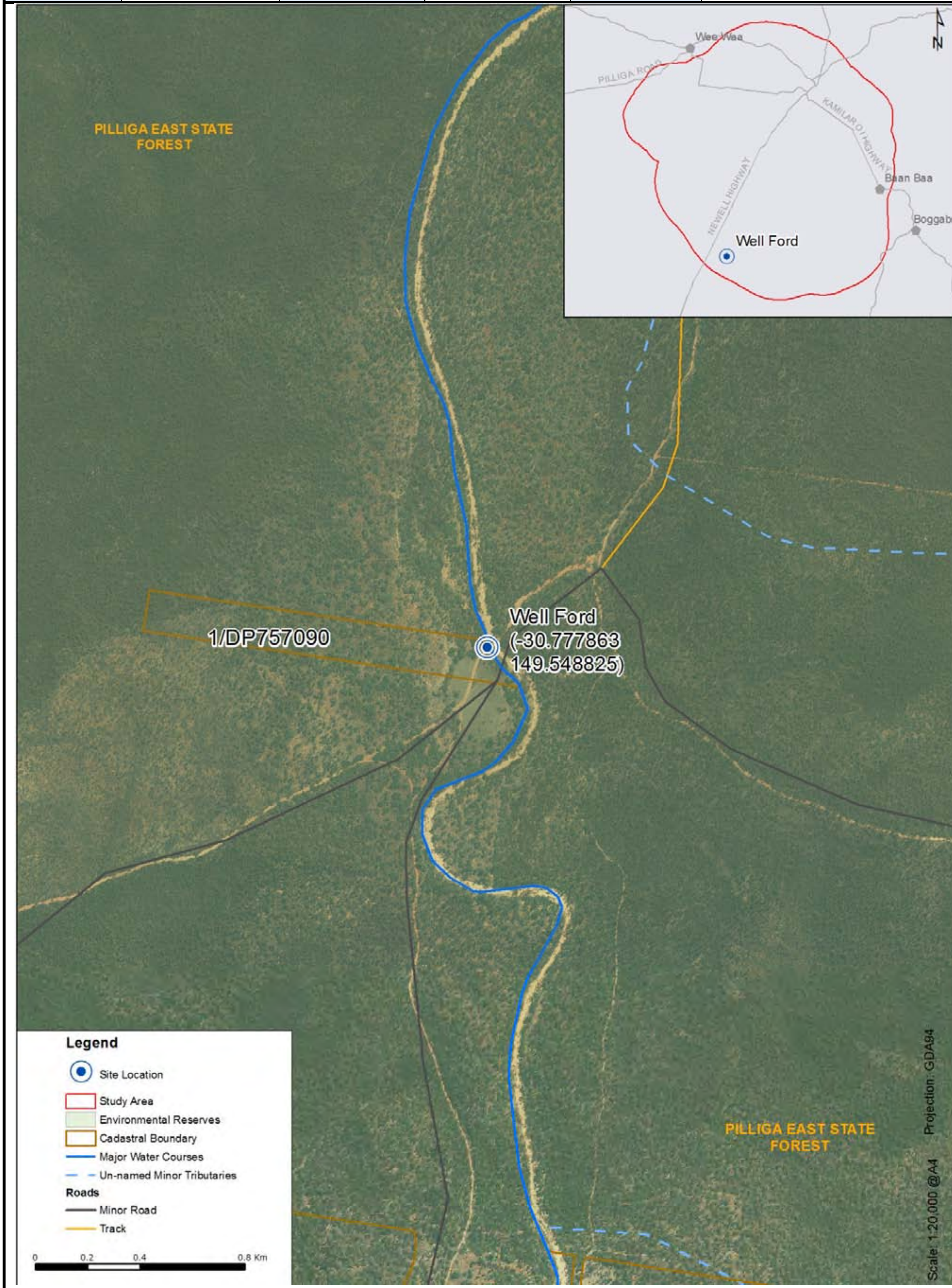
Photograph 1: Facing south towards the wetted area. Flat, dry, sparsely vegetated land surrounding the wetland.

Photograph 2: Facing west. The bore cap of the old exploration well is within the bull rushes in the bottom left corner of the photo. Salt crusting observed on the edges of the pool.

Photograph 3: Facing west towards pooled water with salt crusting. Dense Rush growth surrounding the location of the exploration well.

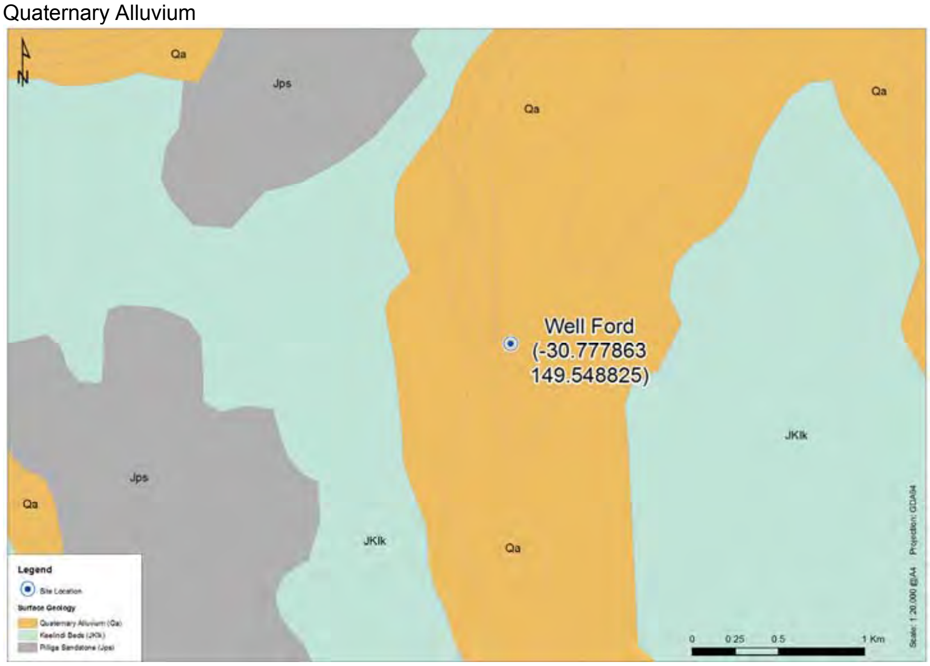
Photograph 4: Close up of the bore cap. The cap was inaccessible due to thick vegetation growth and pooled water approximately 200 mm depth. Grab sample was taken at this location.

PRELIMINARY CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Well Ford		DATE OF SITE VISIT:	NOT VISITED
LATITUDE:	-30.777863	LONGITUDE:	149.548825	ELEVATION:	302 mAHD



<table>
<tr><th colspan="2">PRELIMINARY CHARACTERISATION SUMMARY</th></tr>
<tr><th colspan="2">INITIAL IDENTIFICATION OF SITE</th></tr>
<tr><td>Data source(s):</td><td>Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchments;The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50 000 Topographic Map (Sheet Number 8836N)</td></tr>
<tr><td>Feature identifiers:</td><td>Located on Borah Creek, prominent vegetation, no visible surface water pooling.</td></tr>
<tr><th colspan="2">GENERAL SITE CHARACTERISATION</th></tr>
<tr><td>Site description from desk study:</td><td>This site was identified as a spring symbol on the Pilliga Forest Map. The feature is located on the drainage channel of Borah Creek. The exact location, presence or condition of the feature has not been established through available aerial photography, a site visit is required to confirm or discount this feature.

An old exploration well, Galloway 1, is located 0.2 km south west of the plotted location. Galloway 1 was advanced to a total depth of 499.5 m in 1980. The bore proved the basement volcanics but is assumed to be screened within the Pilliga Sandstone.

Aerial photography suggests the site is surrounded by dense forest on low lying topography.</td></tr>
<tr><td>Surrounding land use from aerial photography:</td><td>The site is located within Pilliga East State Forest.</td></tr>
<tr><td>Hydrology from aerial photography:</td><td>Located on Borah Creek (ephemeral) (tributary of Bohena Creek)</td></tr>
<tr><td>Catchment Area:</td><td>0.10 ha</td></tr>
<tr><th colspan="2">GEOLOGY AND HYDROGEOLOGY</th></tr>
<tr><td>Surface geology from geological mapping:</td><td>Quaternary Alluvium

</td></tr>
<tr><td>Solid geology from geological mapping:</td><td>Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate</td></tr>
<tr><td>Desk top hydrogeological assessment:</td><td>The site is underlain by the Quaternary Alluvium which is considered a significant transmissive unit within the region and the most likely source of a potential GDE present at this location.

There are no registered bores within 5 km of the site. An old exploration well, Galloway 1, is located 0.2 km south west of the site. The bore is assumed to be screened within the Pilliga Sandstone.

From initial desktop assessment this site was classified as a potential base flow creek supported by water table spring sourced by the Quaternary Alluvium or a potential artificial GDE sourced by the proximal exploration bore Galloway 1.</td></tr>
<tr><td>Existing features with potential to impact the site:</td><td>There are no registered bores located within a 5 km radius of site location. The site appears to be relatively remote within the Pilliga East State Forest but is next to a cleared section with a minor road 0.1 km from the location.</td></tr>
</table>

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Llomandra longifolia, Phragmites australis* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	It was not possible to determine the exact feature at this site using available high resolution aerial photography. There is no apparent water at the location in the 2010 or undated images. There is a bare patch of cleared ground beside Borah Creek which may become saturated following prolonged rainfall, though is not permanently wet. Aerial images show the location to be surrounded by relatively dense forest, it is possible the feature is obscured by the trees.
Matters of National Environmental Significance present?	From assessment of high resolution aerial imagery it is considered unlikely that the site could support aquatic Matters of National Environmental Significance given the potentially small size and ephemeral nature of the feature (not visible on photography). Additionally the site may be impacted from the minor roadway adjacent. None of the threatened species listed under the EPBC Act for this area are wetland dependent.
Site condition:	From assessment of high resolution aerial photography the site appears to be in a cleared area of forest beside Borah Creek, however no specific wetland feature has been identified on the images. The location is transected by a road. There are no significant ecological components identifiable on the images.
Significance of the flora and fauna present:	It is unlikely that any threatened species listed above occur at this site given the potentially small size and ephemeral nature of the feature (not visible on photography).
Predicted ecological value of the site:	This site has no significant identifiable ecological components.
Predicted sensitivity of the ecosystem:	The exact feature of this location has not been identified through assessment of high resolution aerial photography. However the site is shown to be transected by a minor roadway suggesting the site is already in a modified state. If a wetland feature is present and sourced by the exploration well Galloway 1 it the groundwater is assumed to be sourced from the Pilliga Sandstone. The wetland will be sensitive to changes in the Pilliga Sandstone.

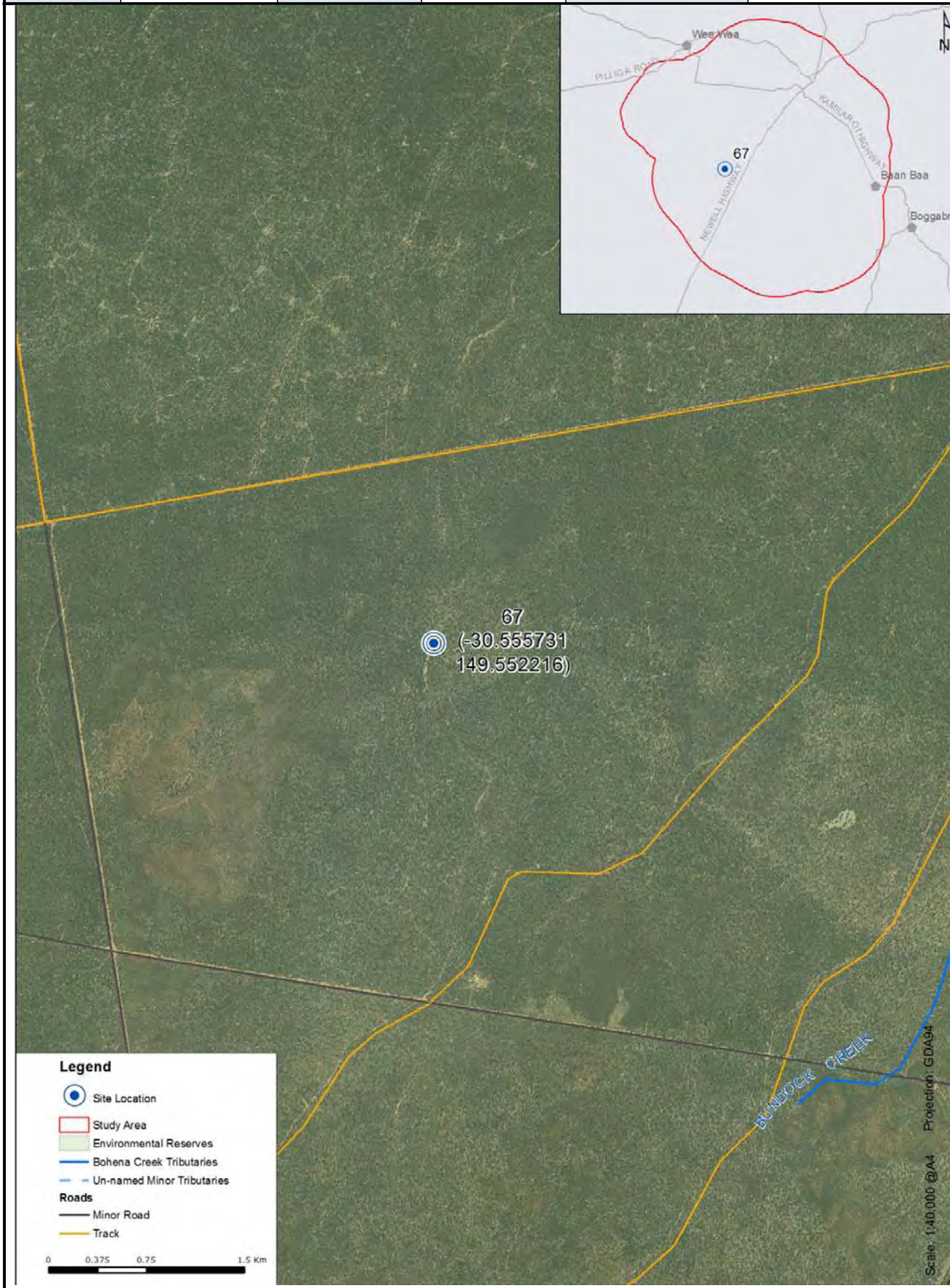
FINAL CONCLUSIONS

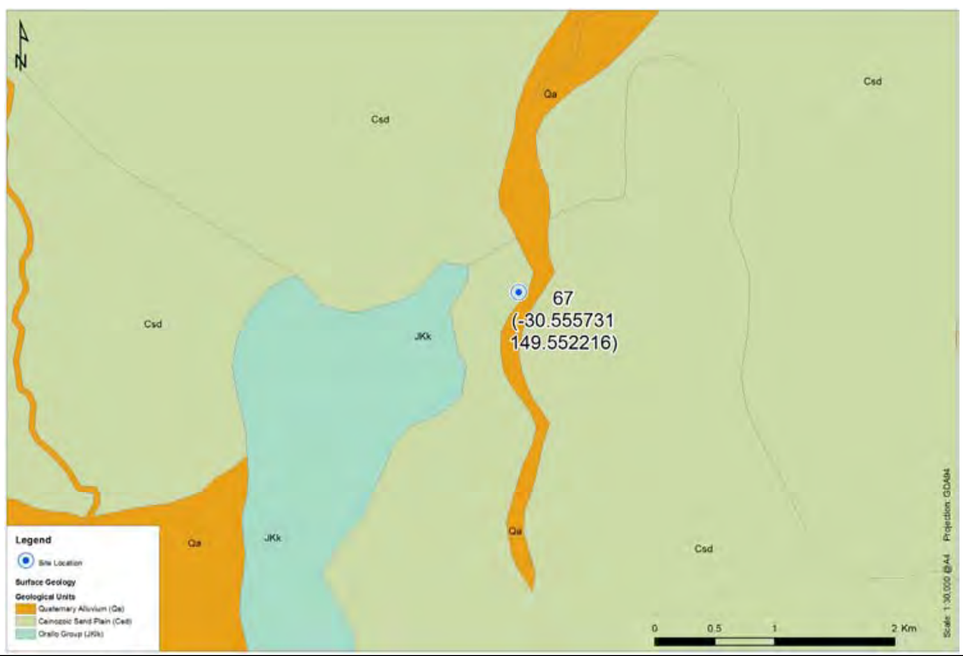
- **The exact wetland feature at this site has not been established using high resolution aerial imagery.**
- A wetland feature present at this site is **considered to be potentially dependent on groundwater** because:
  - An old exploration well (Galloway 1) is located 0.2 km from the site and considered a potential source; and
  - The bore is assumed to be sourced from the Pilliga Sandstone
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography has not made it possible to identify the exact wetland feature at this site suggesting a potential feature will be small and likely ephemeral in nature;
  - A clearing and minor road transects the location suggesting the land is in a modified state; and
  - None of the threatened species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		67		DATE OF SITE VISIT:	24/10/13
LATITUDE:	-30.555731	LONGITUDE:	149.552216	ELEVATION:	256 mAHD



CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Feature located within drainage line that appears to be connected to Bundock Creek, possible meander scar. Dark, low turbidity water suggests potential groundwater influence.
GENERAL SITE CHARACTERISATION	
Site description:	Aerial suggests low lying topography surrounded by dense forest vegetation. Long, dark feature within drainage line that appears to be connected to Bundock Creek (likely intermittent system), possible meander scar. The site comprised a sandy, sparsely vegetated surface water channel which was dry at the time of visit (24/10/13). The channel was flat and varied in width from 2 m to 21 m in the section visited (0.5 km length). There was no evidence of seepages, water pools or vegetation supported by groundwater. The site was surrounded by dense forest. The access track leading to the site was overgrown and blocked by fallen trees.
Surrounding land use:	The site is located within Pilliga East State Forest. The surrounding forest was dense on relatively flat topography. Two old eastern star gas wells/bores were observed approximately 250 m west of the site.
Hydrology:	Bundock Creek (likely intermittent) is 3.8 km to the east. Goona Creek (ephemeral) is located 4.0 km to the west.
Catchment area:	0.08 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Cainozoic Sand Plain 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	No surface outcrops. Fine to medium sand as creek base.
Initial hydrogeological assessment:	The site is located on a Cainozoic sand plain deposit which is considered a significant transmissive unit within the region. No registered bores are located within a 5 km radius of the site. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring most likely sourced from the Cainozoic sand plain.
Existing features with potential to impact the site:	N/A. Site no longer considered to be sourced from groundwater.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	During the site visit (24/10/13), the site was a long sandy scrape. The edge of the scrape was lined by *Cyperus gunnii* and *Lomandra confertifolia.*
Observed plant species:	*Cyperus gunnii*, *Lomandra confertifolia* ssp *pallida*, *Schoenoplectus mucronatus*
EPBC Species or community observed?	None observed.
Observed site condition:	This wetland is in poor ecological condition. Some evidence of pig rooting.
Significance of the flora and fauna present:	None of the species observed were of conservation significance.
Predicted ecological value of the aquifer and site:	This wetland is of little ecological value.
Predicted sensitivity of the ecosystem:	The wetland is not sensitive to change.

HYDROCHEMISTRY					
Water quality sample taken?	No.		**Santos sample reference:**	-	
Sample location and description:	Site was dry at the time of visit (24/10/13). No sample possible.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	-	-	-	-	-

FINAL CONCLUSIONS

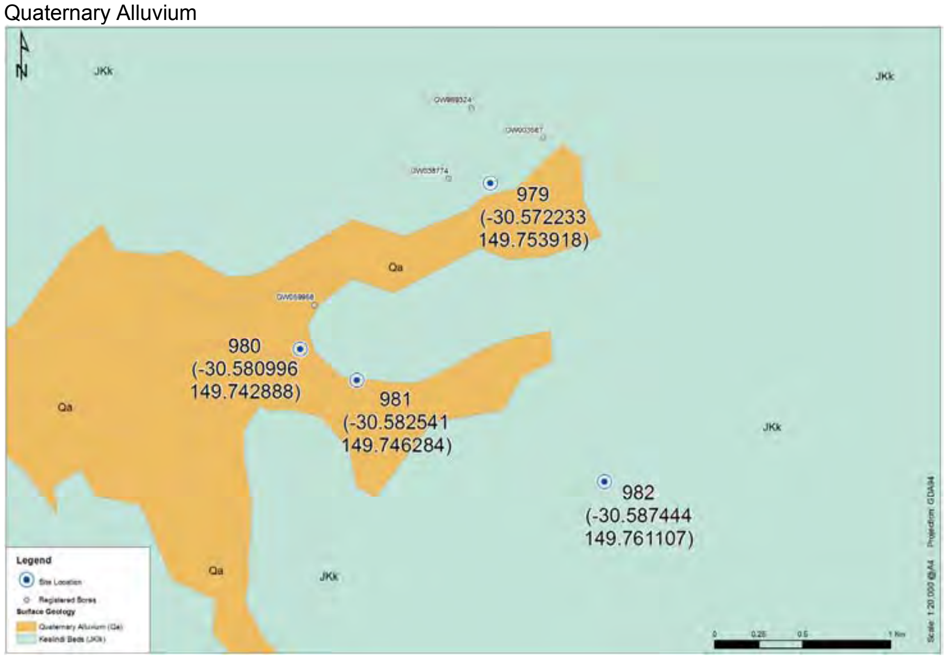
- This site is a surface water channel and **not considered to be dependent on groundwater because:**
  - The site was dry at the time of visit and did not support any wetland vegetation;
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

	
Photograph 1: Northern-most point of Site 67 visited, facing south. Dry sand channel in middle of dense forest.	Photograph 3: Northern-most point of Site 67 visited, facing north. Continuation of dry sand channel in middle of dense forest.
	
Photograph 3: Site 67 facing west into dense forest.	Photograph 4: Southern-most point of Site 67 visited facing south. Dry sand channel in middle of dense forest.

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		981		DATE OF SITE VISIT:	06/11/13
LATITUDE:	-30.582541	LONGITUDE:	149.746824	ELEVATION:	287 mAHD

CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Large water body potentially connected to a minor tributary of Spring Creek
GENERAL SITE CHARACTERISATION	
Site description:	The site comprised a surface water dam, approximately 56 m x 7 m. The dam embankments were up to 1.5 m height. Water was significantly receded from banks, with brown discolouration at the time of visit (06/11/13). The land within the receded area was barren with a dessicated surface. The dam is adjacent to property fence line. Dry channels with a desiccated surface, suggesting previous surface water inflow to the dam were present on the eastern edge of the dam. Access to the site is via Rockdale Road located approximately 60 m to the west of the site. The site is surrounded by dense forest and grassland vegetation on relatively flat topography.
Surrounding land use:	Aerial imagery shows surrounding land use as grazing modified pastures. Bibblewindi State Forest and Pilliga East State Forest is located to the east and the west of the site.
Hydrology:	Spring Creek (ephemeral) is 1.0 km south-west and the site is potentially connected to an un-named ephemeral creek which discharges to Spring Creek.
Catchment area:	0.60 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Alluvium 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	No surface outcrop but gravel to boulder sized fragments of grey mottled orange brown medium to coarse grained sandstone within the dammed banks. Fine to coarse sand soil.
Initial hydrogeological assessment:	The site is located on the Quaternary Alluvium which is considered a significant transmissive unit within the region. The underlying Orallo Formation is considered a negligibly transmissive unit. There are eight registered bores located within a 5 km radius of the site. The source of the bores is not reported on available bore logs. Reported groundwater level of the identified bores range between 239.6 and 224.30 mAHD. Ground surface elevation at the site is 287 mAHD, suggesting there is no hydraulic connection between the bore source and the site. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by water table spring sourced from the Quaternary Alluvium.
Existing features with potential to impact the site:	Potential human and cattle influences are located 0.03 km east of a track close to the site.

ECOLOGY			
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** *Cyperus conicus, Myriophyllum implicatum*. **Other species:** *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.		
Ecological environment observations:	At the time of visit (06/11/13) the site was an exposed farm dam with no overhanging or fringing vegetation. Characeae algae was present in the dam. Three species of aquatic plant were present beyond the bare ground surrounding the water pool. Young *Casuarina cristata* was present at either end of the dam.		
Observed plant species:	Characeae algae, *Juncus* sp., *Gahnia aspera*, *Polygonum aviculare*		
EPBC Species or community observed?	None observed.		
Observed site condition:	Excavation damage next to site (dammed). Evidence of pig rooting. Immediate surrounds of the dam is cleared.		
Significance of the flora and fauna present:	No significant plant or animal species were present. A small herd of wild goats was seen nearby.		
Predicted ecological value of the aquifer and site:	This wetland has a low ecological value. There were 8 aquatic invertebrate taxa, all of which were tolerant to disturbance and typical of farm dams. No fish were observed or collected in the dam.		
Predicted sensitivity of the ecosystem:	This ecosystem is highly disturbed and is not sensitive to change.		

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7567_WSURF_201311060945	
Sample location and description:	Latitude: -30.5687 Longitude: 149.7349 Sample taken on the western bank. Brown discolouration to water. Water depth approx. 250 mm at sample point. Total depth of dam unknown. Some areas with dense algal growth. Turbidity: 33.3 NTU Alkalinity: 39				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	9.19	132.7	7.95	18.7	22.3

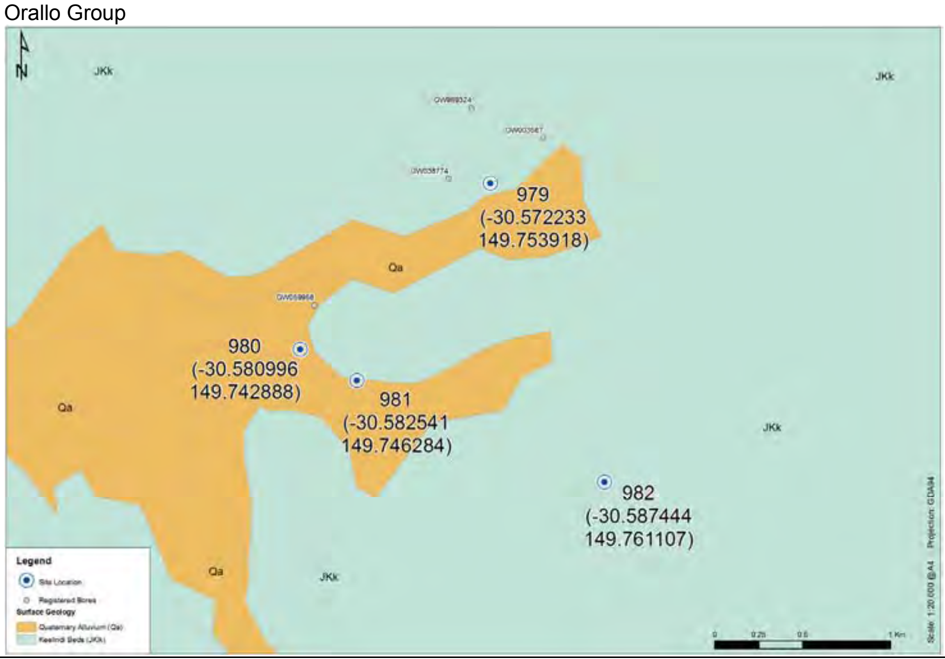
FINAL CONCLUSIONS

- This site is a surface water dam and **not considered to be dependent on groundwater because**:
  - Evidence of surface water inflow was observed onsite; and
  - Water within the dam was receding and turbid suggesting no fresh groundwater input.
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY	
FIELD RECONNAISSANCE PHOTOGRAPHS	
	
Photograph 1: Site 981 facing south. Property fence line approximately 1 m beyond the dammed banks on the left of the photograph. Approximately 15 m dry, desiccated ground before dammed banks on the north edge. Dense forest surrounding the site.	Photograph 2: Site 981 facing north-west. Onset of channel leading to water hole in the foreground. Wet ground approximately 2 m from edge of water, channel dries beyond this (photograph 4).
	
Photograph 3: Location of sample collection. Sandy soil surrounds the water edge with sparse vegetation proximal to the waterhole.	Photograph 4: Dry channel with desiccated surface leading to the waterhole in the north-east corner.

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		982		DATE OF SITE VISIT:	06/11/13
LATITUDE:	-30.587444	LONGITUDE:	149.761107	ELEVATION:	308 mAHD

CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Circular water body disconnected from drainage system. Water body surrounded by dense vegetation.
GENERAL SITE CHARACTERISATION	
Site description:	At the time of visit (06/11/13) the site comprised a dry surface water dam approximately 70 m by 25 m. Embankments on the western edge of the bank were raised to approximately 1.5 m to 2.0 m height. A patch of dessicated mud, approximately 20 m in length was present where the last of the water had been. The remainder of the base of the dam was bare with sand coverage. A sandstone outcrop was exposed in the northern and eastern edges of the dam. The site was relatively remote, surrounded by dense forest dominated by *Eucalyptus creba.* Access to the site is via an overgrown track, not in regular use.
Surrounding land use:	The site is surrounded by Bibblewindi State Forest and Pilliga East State Forest.
Hydrology:	Spring Creek (ephemeral) is located 2.1 km south-west of the site and an un-named ephemeral creek is located 0.8 km to the north-east.
Catchment area:	6.20 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Orallo Group 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	Sandstone outcrop observed towards the north and west of the dam. Sandstone was grey mottled orange brown fine to medium grained (Photograph 3 and 4).
Initial hydrogeological assessment:	Geological maps show the site to be underlain by the Orallo Group which is considered a negligibly transmissive unit in the region. The Orallo group is further underlain by the Pilliga Sandstone which is considered a significant transmissive unit. There are eight bores located within a 2 km radius of the site. The source of the bores in unconfirmed but considered likely to target the Pilliga Sandstone rather than Orallo Group. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring. The Orallo Group formations are unlikely to yield a water source for a potential spring. Although seemingly absent at the site location (from geological maps), it is possible a deposit of shallow alluvium or eroded rock may provide a water source for a potential GDE at this location.
Existing features with potential to impact the site:	The site is located 0.8 km from a track, there appears to be some cattle damage/bare ground surrounding the site. Human and cattle impact are likely.

ECOLOGY					
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.				
Ecological environment observations:	The dam is surrounded by Bibblewindi State Forest. *Eucalyptus creba* overlook the dam, and extend into the forest of *Callitris glaucophylla* further from the dam. The dam was completely dry at the time of visit (06/11/13). A pale crust formed on the dry mud at the lowest part of the dam.				
Observed plant species:	No aquatic plant species were present at the site.				
EPBC Species or community observed?	None observed.				
Observed site condition:	Excavation adjacent to the site (dammed). No evidence of pig rooting or stock trampling seen.				
Significance of the flora and fauna present:	No significant plant or animal species were present. A small herd of wild goats was seen nearby.				
Predicted ecological value of the aquifer and site:	This wetland has a low ecological value.				
Predicted sensitivity of the ecosystem:	This dam is an artificial environment and is not sensitive to disturbance.				
HYDROCHEMISTRY					
Water quality sample taken?	No.		**Santos sample reference:**	-	
Sample location and description:	Site was dry at the time of visit (06/11/13). No sample possible.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	-	-	-	-	-

FINAL CONCLUSIONS

- This site is a surface water dam and **not considered to be dependent on groundwater** because:
  - The site was dry at the time of visit and did not support any vegetation;
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

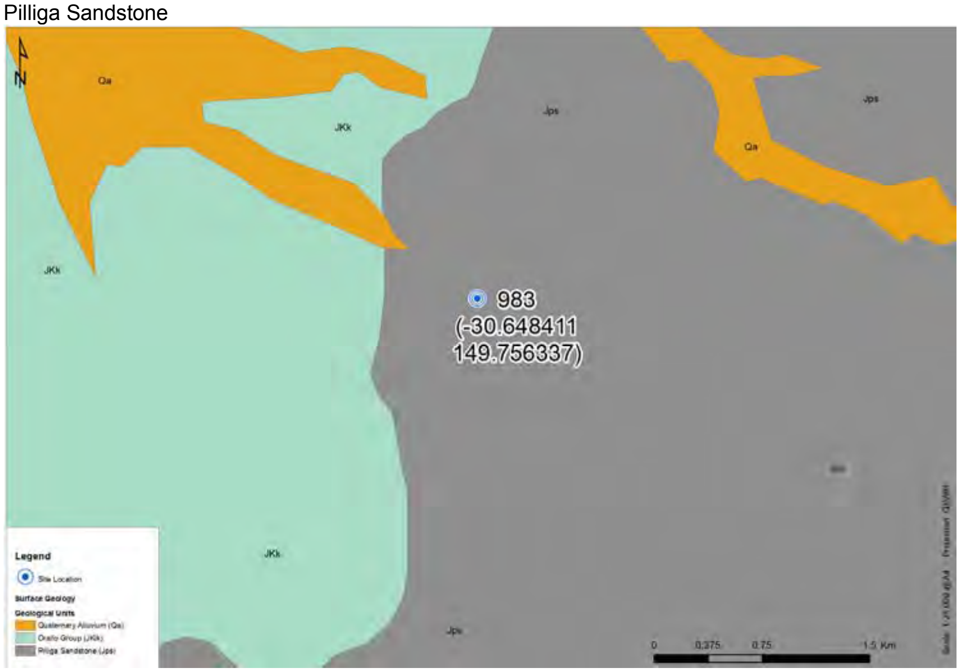
Photograph 1: Site 982 facing north. Crusted surface in the centre. Dammed banks on the western edge. Dense forest surrounding.

Photograph 2: Site 982 facing south. Desiccated surface in the centre. Pilliga Sandstone outcrop in the forefront.

Photograph 3: Pilliga Sandstone outcropping as a stepped edge on the north-western side of the site.

Photograph 4: Exposed sandstone in northern base of the site.

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		983		DATE OF SITE VISIT:	06/11/13
LATITUDE:	-30.648411	LONGITUDE:	149.756337	ELEVATION:	310 mAHD

CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; The Pilliga Forest Map (NSW NPWS 2008), Pilliga State Forest Map (Forestry Commission of NSW 1989), Baan Baa 1:50000 Topographic Map (Sheet Number 8836N)
Feature identifiers:	Water body shown on map as Yellow Spring Creek Dam, adjacent to Yellow Spring Creek (ephemeral). Apparent low turbidity suggests that there is potential for a groundwater connection.
GENERAL SITE CHARACTERISATION	
Site description:	The site is well signposted as Yellow Spring Dam. At the time of visit (06/11/13) the site comprised a dammed pool of water approximately 60 m by 10 m. The dam was excavated on a natural drainage channel, likely to be Yellow Spring Creek, the dry creek channel was clearly visible to the south of the dammed water. The water body had brown colouring but was relatively clear. Total depth of the pool was approximately 1.6 m at the time of sampling but the dam could likely hold another metre of water when full. The pool supports aquatic vegetation. Relatively flat, dense forest surrounds the dam. Behind the earth embankment to the north, a sandy channel was observed orientated roughly east-west for a short distance.
Surrounding land use:	The site is surrounded by Pilliga East State Forest
Hydrology:	Yellow Spring Creek (ephemeral) 0.50 km east and potentially connected to the site.
Catchment area:	0.16 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Pilliga Sandstone 
Solid geology from geological mapping:	Pilliga Sandstone (Late Jurassic – Cretaceous) – fluvial, medium to very coarse grained quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal.
Onsite geological observations:	No surface outcrops. Sandstone gravel in dammed banks. Sandy soil. Silt substrate at base of pool.
Initial hydrogeological assessment:	The site is located on the Pilliga Sandstone which is considered a significant transmissive unit within the region. The site was identified in part by a literature review which included assessment of place names (Yellow Spring Creek). From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring most likely sourced by the Pilliga Sandstone.
Existing features with potential to impact the site:	The site is located approximately 0.7 km north of minor road. The location of the site within state forest suggests that there are little existing pressures, though the feature may be a man-made dam.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** Cyperus conicus, Myriophyllum implicatum. **Other species**: Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum spp., Nymphoides crenata, Potamogeton crispus Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	At the time of visit (06/11/13) the site comprised a small dam surrounded by dense *Callytris* and Ironbark (*Eucalyptus creba)* woodland. The immediate shore was bare of vegetation. The shallow channel of Yellow Springs Creek, which contained no surface water, entered the dam from the south. Fallen and standing dead trees indicated that water covered much of the shallow channel for a distance of approximately 150 m upstream when the dam was full.
Observed plant species:	*Lomandra confertifolia* ssp *pallida*, Gahnia aspera,
EPBC Species or community observed?	None observed.
Observed site condition:	This wetland was created by the damming of Yellow Spring Creek.
Significance of the flora and fauna present:	This wetland contained 14 invertebrate taxa, which is relatively high for similar dams in the Pilliga. This high diversity may be due to the depth and consequent hydrological longevity of the dam. Two fish species, *Gambusia holbrookii* (exotic) and *Hypseleotris* sp. (native) were present.
Predicted ecological value of the aquifer and site:	The relatively high aquatic invertebrate diversity, the location of the dam on a dry creekline, and the depth of the dam suggest that this dam is of moderate ecological value to aquatic organisms in the Pilliga. The extent of fallen and standing dead timber and the density of surrounding trees make it potentially important for terrestrial fauna as well.
Predicted sensitivity of the ecosystem:	This ecosystems is unlikely to be sensitive to change. The dam is relatively deep and likely to persist between rainfall events.

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7557_WSURF_201311061355	
Sample location and description:	Latitude: -30.6338 Longitude: 149.7508 Brown colouration to water. Depth of water approx. 200 to 250 mm where sampled and up to 1.6 m towards the centre. A silty substrate to the pool was observed. Turbidity 32.5 NTU.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	8.54	262.1	5.93	70.8	29.9

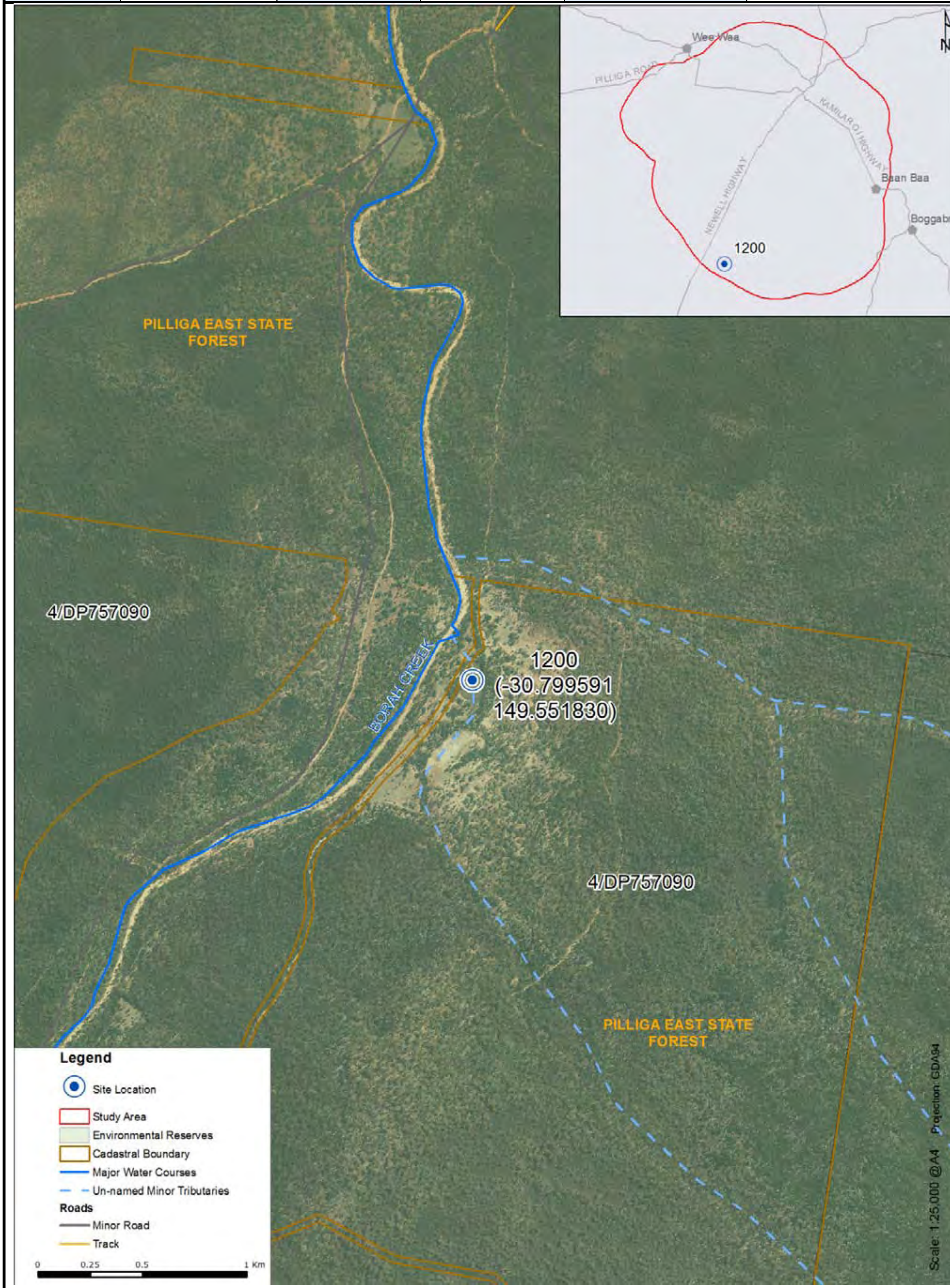
FINAL CONCLUSIONS

- This site is a surface water dam and is **not considered to be dependent on groundwater** because;
    - Surface water channel (Yellow Spring Creek) clearly visible leading into pool and beyond downstream dam embankment.
- **This site has moderate ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY	
FIELD RECONNAISSANCE PHOTOGRAPHS	
	
Photograph 1: 983 (Yellow Spring Dam) facing south. Dense forest surrounding the site. Dry creek channel visible to the south. Sample location proximal to the esky pictured.	Photograph 2: 983 (Yellow Spring Dam) facing north-east. Dammed banks surrounding the majority of the waterhole. Dense forest beyond site.
	
Photograph 3: 983 (Yellow Spring Dam) facing north.	Photograph 4: 983 (Yellow Spring Dam) facing south along the dry creek channel leading to the dam.

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		1200		DATE OF SITE VISIT:	23/10/13
LATITUDE:	-30.799591	LONGITUDE:	149.551830	ELEVATION:	307 mAHD



CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; Namoi Wetlands Assessment and Prioritisation Database
Feature identifiers:	Water body located next to Borah Creek (ephemeral) in an un-named tributary. Large body of water surrounded by dense bush vegetation. Water in wetland appears dark, suggesting support from groundwater.
GENERAL SITE CHARACTERISATION	
Site description:	The site is well signposted as Horseshoe Dam and is adjacent to the Yamborah historic area (also signposted). At the time of visit (23/10/13) the site comprised a dried surface water dam approximately 150 m by 50 m. Height of the embankments ranged between 1.5 m and 2.0 m. Embankments are absent from the south edge of the dam. A single patch of moist mud, approximately 8 m by 4 m, was present in the southern edge of the dam. An area of desiccated mud with two old small boats was present in the north portion of the dam footprint. Grassland and forest was present towards the south of the site.
Surrounding land use:	The site is surrounded by the Pilliga East State Forest and Pilliga Nature Reserve. The Yamborah historic area is adjacent to the site and comprises an old, ruined farm homestead with stockyards and fencing.
Hydrology:	Borah Creek (ephemeral) is located 0.24 km west of the feature. The site is located within the drainage line of an un-named minor tributary of Borah Creek.
Catchment area:	0.03 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Alluvium 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	No surface outcrops. Soil is clayey.
Initial hydrogeological assessment:	The site is located on the Quaternary Alluvium which is considered a significant transmissive unit within the region. The Pilliga Sandstone outcrops to the west of the site and is also considered a significant transmissive unit. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a spring potentially sourced by either the Quaternary Alluvium or the Pilliga Sandstone.
Existing features with potential to impact the site:	A minor road is present 0.5 km west of the site.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Eleocaris blakeana.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	At the time of visit (23/10/13) the site the dam was surrounded by forest of ironbark (*Eucalyptus crebra*) and cypress pine (*Callitris glaucophylla*). A shallow drainage line entered from the south. Wild pigs were present at the southern end of the dam.
Observed plant species:	*Juncus* sp., *Polygonum aviculare*
EPBC Species or community observed?	None observed.
Observed site condition:	The site was dry at the time of sampling (23/10/13). When full, the wetland would be a shallow, potentially well-vegetated basin. It is unlikely that groundwater contributes to the ecological health of the wetland.
Significance of the flora and fauna present:	No aquatic fauna were present. The dam was mostly bare ground. Continuous flocks of birds visited the moist area in the southern corner of the dam. When water is present the wetland is likely to be an important source of drinking water for terrestrial fauna.
Predicted ecological value of the aquifer and site:	This wetland is not a groundwater dependent ecosystem and has little value to the aquatic community of the Pilliga when dry.
Predicted sensitivity of the ecosystem:	This wetland is already modified and is unlikely to be sensitive to changes in the surrounding landscape.

HYDROCHEMISTRY					
Water quality sample taken?	No		**Santos sample reference:**	-	
Sample location and description:	Site dry at time of visit (23/10/13). No sample possible.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	-	-	-	-	-

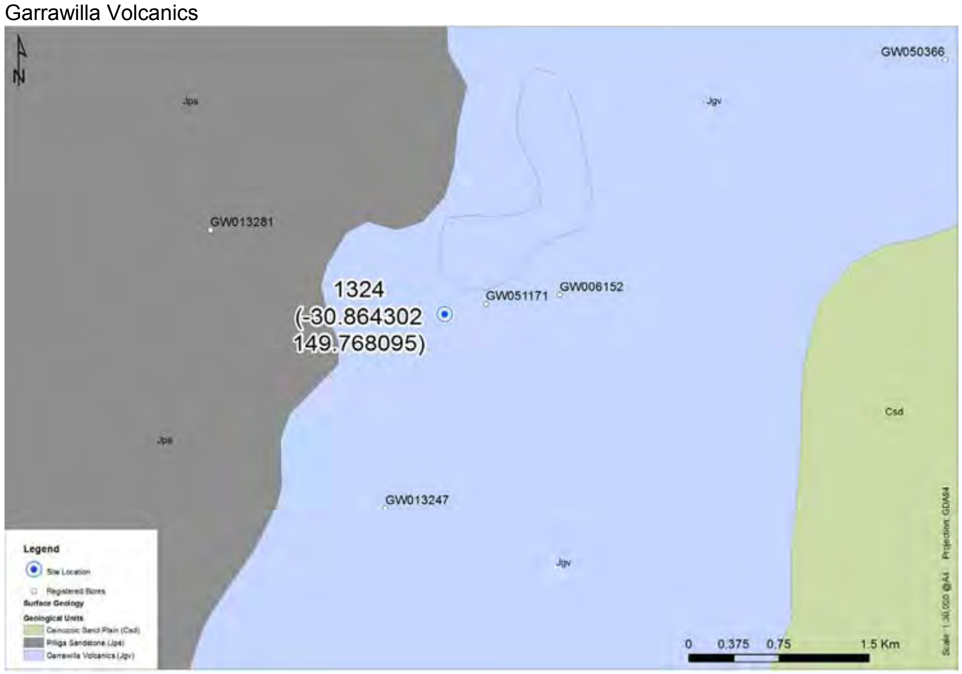
FINAL CONCLUSIONS

- This site is a surface water dam it is **not considered to be dependent on groundwater** because:
  - The site was dry at the time of visit and did not support any vegetation:
  - Areas of desiccated mud were observed where the last of the surface water had receded to; and
  - A clay soil was observed suggesting retention of surface water rather than input of groundwater.
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY	
FIELD RECONNAISSANCE PHOTOGRAPHS	
	
Photograph 1: Site 1200/Horseshoe Dam facing south. Desiccated ground in the foreground. Clayey soil. Sparsely vegetated in footprint of dam. Dense forest surrounds.	Photograph 2: Site 1200/Horseshoe Dam facing north. Site not dammed at southern edge. Grassed area towards the south brown and not healthy.
	
Photograph 3: Final moist area in the southern end of the dam. Soil was contained a large amount of clay.	Photograph 4: Signpost confirming name of site as Horseshoe Dam. Site located adjacent to Yamborah Historic Area.

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		1324		**DATE OF SITE VISIT:**	04/11/13
LATITUDE:	-30.864302	**LONGITUDE:**	149.768095	**ELEVATION:**	334 mAHD

CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; Namoi Wetlands Assessment and Prioritisation Database
Feature identifiers:	Water body on Bara Creek (ephemeral). Water looks fresh and potentially groundwater fed.
GENERAL SITE CHARACTERISATION	
Site description:	The site is a large curved surface water dam excavated on Barra Creek. The landholder notes the waterhole is a permanent feature as far as they are aware. At the time of visit (04/11/13) the waterhole was approximately 130 m by 40 m. Water marks suggest the water level to have been at least a metre higher previously and cover a larger area of the dam. The water was turbid. The dam was constructed with an embankment approximately 1.0 m to 1.5 m height on the eastern edge of the site. No other side of the waterhole appeared to have been excavated. A few dead trees were observed rooted within the dam. A grassed area was present in the western portion of the dammed area. The dry Barra Creek channel was present leading west from the waterhole and grassed area. The dam was surrounded by relatively dense forest. The dam is used for domestic use by an adjacent property, a pump was abstracting from the dam at the time of visit, located on the north-east edge of the dam.
Surrounding land use:	The surrounding land use comprises pasture and agricultural and state forest, namely, Pilliga Nature Reserve to the west and Kerringle State Forest to the east. There is a property located 300 m to the east of the site.
Hydrology:	Located on Bara Creek.
Catchment area:	29.70 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Garrawilla Volcanics 
Solid geology from geological mapping:	Garrawilla Volcanics (Late Triassic – Early Jurassic) – dolerite, basalt, trachyte, tuff and breccia.
Onsite geological observations:	No surface outcrops but some boulders of fine to medium grained sandstone on the dammed banks near the sample spot. Clayey soil next to the waters' edge. Predominantly sand on the dammed banks.
Initial hydrogeological assessment:	The site is located on an outcrop of Garrawilla Volcanics which is considered to be a less significant transmissive unit in the region. The Pilliga Sandstone, considered a significant transmissive unit, outcrops to the west of the site and is the most likely source of groundwater to a potential GDE in this location. Un-named tributaries of Bara Creek appear to originate from the Pilliga Sandstone. There are five registered bores located within 3 km of the site, the source of the bores is unconfirmed. Reported water levels of the registered bores range between 315.8 and 297.5 m AHD. Surface elevation at the site is 334 m. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by water table spring sourced by Pilliga.
Existing features with potential to impact the site:	There is one bore reported as used for stock and domestic purposes close to the site (0.2 km). The source and abstraction rate of the bore is unknown. It is highly likely the site will be impacted by agricultural, cattle grazing and human activities.

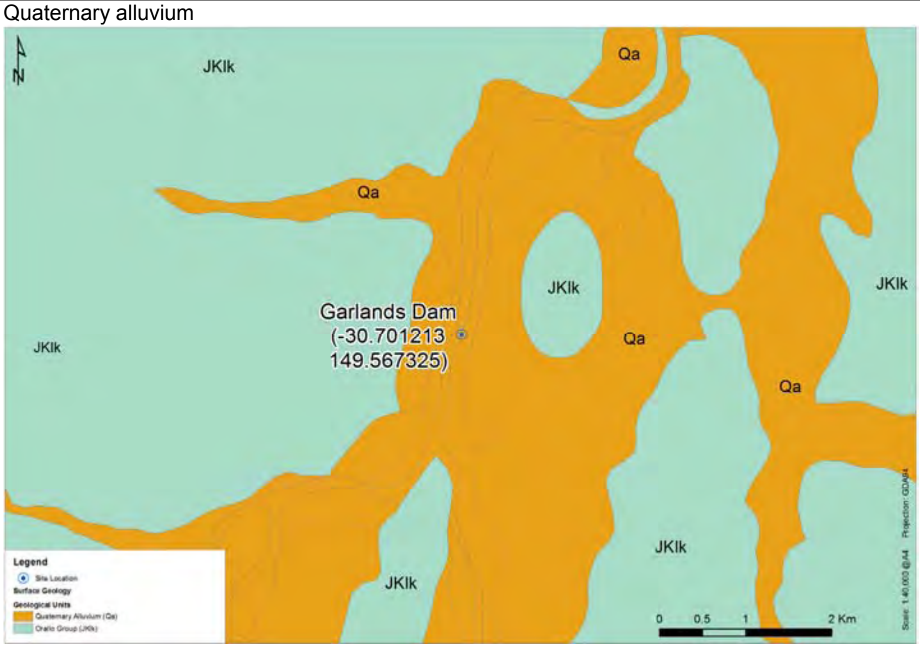
ECOLOGY					
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** *Cyperus conicus, Myriophyllum implicatum.* **Other species***:* *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present				
Ecological environment observations:	At the time of visit (04/11/13) the water was turbid with no signs of submerged aquatic vegetation. The banks surrounding the water were bare up to the high water mark. Beyond the high water mark medium density woodland of white cyperus (*Callitris glaucophylla*) and *Eucalyptus* spp were present. Several large, dead trees stood in the water and further along the channel between the observed and maximum water level.				
Observed plant species:	*Juncus* sp., *Schoenoplectus mucronatus*				
EPBC Species or community observed?	None observed.				
Observed site condition:	Excavation damage adjacent to the site (dammed). Evidence of pig rooting and stock trampling. Landholder said pigs are a problem at the property. Dam is adjacent to farm house and sheds. Pump was extracting water from the dam at time of sampling.				
Significance of the flora and fauna present:	None of the species observed at this site were of conservation significance.				
Predicted ecological value of the aquifer and site:	This wetland is unlikely to be fed by groundwater. This wetland holds a relatively large volume of water, so plays an important role as a refuge for aquatic species. Fifteen invertebrate taxa were collected during sampling, including yabbies and four microcrustacean taxa. No fish were observed here, but the dam is likely to contain carp (*Cyprinus carpio*) and mosquitofish (*Gambusia holbrooki*).				
Predicted sensitivity of the ecosystem:	This wetland is fed by surface water runoff so is likely to be most sensitive to changes that influence the hydrology and water chemistry of Bara Creek. The dam will be fairly tolerant of changes to groundwater levels and inputs.				
HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7563_WSURF_201311041640	
Sample location and description:	Latitude: -30.8503 Longitude: 149.7668 Sample was collected towards the centre of the northern edge of the waterhole. Water was brown and turbid. Sample was not field filtered. Water approx. 150 mm depth at sample point.				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	9.44	70.4	9.42	71.4	26.1

FINAL CONCLUSIONS

- This site is a surface water dam and is **not considered to be dependent on groundwater** because;
    - The site is constructed on Bara Creek;
    - The water was turbid and had receded from the banks; and
    - A clay soil observed on the dam banks suggest surface water retention rather than groundwater input.
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY	
FIELD RECONNAISSANCE PHOTOGRAPHS	
	
Photograph 1: Site 1324 facing west. Turbid brown water indicates it is not fresh. Pig rooting and stock trampling evidenced at the edge of the waterhole. Dense forest surrounds. Property located approx. 60 m towards the north-east. Property abstracts from the waterhole for domestic use.	Photograph 2: Site 1324 facing south. Sample location.
	
Photograph 3: Site 1324 facing north-east. Water shallows and dries up towards the west of the site.	Photograph 4: Pump operated by landholder for domestic use. Located at the north-eastern edge of the waterhole. Pump operational at the time of visit.

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Garlands Dam		**DATE OF SITE VISIT:**	05/11/13
LATITUDE:	-30.701213	**LONGITUDE:**	149.567325	**ELEVATION:**	279 mAHD

CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50000 Topographic Map (Sheet Number 8836N)
Feature identifiers:	Feature located on Bohena Creek
GENERAL SITE CHARACTERISATION	
Site description:	The site is a surface water dam signposted as Garlands Dam. The dam is located off the channel of Bohena Creek. The dam is approximately 15 m by 20 m with sloped embankments of up to 2 m in height on all sides. At the time of visit (05/11/13), the water was turbid. Dried surface water run-off channels were observed on the southern edge of the dam.
Surrounding land use:	The site is surrounded by the Pilliga Nature Reserve. Surrounding topography is relatively flat. Bohena Creek (dry at time of visit) lies approximately 100 m to the west of the site.
Hydrology:	Located along Bohena Creek approximately 1.0 km before tributary of Borah Creek and Sandy Creek
Catchment area:	0.30 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary alluvium 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	No surface outcrops. Sandy soil. Gravel sized fragments of fine to medium grained sandstone in the dammed banks.
Initial hydrogeological assessment:	The site is located on the Quaternary Alluvium which is considered a significant transmissive unit within the region. There are no registered bores close to the site. From initial desktop assessment the site was classified as a potential base flow stream supported by a water table spring (watercourse spring) sourced by the Quaternary Alluvium.
Existing features with potential to impact the site:	No registered bores were identified close to the site, suggesting there is likely to be no impact from groundwater abstraction. The site is located close to a track, there may be some impacts from wild pigs and kangaroos.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	At the time of visit (05/11/13) the small dam was surrounded at a distance by Narrow leaved ironbark (*Eucalyptus crebra*), then further back by the Pilliga East State Forest.
Observed plant species:	*Cyperus vaginatus*, *Gahnia aspera, Juncus* sp., *Lomandra confertifolia* ssp *pallida,* and the algae Characeae.
EPBC Species or community observed?	No EPBC listed species or communities were observed. One Turquoise Parrot (*Neophema pulchella*), a species listed as Vulnerable under NSW Threatened Species Conservation Act 1995, was seen drinking from the dam.
Observed site condition:	The dam is an excavated hole surrounded by raised embankments. No evidence of pig rooting or stock trampling observed.
Significance of the flora and fauna present:	None of the aquatic species present are of conservation significance. One Turquoise Parrot (*Neophema pulchella*), a species listed as Vulnerable under NSW Threatened Species Conservation Act 1995, was seen drinking from the dam.
Predicted ecological value of the aquifer and site:	As an aquatic ecosystem, this dam has little ecological value. Two species of fish, *Gambusia holbrooki* and *Hypseleotris* sp., both common in dams throughout the Pilliga, were present in this dam. Nine invertebrate families occurred in the dam, all of which were common and tolerant of change and disturbance. The wetlands main ecological significance is as a source of drinking water for terrestrial animals.
Predicted sensitivity of the ecosystem:	This dam is fed by runoff, so is sensitive to factors that will influence drainage of the landscape from further upstream.

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7507_WSURF_201311051345	
Sample location and description:	Latitude: -30.9617 Longitude: 149.5668 Sample taken on the southern edge of the waterhole. Brown, turbid water. Sample not field filtered. Water at sample point approx. 200 mm depth. Turbidity: 139 NTU Alkalinity: 58 mEq/L				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	7.7	210.8	2.94	67.6	26.7

FINAL CONCLUSIONS

- This site is a surface water dam it is **not considered to be dependent on groundwater** because:
    - The water was turbid and receded from the banks at the time of visit; and
    - Dried surface water inflow channels were observed at the edge of the dam;
- **One NSW Threatened Species Conservation Act 1995 vulnerable bird species (***Neophema pulchella***) was observed at the site;**
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

	
Photograph 1: Garlands Dam facing north. Surface water run-off channel leading to dam.	Photograph 2: Garlands Dam facing west.
	
Photograph 3: Close up of surface water run-off channels on the southern edge of dam.	Photograph 4: Signposted Garlands Dam upon approach.

CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Ten Mile Dam		DATE OF SITE VISIT:	21/10/13
LATITUDE:	-30.458059	LONGITUDE:	149.726531	ELEVATION:	249 mAHD

<table>
<tr><th colspan="2">CHARACTERISATION SUMMARY</th></tr>
<tr><th colspan="2">INITIAL IDENTIFICATION OF SITE</th></tr>
<tr><td>Data source(s):</td><td>Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; The Pilliga Forest Map (NSW NPWS,2008) Pilliga State Forest Map (Forestry Commission of NSW, 1989) Baan Baa 1:50 000 Topographic Map (Sheet Number 8836N)</td></tr>
<tr><td>Feature identifiers:</td><td>Small water body, disconnected from drainage system. Dark water – fresh? Vegetation surrounds feature.</td></tr>
<tr><th colspan="2">GENERAL SITE CHARACTERISATION</th></tr>
<tr><td>Site description:</td><td>Ten Mile Dam is a surface water dam, approximately 44 m by 24 m. Water depth is up to approximately 1 m. The dam is rectangular in shape (excavated) and surrounded by raised levee banks. The dam embankments are sloped but up to 2 m in height. At the time of visit (21/1013) there was evidence of surface run-off channels leading to pool on the south east edge of the dam (Photograph 3). The banks were mostly bare of vegetation, trees and grasses surrounded the dam further back (Callitris glaucophylla, Eucalyptus crebra). The dam is signposted with an access track and picnic bench is adjacent.</td></tr>
<tr><td>Surrounding land use:</td><td>Ten Mile Dam is located within Jacks Creek State Forest, the site is not very remote, several homesteads are close by.</td></tr>
<tr><td>Hydrology:</td><td>Jacks Creek is 2.8 km east and Bohena Creek 4.8 km west. No major creeks recognised close to feature.</td></tr>
<tr><td>Catchment area:</td><td>99.90 ha</td></tr>
<tr><th colspan="2">GEOLOGY AND HYDROGEOLOGY</th></tr>
<tr><td>Surface geology from geological mapping:</td><td>Quaternary Colluvium

</td></tr>
<tr><td>Solid geology from geological mapping:</td><td>Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate</td></tr>
<tr><td>Onsite geological observations:</td><td>No surface outcrops. Sandy soil surrounding dam. Sandstone gravel in the dammed sides.</td></tr>
<tr><td>Initial hydrogeological assessment:</td><td>The site is underlain by Quaternary Colluvium, which typically has a high clay content and is therefore unlikely to be a source of groundwater for a potential GDE at this location. The interface between the Quaternary Colluvium and the Cainozoic Sand Plain deposits is proximal to the site location. The Cainozoic Sand plain deposits is considered a significant transmissive unit and the mostly likely source of groundwater to a potential GDE at the location of the site. There are 12 registered bores located within a 5 km radius of the site, the source of the bores is unknown but considered likely to be either the Cainozoic Sand Plain deposits or the Quaternary Alluvium.

From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced by the Cainozoic Sand Plains or Quaternary Alluvium.</td></tr>
<tr><td>Existing features with potential to impact the site:</td><td>There are 12 registered bores located within a 5 km radius of the site, abstraction from which may have an impact to a potential GDE at this location. The site is not remote, access tracks, nearby homesteads and picnic facilities suggest the site is often frequented.</td></tr>
</table>

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** *Cyperus conicus.* **Other species***: Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton* sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations:	This wetland is a rectangular dam, scraped into the ground and surrounded by earth embankments. The dam was surrounded by forest of white cypress pine (*Callitris glaucophylla*) and narrow-leaved ironbark (*Eucalyptus crebra*). Ground around the dam was bare, although when full the water may reach the base of ironbark saplings growing on the embankment.
Observed plant species:	*Cyperus eragrostis, Gratiola pedunculata, Eleocaris plana, Cyperus betchei, Typha orientalis,* Characeae (algae)
EPBC Species or community observed?	None observed.
Observed site condition:	This wetland is in poor condition, with little structure or habitat diversity in the water. Water had low electrical conductivity, high pH, and was turbid. There were 11 aquatic invertebrate taxa present, and two of these (Arrenuridae mites, Leptoceridae mayfly nymphs) are sensitive taxa usually found only in relatively undisturbed environments. One species of native (*Hypseleotris* sp.), and one species of pest (*Gambusia holbrookii*) fish were present. Evidence of pig rooting and some stock trampling at the waters' edge and back beyond the dam. Dam is beside a road and is surrounded by bare ground.
Significance of the flora and fauna present:	None of the plant or animal species present were of any conservation significance.
Predicted ecological value of the aquifer and site:	Like similar dams throughout the Pilliga, Ten Mile Dam is of little ecological significance for the aquatic community, apart from its role as an island of water surrounded by an otherwise dry landscape. Likewise, the dam is a source of drinking water for terrestrial fauna
Predicted sensitivity of the ecosystem:	Ten Mile Dam is already a degraded aquatic ecosystem. Although the dam contains a few invertebrate taxa that are sensitive to disturbance, it is unlikely that the ecosystem as a whole is sensitive.

HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7561_WSURF_201310211440	
Sample location and description:	Latitude: -30.4526 Longitude: 149.5558 Water sampled on south west edge of dam. Brown colour to the water, turbid. Water depth approximately 150 mm at sample location.				
Physiochemical characteristics:	**pH**	**EC (μs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (°C)**
	8.54	146.8	6.14	35.5	25.2

FINAL CONCLUSIONS

- This site is a surface water dam and is **not considered to be dependent on groundwater because:**
  - The water level is receding;
  - The water observed is turbid with no evidence of fresh input; and
  - There is evidence of dried surface run-off channels;
- **This site has low ecological value;**
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY

FIELD RECONNAISSANCE PHOTOGRAPHS

Photograph 1: Ten Mile Dam facing west. Note the rectangular shape and dammed sides of the pool indicating it was excavated.

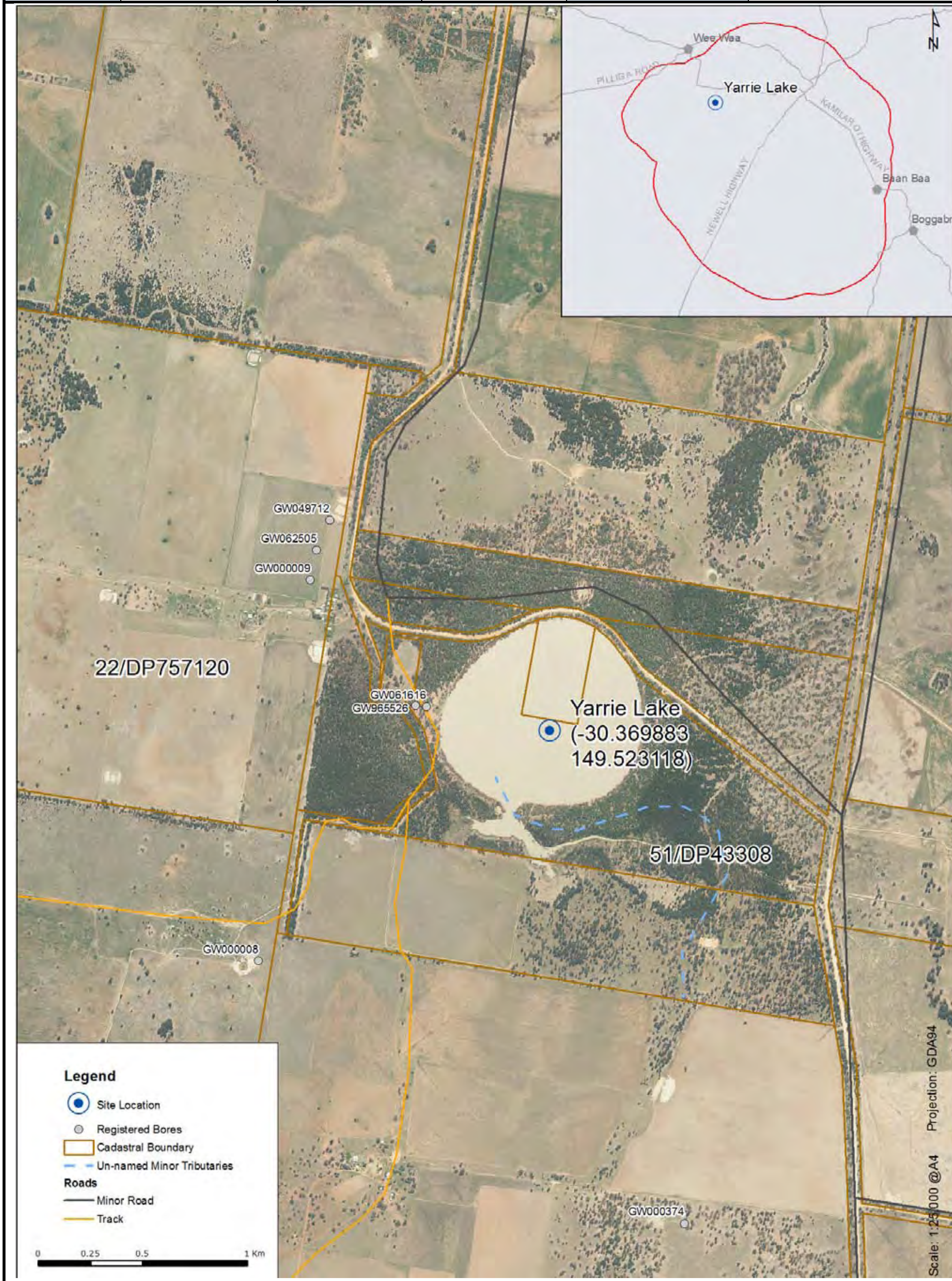
Photograph 2: Sample location, facing east. Note brown colour to water.

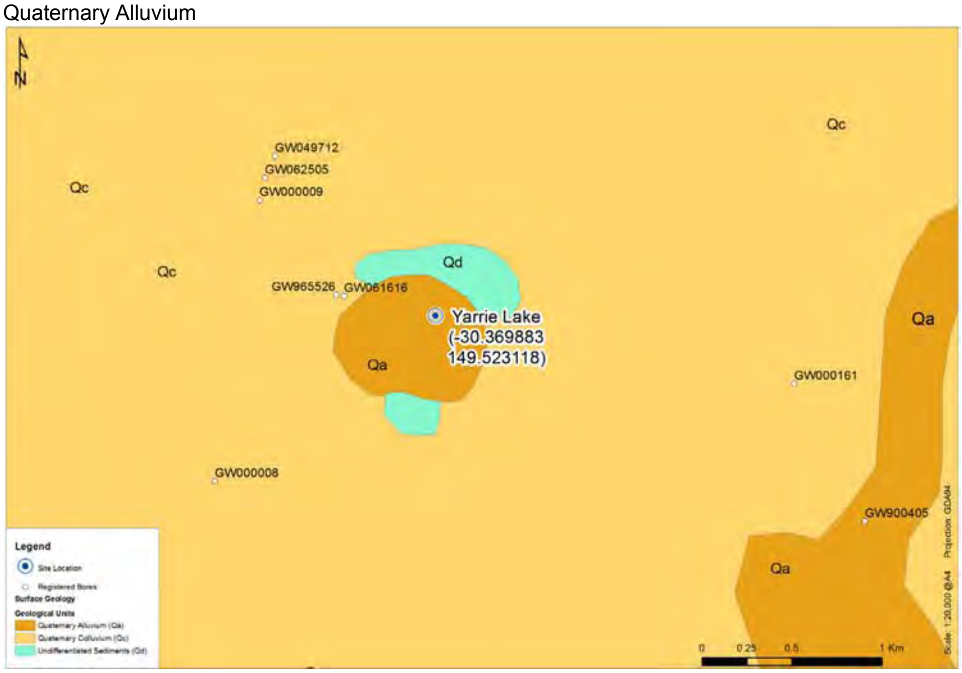
Photograph 3: Dammed bank of the waterhole. Sand covering. Evidence of a dried surface water run-off channel leading to the dam.

Photograph 3: Dammed bank of the waterhole. Sand and dead vegetation covering.

CHARACTERISATION SUMMARY

REFERENCE NUMBER/NAME:		Yarrie Lake		**DATE OF SITE VISIT:**	05/11/13
LATITUDE:	-30.369883	**LONGITUDE:**	149.523118	**ELEVATION:**	213 mAHD



CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Namoi State of the Catchment Report - Wetlands; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; Eco Logical Australia Remote Sensing
Feature identifiers:	Large, circular water body used for recreational purposes. Potential groundwater dependency at location as identified by dense vegetation and drainage to south of water body.
GENERAL SITE CHARACTERISATION	
Site description:	Yarrie Lake is a large, relatively shallow (likely less than 2 m), circular lake with an inlet channel to the south. Yarrie Lake is publically accessible and used for recreational activities, tracks lead all the way around the lake and along the inlet channel. At the time of visit (05/11/13) the lake water was turbid with a high concentration of fine pale particles. At the time of visit, the inlet channel to the south of the lake contained water for a distance of approx. 650 m from the lake mouth. The inlet channel was shallow, up to approx. 0.3 m depth across the width of the channel, which was approximately 2.5 m wide but opened up close to the mouth of the lake. Close to the lake mouth there was limited vegetation along the inlet channel banks which were flat and approximately 8 m wide on the north edge. Further east there were areas of dense reeds up to 3 m height with steep banks. The inlet channel dried to contain isolated puddles approximately 600 m from the lake mouth and was completely dry approximately 650 m from the lake mouth at time of visit (05/11/13). Yarrie Lake was known to be dry in September 2007.
Surrounding land use:	The lake is surrounded by sparse forest in the immediate vicinity then by a predominantly agricultural landscape.
Hydrology:	Bundock Creek (intermittent) is located 4 km to the east of the site. A minor ephemeral creek to the south flows into Yarrie Lake but has no apparent connection to a major drainage.
Catchment area:	0.02 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Alluvium 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Onsite geological observations:	No surface outcrops. Sandy soil on track and adjacent to the lake mouth. Clay soil along the inlet creek towards the east.
Initial hydrogeological assessment:	Yarrie Lake is underlain by Quaternary Alluvium which is considered a significant transmissive unit within the region. There are 14 bores located within a 5 km radius of the lake. Reported groundwater levels of the eight closest registered bores (within 3 km) range between 175.7 and 200.2 mAHD. Ground elevation of Yarrie Lake is 213 mAHD which suggests there is no hydraulic connection between the bores and the site. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced by Quaternary Alluvium.
Existing features with potential to impact the site:	The 14 bores located within a 5 km radius of the site are primarily used for stock and domestic purpose, abstraction from the bores could have an impact from a potential GDE in this location. Other existing features that may impact the lake include nearby agricultural and grazing land, and the use of the lake for recreational activities including the use of boats and jet skis. Yarrie Lake is assessed as exhibiting very low hydrological disturbance but high catchment and habitat disturbance in the Namoi State of Catchment report.

ECOLOGY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** Cyperus conicus. **Other species:** Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum spp., Nymphoides crenata, Potamogeton sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct.
Ecological environment observations:	The lake shore is surrounded by a sparse forest of river red gum (*Eucalyptus camaldulensis*) and dirty gum (*Eucalyptus chloroclada*). Habitat complexity in the lake appears low, with the shallow depth and no visible structure. A channel entering the lake from the south, while shallow, has occasional dead, standing trees and fallen branches near the lake confluence, and dense stands of Broadleaf Cumbungi (*Typha orientalis*) along the channel edge. Duckweed (*Azola* sp.) covers large sections of the water surface in the channel, but apart from where it has been stranded on the shore, appeared absent from the lake. Water is extremely turbid (469 NTU), which has prevented sunlight penetration and kept the temperature low (12ºC). The low temperature and freshness of the water (184.1 µS/cm) make it unlikely that groundwater makes a significant contribution to the hydrology of the lake).
Observed plant species:	Duck weed (*Azola* sp.) is spread along the length of the creek. *Typha orientalis, Cyperus gunnii, Persicaria decipiens, Cyperus exaltatus, Ludwigia peploides* subsp. *Montevidensis*
EPBC Species or community observed?	None observed.
Observed site condition:	The lake is a natural water body and is a relatively unique round, shallow lake. The ecological productivity of the lake is hampered by its high turbidity, which prevents algal production and other forms of submerged aquatic photosynthesis. Seven aquatic invertebrate taxa were collected during sampling, none of which are sensitive to changes.
Significance of the flora and fauna present:	None of the plants or animals at the site are significant
Predicted ecological value of the aquifer and site:	The lake is an important feature of the landscape. It is a large, natural lake with a unique hydrology. The high turbidity of the water keeps aquatic primary production low, which probably means that the lake has a very truncated food web. The lake and surrounding woodland is an important feeding area for birds.
Predicted sensitivity of the ecosystem:	Yarrie Lake occasionally goes dry, so the ecological community is likely to be robust and have strategies that make them resilient to change.

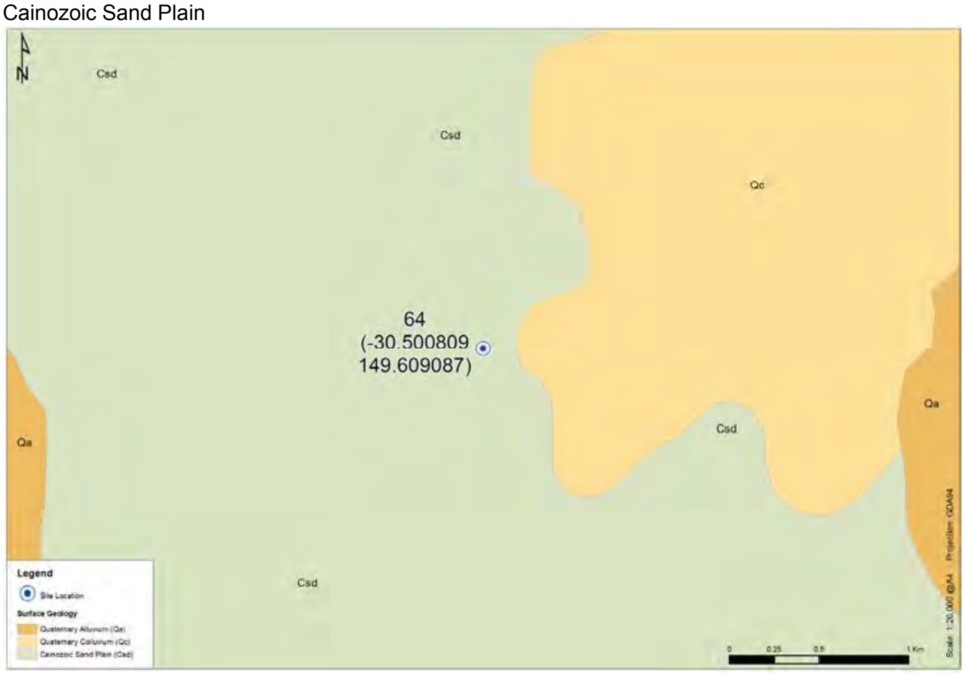
HYDROCHEMISTRY					
Water quality sample taken?	Yes		**Santos sample reference:**	7550_WSURF_201311050730	
Sample location and description:	Latitude: -30.3686 Longitude: 149.5168 Sample taken on the northern edge of the creek approx. 80 m from the mouth of the lake. Water was light brown and turbid. Sample was not field-filtered because of high turbidity. Azola present surrounding the sample point. Water depth approx. 100 mm at sample location. Turbidity 469 NTU. Alkalinity 86				
Physiochemical characteristics:	**pH**	**EC (µs/cm)**	**DO (mg/l)**	**ORP (mV)**	**Temp (ºC)**
	8.31	184.1	8.67	64.2	12.0

FINAL CONCLUSIONS

- This site is a natural lake **not considered to be dependent on groundwater** because:
  - The high turbidity of the lake suggesting little fresh groundwater input; and
  - Anecdotal evidence suggesting the lake goes dry.
- This site is an important ecological feature for bird life;
- **No species of environmental importance were identified at the site;** and
- **No Matters of National Environmental Significance were identified at the site.**

GROUND TRUTHING SUMMARY	
FIELD RECONNAISSANCE PHOTOGRAPHS	
	
Photograph 1: Facing west towards the mouth of the lake. Sandy soil with Azola stranded on the flat banks.	Photograph 2: Sample point, facing west towards the mouth of the lake. Azola present on the northern bank where sample was collected. Soil was clayey at sample point. Sandy non-vegetated soil on the southern bank.
	
Photograph 3: Approximately 135 m east from the mouth of the lake. Inlet channel splits and narrows. Both banks become vegetated. Banks are still flat.	Photograph 4: Approximately 630 m from the mouth of the lake and facing west. Reeds present on both sides of the channel up to 3 m in height. Northern bank narrows and becomes steeper. Channel still full but dries to isolated pools and then completely approximately 20 m further east away from the lake.

PRELIMINARY CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		64	DATE OF SITE VISIT:		NOT VISITED
LATITUDE:	-30.500809	LONGITUDE:	149.609087	ELEVATION:	248 mAHD

PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Ecological Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Round feature comprising aquatic vegetation with pools of low-turbidity water, disconnected from existing drainage.
GENERAL SITE CHARACTERISATION	
Site description from desk study:	High resolution aerial imagery show the site to comprise a rectangular dam of water similar in colour to the surrounding earth. The dam is located in the south eastern corner of an apparent depression that is circular. There is an area of bare ground to north east of the dam, surrounded immediately by grassland and forest. Stock trails lead to the water.
Surrounding land use from aerial photography:	Feature is located within grazing modified pastures and bordered to the west and south by the Pilliga East State Forest
Hydrology from aerial photography:	Bundock Creek (likely intermittent) located 2.7 km west and Bohena Creek (intermittent) located 3.6 km east
Catchment Area:	0.03 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Cainozoic Sand Plain 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey and quartzose sandstone, subordinate siltstone and conglomerate
Desk top hydrogeological assessment:	The Cainozoic Sand Plain deposits is considered a significant transmissive unit in the region and is present at the site location. Should a GDE be present at this location it would most likely be sourced by the Cainozoic Sand Plain deposits. There are no registered bores located within 3 km of the site. From initial desktop assessment this site was classified as a potential groundwater dependent wetland supported by a water table spring, sourced by the Cainozoic sand plain deposits. Further assessment using high resolution photography identified the site to more likely be a man-made surface water dam that is unlikely to be fed by groundwater.
Existing features with potential to impact the site:	N/A Site is no longer considered to be sourced by groundwater.

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	The site is shown to be a rectangular dam of turbid water. The dam occurs in south-eastern corner of an apparent depression that is circular. No visible fringing vegetation in or close to the water. Area of bare ground to north of the dam, surrounded immediately by grassland and forest. Stock trails leading to water.
Matters of National Environmental Significance present?	From assessment of high resolution aerial photography, no species or communities listed under the EPBC Act or NSW Threatened Species Act are considered likely to occur at this site because the habitat is unsuitable and appears to be disturbed by excavation. There is no fringing vegetation to provide habitat for the Australasian Bittern or Painted Snipe identified in the aerial photography. None of the threatened species listed under the EPBC Act for this area are wetland dependent.
Site condition:	Site appears to be excavated and shaped to hold water for stock or water supply.
Significance of the flora and fauna present:	None of the threatened species listed above are likely to occur at this site because of the significant amount of disturbance that has occurred.
Predicted ecological value of the site:	This site is in poor ecological condition as a wetland.
Predicted sensitivity of the ecosystem:	The dam appears to be man-made, the environment is therefore already highly disturbed and not sensitive to change.

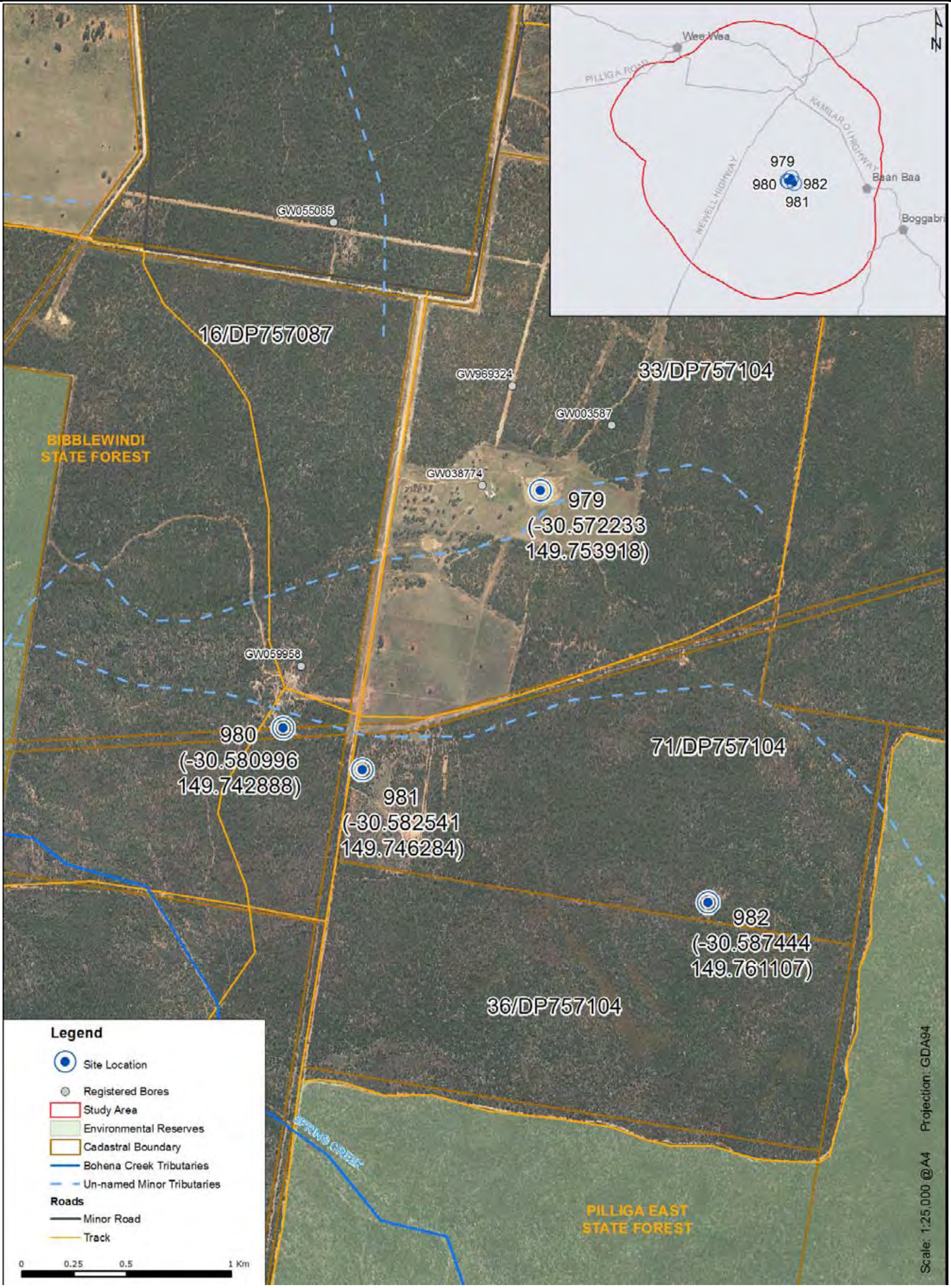
FINAL CONCLUSIONS

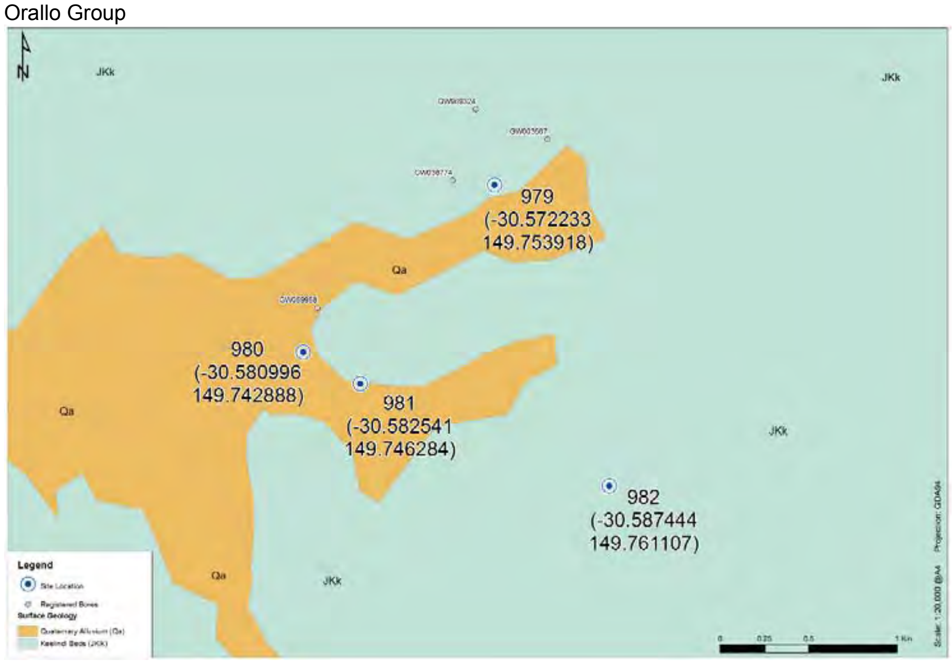
- This site is **not considered to be dependent on groundwater** because:
  - Aerial photography suggests the site to be a man-made dam sourced by surface water; and
  - Aerial photography shows the water to be turbid suggesting a lack of fresh groundwater input.

- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography suggest the habitat has been highly modified (dammed);
  - There is no fringing vegetation to provide habitat for the Australasian Bittern or Painted Snipe identified in the aerial photography;
  - Aerial photography suggest the site to be in poor ecological condition; and
  - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

PRELIMINARY CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		979	**DATE OF SITE VISIT:**		**NOT VISITED**
LATITUDE:	-30.572233	**LONGITUDE:**	149.753918	**ELEVATION:**	295 mAHD



PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment
Feature identifiers:	Large constructed farm dam on drainage line
GENERAL SITE CHARACTERISATION	
Site description from desk study:	High resolution aerial photography show the site to comprise a large dammed area of a drainage line. Large embankments are present along the southern and western edges of the site. The water in the dam is turbid, of a similar colour to the surrounding earth. Stock access trails to waterbody are visible. The land surrounding the dam has been cleared.
Surrounding land use from aerial photography:	The land surrounding the site is cleared grassland. Bibblewindi State Forest and Pilliga East State Forest are located to the west and south of the site respectively.
Hydrology from aerial photography:	Spring Creek (ephemeral) is located 2.3 km to the southwest of the site. An un-named ephemeral creek is located 0.1 km directly south.
Catchment Area:	93.60 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Orallo Group 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Desk top hydrogeological assessment:	The site is located close to the boundary of the Orallo Group and the Quaternary Alluvium. The Orallo Group is considered a negligible transmissive unit in the region. The Quaternary Alluvium is considered a significant transmissive unit. The Quaternary Alluvium is considered the most likely source of a potential GDE in this location. There are eight registered bores located within a 1.7 km radius of the site. A hydraulic connection between the site and the bores could not be proven due to a lack of information. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced from the Quaternary Alluvium. Further assessment using high resolution photography identified the site to more likely be a man-made surface water dam that is unlikely to be fed by groundwater.
Existing features with potential to impact the site:	N/A Site is no longer considered to be sourced by groundwater.

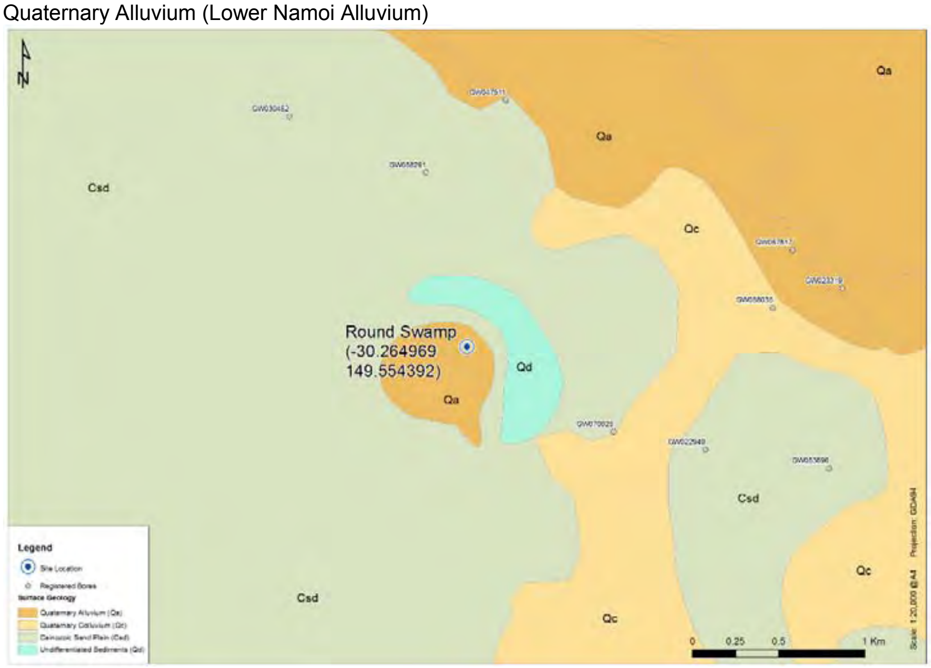
ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species:** *Cyperus conicus, Myriophyllum implicatum*. **Other species:** *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus* Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	Large embankments present along the southern and western edges to create damming of a drainage line. Stock access trails to waterbody. Green tinge in northwestern end of dam in 2010 may be wetland vegetation, but this is absent in 2014. In 2014 there is a fringe of vegetation around part of the dam between water and embankment.
Matters of National Environmental Significance present?	From assessment of high resolution aerial photography, no species or communities listed under the EPBC Act or NSW Threatened Species Act are considered likely to occur at this site because the habitat is unsuitable given the high level of disturbance in the surrounding area. There is no fringing vegetation suitable to provide habitat for the Australasian Bittern or Painted Snipe identified in the aerial photography. None of the threatened species listed under the EPBC Act for this area are wetland dependent.
Site condition:	Poor water quality apparent from cattle access and catchment clearing. No vegetation around dam to provide habitat.
Significance of the flora and fauna present:	Fringing flora likely to be hardy, common species tolerant of disturbed conditions. These are unlikely to be threatened species. None likely, given the high level of disturbance in the surrounding area. No fringing vegetation to provide habitat for Australasian Bittern or Painted Snipe.
Predicted ecological value of the site:	This site is in poor ecological condition as a wetland. This dam is unlikely to be connected to groundwater; it is in a drainage line and is filled by runoff.
Predicted sensitivity of the ecosystem:	The dam appears to be a man-made feature constructed around a drainage line, the environment is therefore already highly disturbed and not sensitive to change.

FINAL CONCLUSIONS

- This site is **not considered to be dependent on groundwater** because:
  - Aerial photography suggests the site to be a man-made damming of a natural drainage line most likely sourced by surface run-off; and
  - Aerial photography shows the water to be turbid suggesting a lack of fresh groundwater input.
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
  - Aerial photography suggest the habitat has been highly modified (dammed);
  - Aerial photography show that there is no fringing vegetation to provide habitat for threatened bird species; and
  - Aerial photography suggests the site to be in poor ecological condition;
  - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent.

HIGH RESOLUTION PHOTOGRAPHY

PRELIMINARY CHARACTERISATION SUMMARY					
REFERENCE NUMBER/NAME:		Round Swamp		DATE OF SITE VISIT:	NOT VISITED
LATITUDE:	-30.264969	LONGITUDE:	149.554392	ELEVATION:	197 mAHD

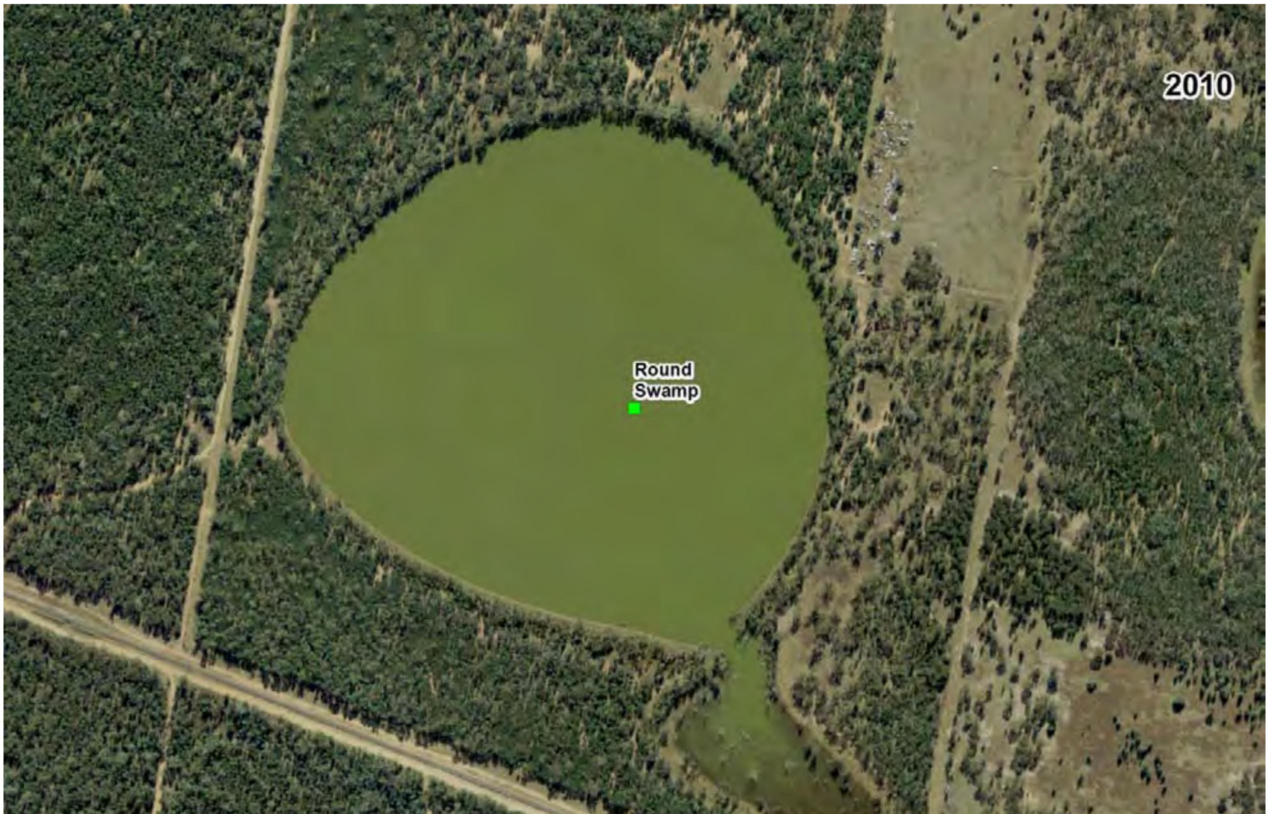
PRELIMINARY CHARACTERISATION SUMMARY	
INITIAL IDENTIFICATION OF SITE	
Data source(s):	Eco Logical Australia Remote Sensing; SKM Report - Mapping Groundwater Dependent Ecosystems in the Namoi Catchment; the Namoi State of Catchment report – Wetlands.
Feature identifiers:	Large body of water surrounded by vegetation. Appears to be disconnected from drainage system.
GENERAL SITE CHARACTERISATION	
Site description from desk study:	Round Swamp is classified as an inland freshwater lake in the Namoi State of Catchment report – Wetlands. From aerial photographs Round Swamp is shown to be a large circular body of water with a channel (unconfirmed if an inlet or outlet channel) in the south east of the site. The water in aerial imagery appears to be turbid. The site is surrounded by low lying topography dominated by vegetation and agricultural land.
Surrounding land use from aerial photography:	Agricultural land and pasture surround the site. Culgoora State Forest is located to the south and south west of the site.
Hydrology from aerial photography:	Bundock Creek is located 3.2 km south-west. An un-named minor tributary of Bundock Creek is located 2.6 km north-east.
Catchment Area:	0.03 ha
GEOLOGY AND HYDROGEOLOGY	
Surface geology from geological mapping:	Quaternary Alluvium (Lower Namoi Alluvium) 
Solid geology from geological mapping:	Orallo Group (Cretaceous) – clayey to quartzose sandstone, subordinate siltstone and conglomerate
Desk top hydrogeological assessment:	The site is underlain by the Lower Namoi Alluvium which is present in the footprint of the swamp. The Lower Namoi Alluvium comprises the Cubbaroo Formation, present at the site, which is considered a significant transmissive unit in the area. There are eight registered bores located within a 4 km radius of the site. The source of the bores is unknown but assumed likely to target the Lower Namoi Alluvium. Reported groundwater levels of the bores range between 183.8 and 179.4 mAHD. The elevation of the site is 197 mAHD which suggest the bores and site are not hydraulically connected. From initial desktop assessment the site was classified as a potential groundwater dependent wetland supported by a water table spring sourced from the Lower Namoi Alluvium. Further assessment of the site using high resolution photography suggests the site is more likely dependent on surface water input.
Existing features with potential to impact the site:	N/A. The site is no longer considered to be sourced by groundwater.

ECOLOGICAL ASSESSMENT FROM HIGH RESOLUTION PHOTOGRAPHY	
Initial assessment of the potential aquatic/riparian species and communities associated with the location and source aquifer:	**Possible threatened species**: *Cyperus conicus, Myriophyllum implicatum.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton* sp. Sloane's Froglet (*Crinia sloanei)* is a vulnerable species and is predicted to be present within the study area. River Snail (*Notopala sublineata)* is an endangered species, possibly extinct, though may be present.
Ecological environment observations (from high resolution photography):	Aerial imagery shows Round Swamp to comprise a large round water body, probably of similar origin as Yarrie Lake. Heavy sediment load and drainage channel is present in the south east of the site. Assessment of high resolution aerial photography suggests the channel to be an inflow to the feature. The land around the site is well-vegetated with forested woodland. No macrophytes visible on aerial photographs, so the site is unlikely to be suitable habitat for Australasian Bittern or Australian Painted Snipe.
Matters of National Environmental Significance present?	From assessment of high resolution photography it is unlikely the site will support any Matters of National Environmental Significance (MNES). No aquatic MNES are known to be present at the site. None of the threatened plant species listed under the EPBC Act for this area are wetland dependent. There is no suitable habitat, visible from aerial photography, for Australasian Bittern and Australian Painted Snipe.
Site condition:	From assessment of high resolution aerial photoprhs this site appears to be a shallow lake recharged by surface runoff. Variable water level and water clarity, from opaque pale grey, indicating high suspended silt concentration, to algal green in 2010, indicates high nutrient concentration. There is well vegetated land around the lake shore, but no obvious macrophytes. Round Swamp is assessed as exhibiting moderate hydrological disturbance and high catchment and habitat disturbance in the Namoi State of Catchments report.
Significance of the flora and fauna present:	Well vegetated riparian land, but no obvious macrophytes. Dead trees in inflowing channel. Water quality appears poor and would only support hardy common species. No species of national significance in the area.
Predicted ecological value of the site:	The site has low ecological value. As a large body of water, the lake is likely to have local significance to water birds, but the site is unlikely to support species of national significance.
Predicted sensitivity of the ecosystem:	Round Swamp is assessed as exhibiting moderate hydrological disturbance and high catchment and habitat disturbance in the Namoi State of Catchments report. As an already modified system the site will have low sensitivity to change.

FINAL CONCLUSIONS

- This site is **not considered to be dependent on groundwater** because:
    - Aerial photography suggests the site to be a natural lake most likely sourced by the surface water channel entering the south-east of the site; and
    - Aerial photography shows the water to be turbid suggesting a lack of fresh groundwater input.
- This site is considered **unlikely to have and Matters of National Environmental Significance** because:
    - Aerial photography suggest there is no suitable habitat for threatened bird species;
    - None of the threatened plant species listed under the EPBC Act for this area are wetland dependent; and
    - The site is defined as exhibiting high catchment and habitat disturbance in the Namoi State of Catchment report.

HIGH RESOLUTION PHOTOGRAPHY



Appendix C – Determination of groundwater dependency

Table C1: Inference of Groundwater Dependence

		12	64	65	67	979	980	981	982	983	1200	1324	Eather Spring	Garlands Dam	Hardy's Spring	Mayfield Spring	Round Swamp	Teds Hole	Ten mile Dam	Well Ford	Yarrie Lake	Drysdale
	Visited?	Yes	no	Yes	Yes	no	no	Yes	Yes	Yes	Yes	Yes	no	Yes	no	no	no	yes	yes	no	yes	yes*
	Surface geology	Pilliga Sandstone	Cainozoic sand plain	Cainozoic sand plain	Cainozoic sand plain	Orallo Group	Quaternary alluvium/ Pilliga Sandstone	Quaternary alluvium	Orallo Formation/ Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Garrawilla Volcanics	Purlawaugh Formation	Quaternary alluvium on Orallo	Purlawaugh Formation	Purlawaugh formation	Quaternary alluvium	Quaternary alluvium on Orallo	Quaternary colluvium on Orallo	Alluvium on Orallo	Quaternary alluvium on Orallo	Quaternary colluvium
General questions	Is the ecosystem identical or similar to another that is known to be groundwater dependent?	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
General questions	Does the community contain species known to require permanent saturation such as within aquifers, karsts, or mound springs or some wetlands?	No	Unknown	No	No	Unknown	Unknown	No	No	Yes	Yes	Unknown	Unknown	Yes	Unknown	Unknown	Unknown	Yes	No	Unknown	Yes	Yes
General questions	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	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No
General questions	Is the distribution of the ecosystem typically confined to locations where groundwater is known or expected to be shallow? For example topographically low areas, major breaks of topographic slope; i.e. Cliffs or escarpments, alluvial and coastal sand beds aquifers, gaining streams?	No	Unknown	No	No	Unknown	No	No	No	N/A	No	No	Unknown	No	Unknown	Unknown	Unknown	yes	No	Unknown	No	Yes
General questions	Does the ecosystem withstand prolonged dry conditions without obvious signs of water stress?	No	No	No	No	Unknown	Unknown	No	No	N/A	No	Unknown	Yes	No	Unknown	Unknown	Unknown	Yes	No	Unknown	No	Yes
General questions	Does expert opinion indicate that the ecosystem(s) is groundwater dependent?	Yes	Unknown	No	No	Unknown	Unknown	No	no	No	No	No	Yes	No	Yes	Yes	Unknown	Yes	No	No	No	yes*
Aquifer ecosystems	is the aquifer highly porous, that is, is it composed of unconsolidated sediments such as gravels, sand layers or contain palaeochannels, or, if consolidated (solid rock), is the rock matrix fractured?	Yes	yes	Yes	Yes	no	Yes	Yes	yes	Yes	Yes	No	No	Yes	No	No	yes	Yes	No	Yes	Yes	No
Aquifer ecosystems	Is there an aquatic invertebrate community within the aquifer (sampled from bores) composed of groundwater obligate species; i.e. Phreatic stygofauna species	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Karst and cave ecosystems	Is there visible water such as pools, sumps, stream flow, wet walls (lamellar flow) or active stalactite/stalagmite formation in the cave during prolonged dry conditions?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Karst and cave ecosystems	Is the aquatic community within the cave composed of groundwater obligate species? I.e. Phreatic stygofauna species?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

		12	64	65	67	979	980	981	982	983	1200	1324	Eather Spring	Garlands Dam	Hardy's Spring	Mayfield Spring	Round Swamp	Teds Hole	Ten mile Dam	Well Ford	Yarrie Lake	Drysdale
	Are there high moisture dependent cavernicolous species such terrestrial cave invertebrates with aquatic larval stages such as glow worms?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Base flow streams	Is there visible water in pools consistent or is flow along the streams consistent or increasing downstream during prolonged dry conditions i.e. Perennial stream?	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A
	Is the stream or sections of the stream known to be gaining; i.e. Receiving water from groundwater discharge where surrounding groundwater levels are higher than the stream bed or there is groundwater up-welling?	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A
	Is the stream bed composed of course grained unconsolidated sediments such as sand or gravel?	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A
	Is the aquatic invertebrate community within the surface water composed of long lived, short range endemic species?	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown	N/A	N/A
	Is the aquatic invertebrate community with the hyporheic zone (within the stream bed substrate) composed of groundwater obligate (stygofauna) species i.e. Phreatic or permanent hyporheic species?	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown	N/A	N/A
Estuarine and near shore marine ecosystems	Is the estuary fed by perennial /baseflow streams or associated with permanent wetlands during prolonged dry conditions?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Is the estuary or near shore marine environment associated with or adjacent to shallow groundwater aquifers such as alluvial or coastal sand bed aquifers?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Is the vegetation, vertebrate or invertebrate community composed of species known to require freshwater or high nutrient contributions?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Is there known submarine groundwater discharge areas?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Phreatophytes - GW	Is the water table 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	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

		12	64	65	67	979	980	981	982	983	1200	1324	Eather Spring	Garlands Dam	Hardy's Spring	Mayfield Spring	Round Swamp	Teds Hole	Ten mile Dam	Well Ford	Yarrie Lake	Drysdale
	Is the vegetation community composed of species known to require permanent saturation or high soil moisture levels?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	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 this groundwater	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Does the vegetation in a particular community occur along stream lines	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	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	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	is the vegetation community known to function as a refuge for more mobile fauna during times of drought?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	For sites that are not receiving significant amounts of lateral surface and sub-surface flows, is the annual rate of water use by the vegetation significantly larger than annual rainfall at the site?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	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?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Groundwater dependent wetlands	Is the vegetation, vertebrate or invertebrate community composed of species known to require permanent saturation in situations that are not obviously fed by surface water?	Yes	Unknown	Yes	N/A	Unknown	Unknown	Yes	No	No	No	N/A	Unknown	Unknown	Unknown	Unknown	Unknown	yes	No	N/A	Unknown	yes*
	Does the location of the wetland suggest that it is likely to be groundwater dependent; e.g. Permanent wetlands on coastal sandbeds or back dune swales, streams with consistent or increasing flow along the flow path during extended dry periods?	Yes	Yes	No	N/A	Yes	Yes	No	No	No	No	N/A	Yes	Yes	Yes	Yes	yes	Yes	No	N/A	Yes	yes*
	Is the wetland associated with a spring or a seep? Groundwater discharge that is concentrated and occurs adjacent to a wetland, suggest that groundwater may be an important source of water to that wetland *	Unknown	Unknown	No	N/A	Unknown	Unknown	No	No	No	No	N/A	Yes	No	Yes	Yes	Unknown	Yes	No	N/A	No	yes*

	12	64	65	67	979	980	981	982	983	1200	1324	Eather Spring	Garlands Dam	Hardy's Spring	Mayfield Spring	Round Swamp	Teds Hole	Ten mile Dam	Well Ford	Yarrie Lake	Drysdale
Is there visible water in the wetland (especially during prolonged dry conditions) and does the wetland lack surface inflow (stream flow)? A wetland that lacks surface inflow is likely to be obtaining its water from groundwater. Check: some permanent wetlands that lack distinct surface water inflows can be perched on hardpan soils and are isolated from groundwater. An aquitard created by clay soils or hardpans will prevent groundwater from reaching the wetland. The source of water for these wetlands is generally rain or surface runoff.	No	Yes	Yes	N/A	Yes	Yes	Yes	No	No	No	N/A	No	Yes	no	Yes	yes	Yes	No	N/A	No	yes*
Does the wetland 1) occur a break in the slope? A break in the slope occurs when the slope of the land surface changes from steep to gentle. Groundwater may intersect the ground surface at this point. In these situations, groundwater is below the ground surface at the top of the slope and moves downhill. Once groundwater nears valleys and depressions, it will often intersect the surface and emerge from the ground **	No	No	No	N/A	No	No	No	No	No	No	N/A	No	No	no	no	no	No	No	N/A	No	No
Does the wetland 2) intersect a confined aquifer with a slope? When groundwater is confined within a permeable deposit such as sand or gravel by deposits that are less permeable, water will move laterally rather than downwards. When that permeable layer intersects a slope, groundwater discharges at the surface. These locations can be recognised in the field by the presence of springs, seeps or wetlands on slopes **	No	No	No	N/A	No	No	No	No	No	No	N/A	NO	No	no	no	no	No	No	N/A	No	No
Does the wetland 3) occur at a point of stratigraphic change? These areas of groundwater discharge occur when groundwater, moving in a permeable geologic deposit, follows a downward topographic gradient and meets a less permeable deposit. At contact, water is forced to discharge at the surface. Geologic contacts can be located when adjacent geologic deposits of differing permeability's are identified **	No	No	No	N/A	No	No	No	No	No	No	N/A	Yes	No	yes	yes	no	No	No	N/A	No	No
Does the wetland lack signs of surface inflow? A wetland that lacks surface inflow is likely to be obtaining its water from groundwater	Yes	Yes	Yes	N/A	No	No	No	No	Yes	No	N/A	Yes	Yes	yes	yes	yes	Yes	No	N/A	No	yes*

	12	64	65	67	979	980	981	982	983	1200	1324	Eather Spring	Garlands Dam	Hardy's Spring	Mayfield Spring	Round Swamp	Teds Hole	Ten mile Dam	Well Ford	Yarrie Lake	Drysdale
Is the wetland considered seasonal? Seasonal wetlands are unlikely to receive significant, season long inputs of groundwater and are likely to be maintained by surface water inputs. However be aware that it may be a wetland that remains dry because of a drop in water table levels and may fill once the aquifer is recharged	No	Unknown	No	N/A	Unknown	Unknown	No	No	No	No	N/A	Unknown	No	Unknown	Unknown	no	No	No	N/A	Yes	No
Number Yes	5	4	4	3	3	4	4	2	4	3	1	7	6	6	7	4	11	0	4	4	3
Number No	10	6	12	9	6	6	12	14	10	14	9	5	9	5	4	6	5	16	3	11	7
Number unknown	2	7	1	1	8	7	1	1	1	0	3	5	2	6	6	7	1	1	6	2	1
Progress to next stage assessment (i.e. confirmed as GDE):	YES	NO	Yes	No	No	YES	No	No	No	No	No	YES	No	YES	YES	No	YES	No	Yes	No	yes*
Reasons this site is/is not perceived to be a GDE:	*Located on major aquifer likely sandy substrate *Flattened depression - dammed, soil is moist below grass vegetation with no obvious signs of surface water sources	*Initially thought could be sourced by bore but no evidence found and photos suggest otherwise	*Ecosystem present, sourced by a bore *Water discoloured and not fresh.	* This site was dry and sparsely vegetated. *No evidence of seepages, water pools or vegetation	Further assessment through high resolution photography suggests that this is a manmade dam on a drainage line.	*Too many unknowns to rule out likelihood of GDE	*This was identified as a surface water dam * Not believed to be groundwater as water was not fresh.	*this site was confirmed as being a dry surface water dam, no ecosystem was identified. *Not groundwater fed	*artificial dam, no strong evidence to suggest groundwater dependence *brown coloured water indicating it was not fresh *No ecosystem present	*Dry dam with desiccated ground, sparsely vegetated	*Dammed surface water - modified feature *feature is turbid - no freshwater source. *considered to be surface water fed.	*Identified as a spring by NOW *Likely to occur due to the interface of the Pilliga Sandstone and the Purlawaugh Formation	*Site visit confirmed that the site is fed by surface water runoff *Artificial dam	*Identified as a spring by NOW *Likely to occur due to the interface of the Pilliga Sandstone and the Purlawaugh Formation	*Identified as a spring by Aquaterra *Likely to occur due to the interface of the Pilliga Sandstone and the Purlawaugh Formation	Further assessment through high resolution photography suggests that there is surface water input (similar to Yarrie Lake).	*Sandstone base, no obvious surface water input *water is relatively fresh.	*excavate dam - artificial * very turbid (not fresh), no groundwater input	*Aerial photography is not clear enough to discard this site.	*The high turbidity of the water and low temp suggest there is little groundwater contribution *	*Artificial wetland created by a bore, dependent entirely on bore water *Ecological community including turtles is present.

Notes:
* springs tend to occur in two types of hydrological settings
1) Where surface topography causes the water table to intersect the land slope. This setting can often be predicted or identified on the landscape using surface topography as a guide. In general, springs of this nature tend to be supported by more local groundwater flow systems and are at risk from activities that threaten shallow water tables.
2) Where subsurface geologic structure forces groundwater to emerge at the surface. These springs are not defined by surface topography but by subsurface geological conditions. Often these springs are supplied by deeper more regional groundwater flows and are at risk from activities that threaten the deeper water flow system.
** Groundwater discharge is likely to occur and produce groundwater dependent wetlands in the described hydro-geologic settings. Depending on the underlying and surrounding geology, a wetland will be more or less strongly associated with and dependent on groundwater. Field visits and examination of geology and topography data layers and maps for an area can help determine if these conditions exist.

Appendix D – Ecological assessment

Table D1: Plant species with the potential to occur in the study area

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Alternanthera nana	Hairy Joyweed	Inland floodplain swamps	Amphibious herb	Nil	Nil
Asperula gemella	Twin-leaved Bedstraw	Moist areas along watercourses	Amphibious herb	Nil	Nil
Asperula charophyton	Strapleaf woodruff	Moist areas along watercourses	Herb	Threatened	Nil
Asterolasia sp. Dungowan Creek (Beckers s.n. 25 Oct 1995)		Rocky alluvial soil along creeks	Herb	Threatened	Nil
Asterolasia hexapetala		Rocky alluvial soil along creeks	Herb	Threatened	Nil
Atriplex semibaccata	Creeping Saltbush	Common on road sides; Common Reed – Bushy Groundsel reed land/ forbland of inland river systems	Herb	Nil	Nil
Azolla pinnata		Still or slowly moving water	Free floating fern	Nil	Nil
Boerhavia coccinea	Tarvine	Artesian Springs EEC	Herb	Nil	Nil
Boerhavia dominii	Tarvine	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Herb	Nil	Nil
Bolboschoenus fluviatilis	Marsh Club-rush	Open swamps – inland floodplain swamps	Emergent rush	Nil	Nil
Bolboschoenus medianus		Grows in swamps	Aquatic grass	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Calandrinia eremaea		Grows in a range of habitats; Golden Goosefoot shrub land swamps of the arid and semi-arid zones	Herb	Nil	Nil
Calandrinia ptychosperma		Along sandy water courses	Herb	Nil	Nil
Callistemon pungens		In sandy creek beds	Shrub	Threatened	Nil
Calostemma purpureum	Garland Lily	Along water courses, seasonally flooded clay flats and in rocky sites	Herb	Nil	Nil
Calotis hispidula	Bogan Flea	Golden Goosefoot shrub land swamps of the arid and semi-arid zones	Herb	Nil	Nil
Casuarina cunninghamiana	River Oak	Banks of permanent fresh water streams	Tree	Nil	Nil
Centaurea melitensis	Cockspur Thistle	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Shrub	Nil	Nil
Centipeda cunninghamii	Common Sneezeweed	Damp areas subject to flooding	Herb	Nil	Nil
Centipeda minima var. *minima*	Spreading Sneezeweed	Cumbungi rush land of shallow semi-permanent water bodies of the inland river systems	Herb	Nil	Nil
Centipeda thespidioides	Desert Sneezeweed	Sites subject to flooding	Herb	Nil	Nil
Chamaesyce drummondii	Caustic Weed	Inland riverine forests	Herb	Nil	Nil
Chara australis	Muskgrass	Inland floodplain swamps – clear water, stationary and	Submerged alga	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
		flowing water bodies, water holes in creeks			
Chenopodium auricomum	Golden Goosefoot	Inland floodplain shrub lands	Shrub	Nil	Nil
Chenopodium cristatum	Crested Goosefoot	Golden Goosefoot shrub land swamps of the arid and semi-arid zones	Herb	Nil	Nil
Cirsium vulgare	Spear Thistle	Common Reed – Bushy Groundsel reed land/ forbland of inland river systems	Herb	Nil	Exotic
Cotula australis	Carrot Weed	Open grassy situations – inland riverine forests	Herb	Nil	Nil
Cyperus concinnus	Trim Flat-sedge	Seasonally wet sites	Amphibious sedge	Nil	Nil
Cyperus conicus		Banks/margins of streams and waterholes	Emergent sedge	TSC: Endangered	Nil
Cyperus difformis		Seasonally wet open situations	Sedge	Nil	Nil
Cyperus exaltatus		Shallow water and on banks of streams and lagoons	Sedge	Nil	Nil
Daucus glochidiatus	Native Carrot	Wide variety of habitats	Amphibious herb	Nil	Nil
Dichanthium sericeum subsp. sericeum	QLD Bluegrass		Grass	Nil	Nil
Dysphania platycarpa		Heavy soils near ephemeral water		Endangered	Nil
Eclipta platyglossa		Damp areas usually near water	Herb	Nil	Nil
Einadia nutans subsp. *nutans*	Climbing Saltbush	River Coobah swamp on floodplains of the Darling Riverine Plains and Brigalow Belt South Bioregions	Herb	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Elatine gratioloides	Waterwort	In or on margins of stationary or slow-flowing water to c. 40cm deep	Aquatic herb	Nil	Nil
Eleocharis acuta	Common Spike-rush	In or alongside perennial wetlands, including channels	Emergent rush	Nil	Nil
Eleocharis blakeana		Ephemeral wet areas e.g. Gilgai	Emergent rush	Threatened	Nil
Eleocharis plana	Flat Spike-sedge	Inland floodplain swamps – ephemeral pools, swamps and periodically inundated floodplains, drainage channels	Emergent sedge	Nil	Nil
Eleocharis pusilla		Moist situations	Grass	Nil	Nil
Eleocharis sphacelata	Tall Spikerush	Still fresh water to at least 5m deep	Aquatic rush	Nil	Nil
Enteropogon acicularis	Curly Windmill Grass	Cracking clay soils	Amphibious grass	Nil	Nil
Enteropogon ramosus	Curly Windmill Grass	River Coobah swamp on floodplains of the Darling Riverine Plains and Brigalow Belt South Bioregions	Grass	Nil	Nil
Eragrostis parviflora	Weeping Lovegrass	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Grass	Nil	Nil
Eriocaulon australasicum		Damp areas, water courses wetland margins		Endangered	Nil
Euphrasia arguta		Grassy areas near rivers		Critically Endangered	Nil
Fimbristylis dichotoma	Common Fringe-sedge	Variety of habitats	Sedge	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Flaveria australasica	Speedy Weed	Disturbed sites – inland floodplain shrub lands	Amphibious herb	Nil	Nil
Glinus lotoides		Drier areas, especially saline conditions or high nitrogen	Herb	Nil	Nil
Hibiscus trionum	Flower-of-an-hour	Disturbed sites	Herb	Nil	Nil
Homopholis proluta		Floodways	Amphibious grass	Nil	Nil
Juncus aridicola	Tussock Rush	Permanently or periodically inundated areas	Emergent rush	Nil	Nil
Juncus continuus		Inland floodplain swamps	Rush	Nil	Nil
Juncus flavidus		Inland floodplain swamps – seasonally and briefly wet conditions	Amphibious rush	Nil	Nil
Juncus ochrocoleus		River Coobah swamp on floodplains of the Darling Riverine Plains and Brigalow Belt South Bioregions	Rush	Nil	Nil
Juncus planifolius		Montane bogs and fens	Grass	Nil	Nil
Juncus subsecundus		Dryish habitats	Rush	Nil	Nil
Juncus usitatus		Stream banks and moist places	Rush	Nil	Nil
Lachnagrostis filiformis	Blown Grass	Inland floodplain shrub lands	Amphibious grass	Nil	Nil
Lachnagrostis filiformis		Moist areas	Grass	Nil	Nil
Lemna disperma		Still or slow-flowing fresh water	Aquatic herb	Nil	Nil
Lepidium aschersonii	Spiny Peppercress	Swamps and lake margins	Aquatic herb	Vulnerable	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Lepidium monoplocoides	Winged Peppercress	Seasonally flooded or waterlogged land	Aquatic herb	Endangered	Nil
Lepidium peregrinum		Wetland margins	Aquatic herb	Endangered	Nil
Leptochloa digitata	Umbrella Canegrass	Swamps and water courses	Amphibious grass	Nil	Nil
Leptospermum gregarium		High altitude swamps and along rocky stream banks	Shrub	Nil	Nil
Lomandra longifolia	Spiny-headed Mat-rush	Variety of habitats	Rush	Nil	Nil
Lomandra patens	Irongrass	Creek banks	Rush	Threatened	Nil
Ludwigia peploides subsp. *montevidensis*	Water Primrose	Margins of lakes and creek banks – Inland floodplain swamps	Amphibious herb	Nil	Nil
Lythrum hyssopifolia	Hyssop Loosestrife	Moist places or near water	Herb	Nil	Nil
Malvastrum americanum	Spiked Malvastrum		Herb	Nil	Exotic
Marsilea angustifolia	Thin-leaf Nardoo		Floating fern - submerged or floating leaves	Nil	Nil
Marsilea costulifera		Widespread in moist sites	Herb	Nil	Nil
Medicago laciniata	Cut-leaved Medic	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Herb	Nil	Exotic
Medicago polymorpha	Burr Medic	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South	Herb	Nil	Exotic

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
		and Darling Riverine Plains Bioregions			
Medicago sp.	A Burr Medic		Herb	Nil	Exotic
Mimulus gracilis	Slender Monkey-flower	Depressed areas after flooding, by clay pans, swamps and creeks	Herb	Nil	Nil
Myriophyllum implicatum		Gilgais, freshwater seeps	Aquatic herb	Critically endangered	Nil
Myriophyllum striatum	Striped Water-milfoil	Damp situations on banks of creeks and around water holes	Emergent herb	Nil	Nil
Nymphoides spinulosperma	Marbled Marshwart	Still or slow-flowing water up to 1 m deep	Floating lily	Threatened	Nil
Osteocarpum scleropterum	Squash Bush	Depressed alluvial plains, dry lake beds	Small bush	Endangered	Nil
Ottelia ovalifolia subsp. *ovalifolia*	Swamp Lily	Stationary or slow-flowing fresh water to c. 1m deep		Nil	Nil
Oxalis perennans		Damp areas	Herb	Nil	Nil
Paspalum distichum	Water Couch	Damp areas and margins of water bodies, creeks, streams, channels and drains	Emergent grass	Nil	Nil
Persicaria hydropiper	Water Pepper	Damp places	Herb	Nil	Possibly introduced
Phalaris aquatic	Phalaris	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Grass	Nil	Exotic
Phalaris paradoxa	Paradoxa Grass	River Coobah swamp on floodplains of the Darling Riverine	Grass	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
		Plains and Brigalow Belt South Bioregions			
Phragmites australis	Common Reed	Stationary or slow-moving water bodies, margins of creeks, streams, channels and drains, swamps, areas with high water or seasonally inundated	Emergent grass	Nil	Nil
Picris barbarorum	Plains Picris	River banks and floodplains	Herb	Threatened	Nil
Pimelea elongata	Rice Flower	Wetland margins, heavy soils with sandy upper layer	Herb	Endangered	Nil
Poa fordeana		Low-lying areas	Amphibious grass	Nil	Nil
Polygonum plebeium	Small Knotweed	Inland floodplain swamps	Amphibious herb	Nil	Nil
Potamogeton crispus	Curly Pondweed	Slowly flowing freshwater, tolerant of slightly saline water common in drains	Submerged grass	Nil	Nil
Potamogeton tricarinatus	Floating Pondweed	Slowly flowing waters of rivers and creeks to 3m deep	Submerged and floating	Nil	Nil
Pratia concolor	Poison Pratia	Moist depressions	Herb	Nil	Nil
Ranunculus lappaceus	Common Buttercup	Inland riverine forests	Herb	Nil	Nil
Ranunculus pumilio	Ferny Buttercup	Intermittently moist sites	Amphibious herb	Nil	Nil
Rapistrum rugosum	Turnip Weed	Shallow freshwater sedge swamps on inland floodplains and depressions	Herb	Nil	Nil
Rhodanthe floribunda	Common White Sunray	Golden Goosefoot shrub land swamps of the arid and semi-arid zones	Herb	Nil	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Rorippa eustylis		Shallow freshwater sedge swamp on inland floodplains and depressions	Herb	Nil	Nil
Rorippa laciniata		Common Reed – Bushy Groundsel reed land/ forbland of inland river systems	Herb	Nil	Nil
Rumex brownii	Swamp Dock	Inland riverine forests	Herb	Nil	Nil
Schoenus apogon	Common Bog-rush	Seasonally wet habitats – montane bogs and fens	Grass	Nil	Nil
Schoenus centralis		Drainage lines		Threatened	Nil
Senecio cunninghamii var. *cunninghamii*	Bushy Groundsel	Inland floodplain shrub lands	Amphibious herb	Nil	Nil
Sida rohlenae	Shrub Sida	Flood out areas, creek banks		Endangered	Nil
Solanum esuriale	Quena	Along seasonal water courses	Herb	Nil	Nil
Sonchus oleraceus	Common Sowthistle	Lignum shrub land on regularly flooded alluvial clay depressions in Brigalow Belt South and Darling Riverine Plains Bioregions	Herb	Nil	Exotic
Sporobolus caroli	Fairy Grass	Floodplains on inland rivers and creeks	Grass	Nil	Nil
Stackhousia muricata		Woodland and grassland, shallow freshwater sedge swamp on inland floodplains and depressions	Herb	Nil	Nil
Thesium australe	Austral toadflax	Damp grassland or woodland	Herb	Vulnerable	Nil

Species Name	Common Name	Wetland zone/Habitat	Growth Form	Threatened Species Status	Exotic / Noxious Weed Status
Triraphis mollis	Purple Needlegrass	Sandy soils in many different habitats	Grass	Nil	Nil
Typha domingensis	Narrow-leaved Cumbungi	Swamps, margins of lakes and streams, irrigation channels and drains	Emergent sedge	Nil	Nil
Typha orientalis	Broad-leaf Cumbungi	Swamps, margins of lakes and streams, irrigation channels and drains	Emergent sedge	Nil	Nil
Vallisneria gigantea	Ribbonweed	Stationary or flowing freshwater to 7m deep	Submerged grass	Nil	Nil
Verbena gaudichaudii		Dry woodlands, often along water courses	Herb	Nil	Nil
Verbena incompta	Purpletop	Disturbed sites	Herb	Nil	Exotic
Xanthium occidentale	Noogoora Burr	Agricultural ground and disturbed pastures, shallow freshwater sedge swamp on inland floodplains and depressions	Herb	Nil	4 – Gunnedah, Narrabri & Tamworth Shires
Xanthium spinosum	Bathurst Burr	Disturbed pastures	Herb	Nil	4 – Gunnedah, Narrabri & Tamworth Shires

Table D2: Potential aquatic/riparian species and communities associated with the location and source aquifer

GDE Name/ ELA Reference Number	Potential aquatic/riparian species and communities associated with the location and source aquifer
Eather Spring	**Possible threatened species**: *Cyperus conicus, Eriocaulon australasicum, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Phragmites australis, Vallisneria* sp*.*
Hardy's Spring	**Possible threatened species**: *Cyperus conicus, Eriocaulon australasicum, Lepidium aschersonii, Lepidium monoplocoides*. **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis*, *Vallisneria* sp.
Mayfield Spring	**Possible threatened species**: *Cyperus conicus, Eriocaulon australasicum, Lepidium aschersonii, Lepidium monoplocoides*. **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis*, *Vallisneria* sp.
Round Swamp	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Myriophyllum implicatum.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton* sp.
Garlands Dam	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis*
Well Ford	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis*
Yarrie Lake	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton* sp.
Ten Mile Dam	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma.* **Other species***: Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton* sp*.*
Teds Hole	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus spp., Eleocharis spp., Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
12	**Possible threatened species**: *Cyperus conicus, Eleocharis blakeana, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp.
64	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*

GDE Name/ ELA Reference Number	Potential aquatic/riparian species and communities associated with the location and source aquifer
65	**Possible threatened species**: *Cyperus conicus, Eleocharis blakeana, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp.
67	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
979	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum*. **Other species:** *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
980	**Possible threatened species**: *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia*, *Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
981	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum*. **Other species:** *Juncus* spp., *Eleocharis* spp., *Carex inversa*, *Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
982	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
983	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*
1200	**Possible threatened species**: *Cyperus conicus, Eleocharis blakeana, Lepidium aschersonii, Lepidium monoplocoides.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Persicaria decipiens, Rumex* spp.
1324	**Possible threatened species:** *Cyperus conicus, Lepidium aschersonii, Lepidium monoplocoides, Nymphoides spinulosperma, Myriophyllum implicatum.* **Other species**: *Juncus* spp., *Eleocharis* spp., *Carex inversa, Lomandra longifolia, Phragmites australis, Myriophyllum* spp., *Nymphoides crenata, Potamogeton crispus*

Table D3: Assessment of Ecological Value

					GDE Reference								
		High	Moderate	Low	12	65	980	Eather	Hardy's	Mayfield	Teds Hole	Well ford	Drysdale
					Pilliga Sandstone	Cainozoic sand plain	Quaternary alluvium/ Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone
GDE environment	GDE or part thereof occurs or is reserved in National Estates, listed wetlands, SEPP 26 Etc	Yes	N/a	No	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Presence of exotic flora or fauna within GDE	None exist	Exotic species in small numbers	Exotic species in large populations of one or more species	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Removal or alteration of GDE type or subtype	no detectable change in physical structure, composition or size in GDE type or subtype	Minor change or alteration in physical structure, species composition, or size resulting in a temporary change in GDE type or subtype	Major change/alteration in physical structure, species composition, or size resulting in a permanent change in GDE type or subtype	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Low	Low
Aquifer Water quality parameters	Alteration of the frequency and /or magnitude and/or timing of water table level fluctuations	No detectable change from natural seasonal variation	Fluctuation in groundwater levels resulting in temporary change to part of dependent habitat types	Fluctuation in groundwater levels resulting in permanent loss of dependent habitat types	High	High	High	Moderate	Moderate	Moderate	Moderate	Low	Low
	Alteration of groundwater pressure	No detectable change from natural seasonal variation	Fluctuation in groundwater pressure resulting in temporary change to part of dependent habitat types	Fluctuation in groundwater resulting in permanent loss of dependent habitat types	Low	Low	Unknown	Moderate	Moderate	Moderate	Moderate	Low	Moderate
	Alteration to direction of hydraulic gradients	No detectable change from natural seasonal variation	Temporary changes resulting in short-term alterations to habitat conditions	Permanent reversals in hydraulic gradients resulting in changes to dependent habitat types	Moderate	Moderate	Unknown	Moderate	Moderate	Moderate	Moderate	Low	Low
	Alteration of base flow conditions	No detectable change from natural seasonal variation	Temporary reduction in baseflow conditions exceeding seasonal variation	Permanent loss or reversal of base flow conditions	Low	Low	Unknown	Moderate	Moderate	Moderate	High	Low	High
	Degree of acid runoff or acidification of aquifer	No detectable change from natural seasonal variation	Temporary exposure of acid sulphate soils with likely runoff into dependent ecosystems	Permanent exposure of acid sulphate soils with likely runoff into dependent ecosystems	High	High	High	High	High	High	High	High	High
	Degree of nutrient load	No detectable change from natural seasonal variation	Temporary increase in nutrient load to dependent ecosystems	Permanent increase in nutrient load to dependent ecosystems	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Degree of groundwater salinity	No detectable change from natural seasonal variation	Temporary increase in salinity to dependent ecosystem	Permanent increase in salinity to dependent ecosystem	High	High	High	High	High	High	High	High	Moderate

					GDE Reference								
		High	Moderate	Low	12	65	980	Eather	Hardy's	Mayfield	Teds Hole	Well ford	Drysdale
					Pilliga Sandstone	Cainozoic sand plain	Quaternary alluvium/ Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone
Aquifer structure	Degree of bioaccumulation i.e. heavy metal contamination	No detectable change from natural seasonal variation	Temporary exposure of dependent ecosystems to heavy metals and/or toxins	Permanent exposure of dependent ecosystem to heavy metal and/or toxins	High	High	High	High	High	High	High	High	High
	Degree of alteration of aquifer structure e.g. Quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction	No detectable change in aquifer structure	Minor change/ alteration of aquifer structure resulting in temporary change in GDE habitat	Major change/alteration of aquifer structure resulting in a permanent change in GDE habitat	High	High	High	High	High	High	High	High	High
Biodiversity: Rarity within catchment/ aquifer	Presence of threatened, rare, vulnerable or endangered species, population or ecological community within GDE	Yes	N/A	No	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Presence of indicator, keystone, flagship, endemic or significant species, populations or communities within GDE	Yes	N/A	No	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Patch size rank of GDE relative to other patches of the same GDE type/subtype	>50	49 to 30	<30	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Patch size percentage of GDE relative to original / historic extent	>50%	49 to 30	<30	Unknown	Unknown	Unknown	High	High	High	High	Unknown	High
Diversity within	Diversity of groundwater dependent native flora and fauna species within a GDE	Presence of five or more species or >80% number of species relative to reference site	Presence of two to four species or 80 to 50% of species relative to reference sites	Presence of one species or less than 50 percent of species relative to reference sites	Low	Low	Low	Low	Low	Low	Low	Low	Low
Special features within catchment/aquifer	Provides drought refuge for terrestrial or aquatic species	The only water source within a radius of >10km	The only water source within a radius of 1 to 9km and no access to multiple water sources	Access to multiple water sources	Low	Low	Low	Low	Low	Low	Low	Low	Low
	Presence of rare physical/physio-chemical features or environments e.g. karsts, mound springs, natural saline wetlands, peat swamps	Occurs only within the aquifer	Occurs only within the catchment	Occurs only within the state	Low	Low	Low	Low	Low	Low	Low	Low	Low

					GDE Reference								
		High	Moderate	Low	12	65	980	Eather	Hardy's	Mayfield	Teds Hole	Well ford	Drysdale
					Pilliga Sandstone	Cainozoic sand plain	Quaternary alluvium/ Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone
	Delivers ecosystem services through biogeochemical processes: carbon processing, nitrification/denitrification, biodegradation through aquifer connectivity	Unconfined aquifer with connection to terrestrial and aquatic ecosystems	Semi confined aquifer with limited (spatial and or temporal) connectivity to terrestrial and aquatic ecosystems	Confined aquifer has very limited or no connection to terrestrial and aquatic ecosystems	Low	Low	Low	Low	Low	Low	Low	Low	Low
				No. High	5	5	5	5	5	5	6	4	5
				No. Moderate	2	2	1	6	6	6	5	1	3
				No. Low	12	12	10	9	9	9	9	14	12
				No. unknown	1	1	4	0	0	0	0	1	0
				Summary	LEV	LEV	LEV	LEV	LEV	LEV	LEV	LEV	LEV

Appendix E – Detailed risk assessment

Table E-1: Likelihood of Impact

Aquifer Asset	Impact	12	65	980	Eather	Hardy's	Mayfield	Teds Hole	Well ford	Drysdale	
	Aquifer:	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone	Comment
Water quantity	Will there be an alteration to the water table levels?	Likely	unlikely	unlikely	Likely	Likely	Likely	unlikely	Likely	Likely	Impacts have been identified within the Pilliga Sandstone
	Will there be alteration to the aquifer flow paths?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be alteration of aquifer discharge volume to off-site GDEs?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration of the frequency/timing of water table level fluctuations?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be alteration of river base flow in the karst/cave?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration of surface river base flow?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be a reduction in artesian/spring water pressure?	unlikely	Likely	unlikely	unlikely	unlikely	unlikely	unlikely	Likely	Likely	Possibly changes to the artesian pressure at wetlands sourced from artesian bores
Water quality	Will there be an alteration to the natural groundwater chemistry and /or chemical gradients	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	Likely	unlikely	unlikely	Potential impact at Teds Hole from the managed release scheme on Bohena Creek
	Will acid sulphate soils be exposed, resulting in acidification of aquifer and acid runoff?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration in nutrient loads?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration in sediment loads?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration in groundwater salinity levels?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	Likely	unlikely	unlikely	Potential impact at Teds Hole from the managed release scheme on Bohena Creek
	Will there be an alteration in groundwater temperatures?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be bioaccumulation of heavy metals?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
Aquifer integrity	Will there be substrate alteration compaction e.g. aquifer, river, gravel bed compaction by heavy machinery or over extraction of water?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be cracking or fracturing of the bedrock?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
Biological integrity	Will there be an alteration to the number of native species within the groundwater dependent communities?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be an alteration to the species composition of the groundwater dependent communities?	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
	Will there be removal or alteration of GDE type /subtype habitat; e.g. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	
Total valuation	**No. of Likely**	1	1	0	1	1	1	2	2	2	
	No. of Unlikely	18	18	19	18	18	18	17	17	17	
	No. of insufficient data	0	0	0	0	0	0	0	0	0	
	Summary	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	unlikely	

Table E-2: Risk Assessment

Aquifer and GDE risk assessment - for potential GDE sites only
Answer 'high', 'moderate', 'low' or 'insufficient data/unknown'
Refer to Table 5 for guidance and descriptions of high, moderate and low risk.

Aquifer Asset	Impact	12	65	980	Eather	Hardy's	Mayfield	Teds Hole	Well ford	Drysdale	
	Source aquifer:	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone	Pilliga Sandstone	Quaternary alluvium	Pilliga Sandstone	Pilliga Sandstone	Comments
Water quantity	What will be the risk of a change in groundwater levels/pressure on GDEs?	Low	Low	Low	Low	Low	Low	Low	Low	Low	Predicted impacts in the Pilliga Sandstone are less than seasonal variations
	What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
	What will be the risk of changing base flow conditions on GDEs?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
Water quality	What is the risk of changing the chemical conditions of the aquifer?	Low	Low	Low	Low	Low	Low	Low	Low	Low	There may be negligible changes to the groundwater quality at Teds Hole downstream of the Managed Release Scheme site.
	What is the risk on the aquifer by a change in the freshwater/salt water interface?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
	What is the likelihood of a change in beneficial use (BU) of the aquifer?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
Aquifer Integrity	What is the risk of damage to the geological structure?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
Biological Integrity	What is the risk of alterations to the number of native species within the groundwater dependent communities?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
	What is the risk of alterations to the species composition of the groundwater dependent communities?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
	What is the risk of increasing the presence of exotic flora or fauna?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
	What is the risk of removing or altering a GDE subtype habitat e.g. Quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction?	Low	Low	Low	Low	Low	Low	Low	Low	Low	
Total valuation	**No. of high**	0	0	0	0	0	0	0	0	0	
	No. of moderate	0	0	0	0	0	0	0	0	0	
	No. of low	11	11	11	11	11	11	11	11	11	
	No. of insufficient data/unknown	0	0	0	0	0	0	0	0	0	
	Final risk (highest count high/moderate/low):	Low	Low	Low	Low	Low	Low	Low	Low	Low	

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Appendix C - Predicted Likelihood of Impacts and Risks to Potential Type 3 GDEs

Likelihood of impacts to potential Type 3 GDEs

Aquifer Asset	Impact	GDE atlas[1]	Eco Logical vegetation mapping[2] (1:10,000)	Comments
Water quantity	Will there be an alteration to the water table levels.	Likely	Likely	Gradual change over 800 years
	Will there be alteration to the aquifer flow paths	Unlikely	Unlikely	
	Will there be alteration of aquifer discharge volume to offsite GDEs.	Unlikely	Unlikely	
	Will there be an alteration of the frequency/timing of water table level fluctuations.	Unlikely	Unlikely	
	Will there be alteration of river base flow in the karst/cave.	Unlikely	Unlikely	
	Will there be an alteration of river base flow.	Unlikely	Unlikely	
	Will there be a reduction in artesian/spring water pressure.	Na	Na	
Water quality	Will there be an alteration to the natural groundwater chemistry and /or chemical gradients	Unlikely	Unlikely	
	Will acid sulphate soils be exposed, resulting in acidification of aquifer and acid runoff?	Unlikely	Unlikely	
	Will there be an alteration in nutrient loads.	Unlikely	Unlikely	
	Will there be an alteration in sediment loads.	Unlikely	Unlikely	
	Will l there be an alteration in groundwater salinity levels.	Unlikely	Unlikely	
	Will there be an alteration in groundwater temperatures.	Unlikely	Unlikely	
	Will there be bioaccumulation of heavy metals.	Unlikely	Unlikely	
Aquifer integrity	Will there be alteration compaction; e.g., aquifer, river, gravel bed compaction by heavy machinery or over extraction of water?	Unlikely	Unlikely	
	Will there be cracking or fracturing of the bedrock.	Unlikely	Unlikely	
Biological integrity	Will there be an alteration to the number of native species within the groundwater dependent communities.	Unlikely	Unlikely	
	Will there be an alteration to the species composition of the groundwater dependent communities.	Unlikely	Unlikely	
	Will there be removal or alteration of GDE type /subtype habitat; e.g., quarrying of limestone around karsts, trampling of cave habitats, and gravel extraction	Unlikely	Unlikely	
Summary	Number of likely scores	1	1	
	Number of unlikely scores	18	18	
	Number of insufficient data and unknown scores	0	0	
	Summary	unlikely	unlikely	

[1] *Eucalyptus fibrosa* (Red Ironbark), *Callitris* (Cypress Pine), *Allocasuarina luehmannii* (Bulloak), *Eucalyptus crebra* (Narrow leaved Ironbark), *Eucalyptus blakelyi* (Red Gum) and *Angophora floribunda* (Rough barked apple tree); [2]Rough-barked Apple – red gum – cypress pine woodland, Red gum – Rough-barked Apple +/- tea tree sandy creek woodland, Fuzzy Box Woodland, River Red Gum riparian tall woodland / open forest wetland and Carbeen - White Cypress Pine – Curracabah – White Box tall woodland

Risk of impacts to potential Type 3 GDEs

Aquifer Asset	Impact	GDE atlas[1]	Eco Logical vegetation mapping[2]	Comments
Water quantity	What will be the risk of a change in groundwater levels/pressure on GDEs?	Low	Low	Gradual change over 800 years
	What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?	Low	Low	Gradual change over 800 years
	What will be the risk of a changing baseflow?	Low	Low	
Water quality	What is the risk of changing the chemical conditions of the aquifer?	Low	Low	
	What is the risk on the aquifer by a change in the freshwater/salt water interface?	Low	Low	
	What is the likelihood of a change in beneficial use (BU) of the aquifer?	Low	Low	
	Will there be a reduction in artesian/spring water pressure?	Low	Low	
Aquifer integrity	What is the risk of damage to the geological structure (of source aquifer)?	Low	Low	
Biological integrity	What is the risk of alterations to the number of native species within the groundwater dependent communities?	Low	Low	
	What is the risk of alterations to the species composition of the groundwater dependent communities?	Low	Low	
	What is the risk of increasing the presence of exotic flora or fauna?	Low	Low	
	What is the risk of removing or altering a GDE subtype habitat; e.g., quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction?	Low	Low	
Summary	Number of high scores	0	0	
	Number of moderate scores	0	0	
	Number of low scores	12	12	
	Number of insufficient data and unknown scores	0	0	
	Final risk (highest count high/moderate/low):	low	Low	

[1] *Eucalyptus fibrosa* (Red Ironbark), *Callitris* (Cypress Pine), *Allocasuarina luehmannii* (Bulloak), *Eucalyptus crebra* (Narrow leaved Ironbark), *Eucalyptus blakelyi* (Red Gum) and *Angophora floribunda* (Rough barked apple tree); [2]Rough-barked Apple – red gum – cypress pine woodland, Red gum – Rough-barked Apple +/- tea tree sandy creek woodland, Fuzzy Box Woodland, River Red Gum riparian tall woodland / open forest wetland and Carbeen - White Cypress Pine – Curracabah – White Box tall woodland

Appendix C - Hydrogeological Properties

Basement Rocks

Currently no field or laboratory data are available from the project area to assess the hydrogeological properties of the Boggabri Volcanics or Werrie Basalts, which are understood to form the basement of the Bohena Trough.

AGE (2011) reported packer testing for the Maules Creek Coal Project Groundwater Impact Assessment (bores MAC257/265) indicating no significant water flows and interpreted as yielding likely hydraulic conductivity values of less than 1.0e-4 m/d. Calibrated model parameters adopted for the basement of the Maules Creek GIA groundwater flow model comprised: horizontal hydraulic conductivity (*Kh*) of 1.01e-2 m/d; vertical hydraulic conductivity (*Kv*) of 5.93e-4 m/d; specific yield (*Sy*) of 1.0e-3; and specific storage (*Ss*) of 1.0e-5 1/m. AGE (2011) identifies that these rocks were subject to extensive weathering and erosion during Early Permian and hence whilst representing a low hydraulic conductivity floor to the Maules Creek Sub-basin, also include a potentially permeable thin surface layer.

The Whitehaven Coal – Werris Creek Coal Project Groundwater Impact Assessment identifies the Werrie Basalt within a geological sequence significantly different from that prevailing in the Bohena Trough and hence the hydraulic parameters given by RCA Australia (2010) are not considered applicable to this assessment.

The neighbouring Narrabri Mine Stage 2 Longwall Project Hydrogeological Assessment modelled the Pamboola Formation (of the lower Black Jack Group) as the effective base of the hydrogeological sequence and hence no parameterisation was provided for underlying sediments of the Millie Group or meta-volcanic basement rocks.

AGE (2010) recognised the Boggabri Volcanics as forming the basal layer of its conceptual and numerical groundwater flow models for the Boggabri Coal Mine Continuation groundwater assessment and assigned the following parameters: *Kh* = 1.0e-4 m/d; Kz = 1.0e-5 m/d; *Sy* = 1.0e-5; and *Ss* = 1.0e-5 1/m.

In summary, the hydrogeological properties of the basement rocks are estimated from specific and general published sources to comprise *Kh* from less than 1.0e-4 to 1.0e-2 m/d; Kz from 1.0e-5 to 6e-4 m/d; *Sy* from 1.e-03 to 1.0e-5; and *Ss* = 1.0e-5 1/m.

Permian Strata

Bellata Group

The Bellata Group comprises the basal Leard Formation successively overlain by the Goonbri Formation and Maules Creek Formation. The Maules Creek Formation includes the coal seam gas targets(from shallowest to deepest): the Rutley, Namoi, Parkes and Bohena seams.

The Leard and Goonbri Formations are understood to be characteristically relatively thin and discontinuous in the Bohena Trough and the hydrogeological properties of these deposits are subsumed into the overlying Maules Creek Formation.

Limited field data are available to characterise the hydraulic parameters of the Maules Creek Formation with the majority of analyses focussed on the properties of the coal seams.

AGE (2011) reported exploration values for Maules Creek Formation coal seams of *Kh* = 1.53e-2 to 1.7e-1 m/d and calibrated values of *Kh* = 5.43e-2 m/d; *Kv* = 5.0e-3 m/d; *Sy* = 5.0e-3; and *Ss* = 1.0e-5 1/m. AGE presented calibrated values for interburden of *Kh* = 1.88e-4 m/d and *Kv* = 5.96e-5 m/d; *Sy* = 1.0e-4; and *Ss* = 1.0e-6 1/m, although these values incorporate Middle Permian Millie Group rocks. However, a horizontal to vertical to anisotropy of 100:1 is considered to be reasonable on the basis of the stratigraphic description (Golder Associates 2011).

Field testing of the Bohena Seam by ESG indicated *Kh* (arithmetic mean) = 1.25e-2 m/d, *Kv* (harmonic mean) = 4.8e-4 m/d and *Kh*:*Kv* (arithmetic mean/harmonic mean) = 26:1. The results of field testing on the Namoi and Maules Creek Seams were similar.

Core testing (permeability to air) of samples from the Maules Creek Seam indicated *Kh* (arithmetic mean) = 7.6e-3 m/d, *Kv* (harmonic mean) = 4.8e-4 m/d and inferred anisotropy of 16.

A drawdown of approximately 700 m was achieved at the Bibblewindi pilot site (Golder Associates 2011) while only producing a yield of 3 L/s. This implies a very low hydraulic conductivity and low storativity environment likely to be dominated by fracture porosity.

It is noted that the Bohena Seam is not included in the groundwater model as a distinct hydrogeological unit, with interburden above and below, but as a surrogate for the four Early Permian coal seams which will be targeted jointly.

In summary, the hydrogeological properties of the Maules Creek strata are estimated from specific and general published sources to comprise *Kh* from less than 1.0e-4 to 1.0e-2 m/d; Kz from 1.0e-5 to 6e-4 m/d; *Sy* from 1.0e-3 to 1.0e-5; and *Ss* = 1.0e-5 1/m.

Millie Group

The Millie Group comprises the lithic sandstone-dominated Porcupine Formation overlain by the sandstone-siltstone-mudstone-dominated Watermark Formation.

Currently no field data are available from the project area to determine the hydrogeological properties of the Porcupine/Watermark Formation. Laboratory testing of core samples (permeability to air) indicated *Kh* = 2.9e-3 m/d (arithmetic mean), *Kv* = 1.7e-4 m/d (harmonic mean) with *Kh*:*Kv* (arithmetic mean/harmonic mean) = 17:1. Core testing was also conducted on the vertical axis on Porcupine/Watermark Formation samples yielding test results (vertical only, permeability to air) with a geometric mean of 4.5e-4 m/d.

Generic siltstones and mudstones are reported to have a typical horizontal hydraulic conductivity of 1.0e-6 to 1.0e-3 m/d (USGS 2002). AGE (2011, Section 6.1.2) reported calibrated parameter values for Permian interburden (including the Bellata Group interburden) of *Kh* = 1.88e-4 m/d and *Kv* = 5.96e-5 m/d. Schlumberger (2012a) provides indicative values after Freeze and Cherry (1979) for construction of the Namoi Catchment Water Study numerical groundwater flow model comprising *Kh* from 1.4e-4 to 9.0e-4 m/d; Kz from 9.0e-5 to 1.4e-3 m/d; *Sy* 1.0e-2; and *Ss* = 1.0e 5 1/m. Calibrated model parameters for the same model included *Kh* = 1.0e-2 m/d; Kz from 1.0e-3 m/d; *Sy* = 1.0e-2; and *Ss* = 1.0e-6 1/m. Golder Associates (2011) considered the estimated horizontal to vertical anisotropy of 100:1 to be reasonable.

In summary, the hydrogeological properties of the Millie Group Porcupine and Watermark Formations are estimated from specific and general published sources and numerical model calibration to comprise *Kh* from 1.0e-6 to 1.0e-2 m/d; Kz from 5.96e-5 to 1.0e-3 m/d; *Sy* from 1.0e-5 to 1.0e-2; and *Ss* from 1.0e-6 to 1.0e-5 1/m.

Black Jack Group

The Black Jack Group consists of the three subgroups, the Brothers subgroup comprising the Pamboola Formation, Melvilles Coal, Arkarula Formation and Brigalow Formation; the Coogal subgroup, comprising the Hoskissons Coal (potential coal seam gas target), Clare Sandstone incorporating the Benelebri Member and including the Hows Hill and Breeza Coals; and the Nea subgroup comprising the Wallala and Trinkey Formations.

Aquaterra (2009) estimated the hydraulic conductivity of the composited Black Jack consisting of all strata of the Pamboola Formation to Hoskissons Coal Member from 2.0e-3 to 3.0e-2 m/d. Data were collated from falling head tests conducted in 2006 by GHD and 2007 by RCA together with downhole injection tests and slug and bore tests in 2008 by Aquaterra and the calibrated groundwater flow model for the Narrabri Coal Mine yielded the following hydrogeological properties for the Hoskissons Coal: *Kh* from 5.0e-3 to 4.0e-2 m/d; *Kv* = 6.0e-6 m/d; *Sy* = 1.0e-3 and *Ss* = 5.0e-6 1/m; Arkarula Formation: *Kh* from 5.0e-4 to 4.0e-2 m/d; *Kv* = 1.0e-6 m/d; *Sy* = 1.5e-3 and *Ss* = 5.0e-6 1/m; and Pamboola (described as "basement" in the report): *Kh* from 1.0e-2 m/d; *Kv* = 1.0e-3 m/d; *Sy* = 5.0e-3 and *Ss* = 5.0e-6 1/m.

Analysis of core testing conducted by Eastern Star Gas (permeability to air) indicates that the Upper Black Jack Seam has *Kh* = 4.0e-3 m/d (arithmetic mean), *Kv* = 9.0e-4 m/d (harmonic mean) and *Kh*:*Kv* (arithmetic mean/harmonic mean) = 4.4:1. Field testing of the Upper Black Jack Seam indicated *Kh* = 2.5 m/d, *Kh*:*Kv* = 5:1.

Results from core testing of the Lower Black Jack Seam were *Kh* = 1.3e-1 m/d; *Kv* = 5.8e-2 m/d; *Kh*:*Kv* = 2.2:1. Golder Associates (2011) assumed that hydraulic parameters for the Hoskissons Seam would be similar. Field testing of the Hoskissons Seam indicated *Kh* = 5.1e-3 m/d, *Kv* = 6.7e-5 m/d; *Kh*:*Kv* = 76:1.

Typical values for horizontal hydraulic conductivity for sandstone collated by the USGS (2002) are 1.0e-3 to 1.0e1 m/d, however the Black Jack Group is also reported to contain conglomerate and siltstone, so the horizontal hydraulic conductivity is likely to be at the lower end of that range (Golder Associates 2011). A horizontal to vertical anisotropy of 100:1 is likely to be reasonable for this unit.

Investigations by Eastern Star Gas indicated that the hydraulic conductivity of the Hoskissons Coal is fracture controlled rather than cleat controlled. Interpretation of borehole fracture orientation data indicated a dominant fracture strike orientation of NE/SW, and that fractures are generally close to vertical (ESG 2009a). Accordingly, a NE-SW anisotropy was incorporated into the numerical model with respect to this hydrostratigraphic unit

In summary, the hydrogeological properties of the Black Jack Group are distinguished between the hydrogeological properties of the seams and those of the interburden. The hydrogeological properties of the Hoskissons Coal are estimated from specific published sources and numerical modelling work to comprise *Kh* from 5.0e-3 to 1.3e-2 m/d; Kz from 6.0e-6 to 1.0e-3 m/d; *Sy* from 1.0e-5 to 1.0e-2; and *Ss* from 1.0e-6 to 1.0e-5 1/m. The hydrogeological properties of the Black Jack Group strata beneath the Hoskissons Coal (Brothers) are estimated from specific published sources and numerical modelling work to comprise *Kh* from 1.2e-5 to 4.0e-2 m/d; Kz from 1.0e-6 to 1.0e-3 m/d; *Sy* from 1.5e-3 to 5.0e-3; and *Ss* = 5.0e-6 1/m.

Triassic Strata

Digby Formation

Aquaterra (2009) reported the hydraulic conductivity of the Digby Formation from DSTs by Sigra in 2006 for the Narrabri Coal Project in the range from 9.2e-5 to 1.4e-4 m/d. Drill stem tests from the project area (Bohena 2) have indicated a hydraulic conductivity of 6.3e-2 m/d.

Aquaterra applied the following hydraulic parameters in its Narrabri Coal Project groundwater flow model: *Kh* from 4.0e-3 to 4.0e-2 m/d; *Kv* from 6.0e-6 to 1.0e-3 m/d and the calibrated groundwater flow model for the same project yielded the following hydrogeological properties for the Digby Formation: *Kh* from 5.0e-4 to 4.0e-2 m/d; *Kv* = 1.5e-5; *Sy* = 1.0e-3 and *Ss* = 5.0e-6 1/m.

Core testing of the Digby Formation by Eastern Star Gas (permeability to air) indicated *Kh* = 2.6e-2 m/d (mean), *Kv* = 1.8e-4 m/d (harmonic mean), with *Kh*:*Kv* (arithmetic mean / harmonic mean) = 144:1. A horizontal to vertical anisotropy of 100:1 was considered to be reasonable for claystone and siltstone (Golder 2011).

Napperby Formation

Aquaterra (2009) reported the hydraulic conductivity of the Napperby Formation from DSTs by Sigra in 2006 for the Narrabri Coal Project as 8.3e-6 m/d. Exploration at the neighbouring Narrabri Coal Project to the immediate east of the project area has indicated the presence of an igneous sill intruded into the Napperby Formation. However, comparison of field data indicates that the properties of the Napperby Formation are not significantly different above and below the sill. Aquaterra (2009) applied the following hydraulic parameters in its Narrabri Coal Project groundwater flow model: *Kh* from 1.0e-3 to 4.0e-2 m/d; *Kv* from 6.0e-6 to 1.0e-3 m/d and the calibrated groundwater flow model for the same project yielded the following hydrogeological properties: *Kh* from 1.0e-3 to 4.0e-2 m/d; *Kv* from 2.4e-5 to 1.0e-4 m/d; *Sy* = 1.0e-3 and *Ss* = 5.0e-6 1/m.

The base of the formation is characterised by a shale. The hydrogeological properties have not been reported but typically would be several orders of magnitude lower than the overlying sandstone strata. It is anticipated that proposed field investigations will confirm that the basal Napperby shale exhibits very low hydraulic conductivity.

Jurassic Strata

Garrawilla Volcanics

Golder Associates (2011) quoted USGS (2002) typical values for horizontal hydraulic conductivity for basalts in the range 1.0e-2 to 1.0e+2 m/d and suggested that given their origin, a horizontal to vertical anisotropy of 1:1 to 5:1 would be typical.

Aquaterra (2009) reported results from drill stem tests (Sigra 2006) for the Garrawilla Volcanics indicating horizontal hydraulic conductivity of 8 m/d, which may reflect localised degradation of the substrate. GHD (2006) calculated *Kh* from falling head tests at 4.7e-2 m/d. The pre- and post-calibrated groundwater flow model for the Narrabri Coal Mine (Aquaterra 2009) yielded the following hydrogeological properties for the Garrawilla Volcanics: *Kh* from 1.0e-3 to 4.0e-2 m/d; *Kv* from 6.0e-6 to 1.0e-3; *Sy* = 2.0e-3 and *Ss* = 5.0e-6 1/m. It is noted that the volcanics are not ubiquitous and are commonly absent in boreholes penetrating the underlying Triassic strata within the project area.

Purlawaugh Formation

Golder Associates (2011) cited literature values for horizontal hydraulic conductivity of claystone and siltstone in the range 1.0e-6 to 1.0e-3 m/d (USGS 2002). A horizontal to vertical anisotropy of 100:1 was also considered to be reasonable (Golder Associates 2011).

Aquaterra (2009) estimated the hydraulic conductivity of the Purlawaugh Formation in the range from 1.0e-2 to 2.0e-2 m/d although this may be influenced by the presence locally of a basalt sill at the site. The calibrated groundwater flow model for the Narrabri Coal Mine yielded the following hydrogeological properties for the Purlawaugh Formation: *Kh* from 4.0e-3 to 2.0e-2 m/d; *Kv* from 1.5e-5 to 2.0e-3 m/d; *Sy* = 1.0e-3 and *Ss* = 5.0e-6 1/m.

Pilliga Sandstone

Typical values for horizontal hydraulic conductivity of the Pilliga Sandstone range between 1.0e-3 to 1.0e+1 m/d (Golder Associates 2011; after USGS 2002). Aquaterra (2009) reported calibrated values for the Narrabri Coal Project groundwater flow model of *Kh* ranging from 4.0e-3 to 2.65e-1 m/d, with *Kv* ranging from 1.5e-5 to 2.0e-3 m/d, *Sy* = 1.0e-1 and *Ss* = 5.0e-5 1/m. A horizontal to vertical anisotropy of 100:1 was considered representative for sandstone by Golder Associates (2011).

Cretaceous Strata

Blythesdale Group (Keelindi Beds)

The Blythesdale Group (Keelindi Beds) are understood to be approximately 30 to50 m thick in the project area (AGE 2006) although corehole and bore log data provided by Santos is inconclusive. URS (2012) has calculated the thickness in the project area to range from 0 to88 m, averaging approximately 46 m. As a consequence of the uncertainty surrounding the presence and properties of this formation, and based on its characteristic lithologies, in this assessment it has been subsumed into the underlying Pilliga Sandstone.

Namoi Alluvium

Alluvial deposits are represented in various local models developed to assist in water resource planning within the Namoi Catchment and specifically targeted at the Namoi alluvium, including the Lower Namoi GMA groundwater model (Merrick 2000) and the Upper Namoi numerical groundwater model (McNeilage 2006). Limited published information is available concerning the former model, whilst the latter model represents the Namoi alluvium as two layers corresponding to the characteristic formations of the Gunnedah Formation (Layer 2) and Narrabri Formation (Layer 1). The confined Gunnedah Formation is assigned hydraulic parameters as follows: *Kh* ranging from 5.0e-2 to 3.0e+1 m/d and *Ss* from 1.0e-7 to 5.0e-4 1/m. The unconfined Narrabri Formation is assigned hydraulic parameters as follows: *Kh* ranging from 1.0e-1 to 3.0e+1 m/d and *Sy* from 5.0e-3 to 1.0e-1. The Lower Namoi GMA groundwater model incorporates the basal alluvial Cubbaroo Formation.

High yielding bores are common in the shallow alluvial groundwater source with hydraulic conductivities in gravel layers reported as being up to 138 m/d (AGE 2009).

Aquaterra (2009) reported calibrated values of horizontal hydraulic conductivity for general alluvium in the range from 2.85e-1 to 5 m/d, with vertical hydraulic conductivity ranging from 5.0e-4 to 5.0e-3 m/d. A horizontal to vertical anisotropy 5:1 or 10:1 is stated as typical for alluvial formations (Golder Associates 2011).

AGE (2011) reported calibrated parameter values for Narrabri and Gunnedah Formations of *Kh* = 7.0 and 8.3 m/d respectively and *Kv* = 6.25e-2 and 2.4 m/d, respectively, with specific yield of the Narrabri Formation of 5.0e-2 and storativity of the Gunnedah Formation of 5.0e-4 1/m. Schlumberger (2012a) reproduces values after Golder Associates (2010) for construction of the Namoi Catchment Water Study numerical groundwater flow model comprising *Kh* from 5.0e-1 to 3.0e+1 m/d (all alluvium); Kz from 1.7e-6 to 3.7e-2 m/d (Narrabri Formation) and 3.5 to 7.2 m/d (Gunnedah Formation); *Sy* 5.0e-3 to 1.5e-1; and *Ss* from 1.0e-6 to 5.0e-4 1/m, although these are largely generic and assumed from literature.

In summary, the hydrogeological properties of the Alluvium is estimated from specific and general published sources and numerical model calibration to comprise *Kh* from 5.0e-1 to 3.0e+1 m/d; Kz from 1.7e-6 to 2.4 m/d; *Sy* from 5.0e-3 to 1.5e-1; and *Ss* from 1.0e-7 to 5.0e-4 1/m.

Weathered Regolith

AGE (2011) provided hydraulic parameters for the weathered surface of exposed Permian (hard rock) strata including *Kh* 1.5e-1 m/d; *Kv* 9.2e-3 m/d; *Sy* 1.0e-3; and *Ss* from 1.0e-5 1/m.

Appendix D - Aquifer Interference Framework

Table 1. Does the activity require detailed assessment under the AIP?

	Consideration	Response
1	Is the activity defined as an aquifer interference activity?	**YES,** continue to Question 2.
2	Is the activity a defined minimal impact aquifer interference activity according to section 3.3 of the AIP?	**NO**, continue on for a full assessment of the activity.

1. Accounting for, or preventing the take of water

Where a proposed activity will take water, adequate arrangements must be in place to account for this water. It is the proponent's responsibility to ensure that the necessary licences are held. These requirements are detailed in Section 2 of the AIP, with the specific considerations in Section 2.1 addressed systematically below.

Where a proponent is unable to demonstrate that they will be able to meet the requirements for the licensing of the take of water, consideration should be given to modification of the proposal to prevent the take of water.

Table 2. Has the proponent:

	AIP requirement	Proponent response	NSW Office of Water comment
1	Described the water source(s) the activity will take water from?	EIS Chapter 6 provides a detailed project description. GIA Section 1 describes the activity, Section 6.8.1 describes how the water would be taken and Section 5 provides detailed analysis of the identified water sources.	
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	GIA Section 6.8.1 presents the indicative Field Development Plan adopted for the GIA. Sections 6.8.1.1 and 6.8.1.2 describe the calculation of water take from each simulated target.	
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	Section 6.9.1 provides detailed analysis of the predicted water takes from contributing hydrostratigraphic units, including quantification of fluxes from contributing units during and following the activity, and net totals from each unit from inception of the activity to full final recovery of the hydrostratigraphic system.	

	AIP requirement	Proponent response	NSW Office of Water comment
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (refer to Table 3, below)	See Table 4 below.	
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	The water take is wholly made from the Gunnedah-Oxley Basin water source.	
6	Described how any licence exemptions might apply?	No known exemptions are currently in place for abstraction of water for the proposed activities	
7	Described the characteristics of the water requirements?	EIS Chapter 6 describes the proposed project water production profile. GIA Sections 6.8 and 6.9 elaborate an interpretation of the field development plan that is used for the GIA simulations.	
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	There is currently sufficient water available on the water market for the Gunnedah-Oxley Basin (Other) groundwater source. Where there are limitations in the market for this particular water source, Santos will seek further controlled allocations from the State Government.	
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	Santos has considered the rules prescribed in the Water Sharing Plans for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011, NSW Great Artesian Basin Groundwater Sources 2008, and Upper and Lower Namoi Groundwater Sources 2003, and believes it can meet these rules in relation to the project area.	
10	Determined how it will obtain the required water?	Based on the forecast take of water, Santos will acquire adequate water access licences to account for its requirements.	
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	Santos is not aware of any existing entitlement that has not already been activated for this water source.	
12	Considered actions required both during and post-closure to minimize the risk of inflows to a mine void as a result of flooding?	Not applicable.	

AIP requirement		Proponent response	NSW Office of Water comment
13	Developed a strategy to account for any water taken beyond the life of the operation of the project?	As Santos is proposing to take water from a regulated water source, recharge to this source from other water sources has been accounted for in accordance with the principles used to calculate the Sustainable Diversion Limits.	
Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? In accordance with the minimal impact criteria of the Aquifer Interference Policy, groundwater modelling has predicted no significant impacts on water users. If **YES,** items 14-16 must be addressed.			
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Not required	
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	Not required	
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the project, and how these requirements will be accounted for?	Not required	

Table 3. Determining water predictions in accordance with Section 3.2.3 (complete one row only – consider both during and following completion of activity)

	AIP requirement	Proponent response	NSW Office of Water comment
1	**For the Gateway process**, is the estimate based on a simple modelling platform, using suitable baseline data, that is, fit-for-purpose?	The project is exempt from the Gateway process. A Site Verification Certificate was issued by NSW Planning and Environment on 1 December 2015 verifying that the project area does not contain Biophysical Strategic Agricultural Land (BSAL).	
2	**For State Significant Development or mining or coal seam gas production**, is the estimate based on a complex modelling platform that is: • Calibrated against suitable baseline data, and in the case of a **reliable water source,** over at least two years? • Consistent with the Australian Modelling Guidelines? • Independently reviewed, robust and reliable, and deemed fit-for-purpose?	Yes. The development of a fit for purpose numerical groundwater model for the project is described in detail in Section 6 of this GIA. The model is calibrated against the available baseline data within the project area and GIA study area, and is developed in accordance with the guiding principles of the Australian Groundwater Modelling Guidelines. The model has been independently reviewed by CSIRO (Appendix F) against the model review checklist established in the guidelines. The independent review found that "The regional groundwater MODFLOW model for the Gunnedah basin can be considered state of the art and is suited to assess potential impacts of water extraction for coal seam gas depressurisation on the surface water and groundwater resources in the Gunnedah Basin district."	
3	In all other processes, is the estimate based on a desk-top analysis that is: • Developed using the available baseline data that has been collected at an appropriate frequency and scale; and • Fit-for-purpose?	Yes. In addition to estimates based on the numerical groundwater modelling, this GIA incorporates a detailed assessment of the potential for the project to cause impacts to GDEs (Appendix B) which is undertaken in line with the current national framework for assessing the environmental water requirements of GDEs—utilising the GDE toolbox—and following DPI Water's 'Risk assessment guidelines for GDEs, and based on site visits and collection of baseline data, The assessment of subsidence potential (Appendix G) is undertaken based on industry standard methods and includes subsidence baseline monitoring commissioned by Santos.	

Other requirements to be reported on under Section 3.2.3

Table 4. Has the proponent provided details on:

	AIP requirement	Proponent response	NSW Office of Water comment
1	Establishment of baseline groundwater conditions?	GIA Section 4 presents a description of the existing environment, including the baseline hydrological (Section4.4) and hydrogeological (Section 4.5) conditions. This information informs the conceptual hydrological model and calibration of the numerical groundwater flow model. In addition, the Water Baseline Report (EIS Technical Appendix G4) presents an analysis of all pertinent hydrologic baseline data, including groundwater and surface water characteristics relevant for establishing pre-activity baselines.	
2	A strategy for complying with any water access rules?	Adequate water access licences in accordance with the *Water Management Act 200*0 will be acquired prior to the take of water. Note: GIA Section 6.8.6 describes the Water Sharing Plan (WSP) areas and groundwater sources that are relevant to the project. Groundwater modelling in GIA Section 6.9 predicts the induced water takes from each groundwater source, both during and following the activity; however, all direct take of water will be entirely from the Gunnedah-Oxley Basin Groundwater Source, and implicit in the Sustainable Diversion Limit (SDL) and Long-Term Average Annual Extraction Limit (LTAAEL) for this water source is allowance for recharge from connected sources.	
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	GIA Section 4.8 identifies the existing water abstraction and entitlements, including nearby basic landholder rights water users. Section 6.9 describes the potential impacts determined from the base case simulation. Section 6.12 confirms that no impact is predicted that exceeds the Minimal Impact Consideration criteria listed in Table 1 of the AIP for the relevant classifications of beneficially-used groundwater sources	
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	GIA Section 4.8 identifies the existing water abstraction and entitlements including nearby basic landholder rights water users. Section 6.9 predicts the potential impacts of the activity on existing groundwater uses, and Section 7.4.4	

	AIP requirement	Proponent response	NSW Office of Water comment
		assesses the risks from these potential impacts. Section 6.12 confirms that no impact is predicted that exceeds the Minimal Impact Consideration criteria listed in Table 1 of the AIP for the relevant classifications of beneficially-used groundwater sources.	
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	Section 6.9 predicts the potential impacts of the activity on existing groundwater uses. No impact is predicted that exceeds the Minimal Impact Consideration criteria listed in Table 1 of the AIP for the relevant classifications of groundwater sources. No impact to high priority GDEs are predicted.	
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	Section 6.9 predicts the potential impacts of the activity on existing groundwater uses.. No negative impacts on water quality are predicted to occur as a consequence of water extraction or beneficial uses of groundwater and surface water.	
7	Potential to cause or enhance hydraulic connection between aquifers?	Sections 7.4.2 and 7.4.3 addresses risk and mitigation of enhanced connectivity between aquifers due to the activity, including via existing and proposed wells, via existing groundwater bores, and via geological faulting.	
8	Potential for river bank instability, or high wall instability or failure to occur?	Not applicable	
9	Details of the method for disposing of extracted activities (for coal seam gas activities)?	Addressed in EIS Chapter 6 and supported by Technical Appendix G2 "Irrigation Concept Design" and Technical Appendix G1 "Managed Release Scheme – Bohena Creek".	

2. Addressing the minimal impact considerations

Table 5. Minimal impact considerations

Aquifer	Alluvial aquifer – Upper and Lower Namoi Groundwater Sources
Category	Highly Productive

Level 1 Minimal Impact Consideration	Assessment
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic post-water sharing plan variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. **OR** A maximum of a 2 metre water table decline cumulatively at any water supply work.	GIA Sections 6.9, 61.2 and 7.4.4. No high-priority GDEs associated with the Upper and Lower Namoi Groundwater Sources have been identified in the assessment area. No high priority culturally significant sites are present in the project area. *The project is considered to be **acceptable** in regard to water table decline at GDEs, culturally significant sites and water supply work.*
Water pressure A cumulative pressure head decline of not more than 40% of the post-water sharing plan pressure head above the base of the water source to a maximum of a 2 metre decline, at any water supply work. **OR**, for the Lower Murrumbidgee Deep Groundwater Source: A cumulative pressure head decline of not more than 40% of the post-water sharing plan pressure head above the top of the relevant aquifer to a maximum of a 3 metre decline, at any water supply work.	No drawdown greater than 0.5 metres is predicted in the Namoi Alluvium, which contains the majority of water supply works. *The project is considered to be **acceptable** in regard to water pressure decline at water supply works.*
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200 metres laterally from the top of high bank or 100 metres vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a reliable water supply.	GIA Section 7.4.4.4. Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for change in water quality of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. No change in the beneficial use category of the groundwater sources is predicted to occur. No mining activity is included as part of the project.

Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 metres laterally from the top of high bank and 100 metres vertically beneath a highly connected surface water source that is defined as a reliable water supply.	*The project is considered to be* ***acceptable*** *in regard to water quality*.

Aquifer	Porous Rock – Great Artesian Basin – Southern Recharge Groundwater Source
Category	**Highly Productive**
Level 1 Minimal Impact Consideration	**Assessment**
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. **OR** A maximum of a 2 metre water table decline cumulatively at any water supply work.	GIA Sections 6.9, 61.2 and 7.4.4. No high-priority GDEs associated with the Pilliga Sandstone aquifer have been identified in the assessment area. The groundwater modelling predicts maximum drawdown less than 0.5 metres in the Pilliga Sandstone at the locations of the springs. No high priority culturally significant sites are present in the project area. *The project is considered to be* ***acceptable*** *in regard to water table decline at GDEs, culturally significant sites and water supply work*.
Water pressure Less than 0.2 metre cumulative variation in the groundwater pressure, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. A cumulative pressure level decline of not more than 15 metres, allowing for typical climatic 'post-water sharing plan' variations. The cumulative pressure level decline of no more than 10% of the 2008 pressure level above ground surface at the NSW State border, as agreed between NSW and Queensland.	GIA Sections 6.9, 61.2 and 7.4.4. The groundwater modelling predicts maximum drawdown less than 0.5 metres in the Pilliga Sandstone at the locations of nine GDEs that may be reliant on surface expression of groundwater (potential Type 2 GDEs). Drawdown at the potential Type 2 GDEs may meet the criteria of 0.2 metres. All potential Type 2 GDEs are assessed to have low ecological values, mainly due to the absence of protected or important wetland species, and due to the heavily or moderately modified nature of the sites. None of the potential Type 2 GDEs meet the definition of a high-priority GDE in NSW, and none support MNES under the EPBC Act.. No high priority culturally significant sites are present in the project area. No impact on pressure levels would occur at the NSW State border as a result of the project. *The project is considered to be* ***acceptable*** *in regard to water pressure decline at water supply works*.
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	GIA Section 7.4.4.4.

	Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for change in water quality of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential changes in water quality of the Pilliga Sandstone due to downward flows from overlying sources are expected to be very slow and imperceptible. No change in the beneficial use category of the groundwater sources is predicted to occur. *The project is considered to be* ***acceptable*** *in regard to water quality.*

Aquifer	Porous Rock – Great Artesian Basin – Surat Groundwater Source
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water table NOT APPLICABLE	
Water pressure Less than 0.2 metre cumulative variation in the groundwater pressure, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. A cumulative pressure level decline of not more than 30 metres, allowing for typical climatic 'post-water sharing plan' variations. The cumulative pressure level decline of no more than 10% of the 2008 pressure level above ground surface at the NSW State border, as agreed between NSW and Queensland.	GIA Sections 6.9, 61.2 and 7.4.4 No high-priority GDEs associated with the GAB Surat Shallow Groundwater Source have been identified in the assessment area. No high priority culturally significant sites are present in the project area. No impact on pressure levels would occur at the NSW State border as a result of the project. *The project is considered to be **acceptable** in regard to water table decline at GDEs, culturally significant sites and water pressure decline.*
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	GIA Section 7.4.4.4 Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for change in water quality of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential changes in water quality of the Pilliga Sandstone due to downward flows from overlying sources are expected to be very slow and imperceptible. No change in the beneficial use category of the groundwater sources is predicted to occur. *The project is considered to be **acceptable** in regard to water quality.*

Aquifer	Porous rock or fractured rock – Gunnedah-Oxley Basin Groundwater Source
Category	Less productive

Level 1 Minimal Impact Consideration	Assessment
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the relevant water sharing plan. **OR** A maximum of a 2 metre water table decline cumulatively at any water supply work.	GIA Sections 6.9, 61.2 and 7.4.4. No high-priority GDEs associated with the Gunnedah-Oxley Basin Groundwater Source have been identified in the assessment area. No high priority culturally significant sites are present in the assessment area. Limited information on water supply works is available for the Gunnedah-Oxley Basin. The Clare Sandstone is the only recognised hydrostratigraphic unit with potentially significant transmissivity within the basin strata directly above the target coal seams; however, it is not generally utilised as a groundwater source due to its large depth below ground surface, unreliable water quality and the availability of alternate, shallower and better quality groundwater sources. *The project is considered to be **acceptable** in regard to water table decline at GDEs, culturally significant sites and water supply work.*
Water pressure A cumulative pressure head decline of not more than a 2 metre decline, at any water supply work.	GIA Sections 6.9, 61.2 and 7.4.4 Limited information about water supply works is available for the Gunnedah-Oxley Basin. The Clare Sandstone is the only recognised hydrostratigraphic unit with potentially significant transmissivity within the basin strata directly above the target coal seams; however, it is not generally utilised as a groundwater source due to its large depth below ground surface, unreliable water quality and the availability of alternate, shallower and better quality groundwater sources. *The project is considered to be **acceptable** in regard to water pressure decline at water supply works.*
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	GIA Section 7.4.4.4

	Depressurisation of the target coal seams for the project would induce small groundwater flows from the Pilliga Sandstone into the underlying depressurised strata within the Gunnedah-Oxley Basin, and even smaller flows from the Namoi Alluvium to the Pilliga Sandstone and Gunnedah-Oxley Basin. Because the direction of induced groundwater flow would be downward toward the depressurised coal seams, the potential for change in water quality of shallow groundwater sources by poorer quality water in the deeper strata is considered to be negligible and not a risk. Potential improvements in water quality of the deep groundwater sources from downward flows are expected to be very slow and imperceptible. No change in the beneficial use category of the groundwater sources is predicted to occur. *The project is considered to be* ***acceptable*** *in regard to water quality.*

Appendix E - IESC Information Requirements Checklist (October 2015)

Description of the proposal	
✓ A regional overview of the proposed project area including a description of the geological basin, coal resource, surface water catchments, groundwater systems, water-dependent assets, and past, current and reasonably foreseeable coal mining and CSG developments. *EIS and GIA Section 1*	✓ A description of the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets. *EIS and GIA Section 1 and 5.6.2*
✓ A description of the statutory context, including information on the proposal's status within the regulatory assessment process and on any water management policies or regulations applicable to the proposal. *EIS and GIA Sections 1.4 and 2*	✓ A description of how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions. *EIS and GIA Sections 2*
Groundwater	
Context and conceptualisation	
✓ Descriptions and mapping of geology at an appropriate level of horizontal and vertical resolution including: • definition of the geological sequence/s in the area, with names and descriptions of the formations with accompanying surface geology and cross-sections. • definitions of any significant geological structures (e.g. faults) in the area and their influence on groundwater, in particular, groundwater flow, discharge or recharge. *GIA Section 4.5*	✓ Data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, hydrographs and hydrochemical characteristics (e.g. acidity/alkalinity, electrical conductivity, metals, major ions). Time series data representative of seasonal and climatic cycles. *GIA Section 5* ✓ Description of the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development. *GIA Section 5.5 and 5.6*
✓ Values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and storage characteristics) for each hydrogeological unit. *GIA Section 5.3 and Appendix C*	✓ Assessment of the frequency, location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water. *GIA Section 4.4.4*

Analytical and numerical modelling	
✓ A detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling. *GIA Section 6*	✓ Identification of the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit. *GIA Section 6*
✓ Undertaken in accordance with the Australian Groundwater Modelling Guidelines, including peer review. *GIA Section 6 and 6.2*	✓ An explanation of the model conceptualisation of the hydrogeological system or systems, including key assumptions and model limitations, with any consequences described. *GIA Section 6.4*
✓ Calibration with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow). *GIA Section 6.5*	✓ Consideration of a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations. *GIA Section 6.4*
✓ Representations of each hydrogeological unit, the thickness, storage and hydraulic characteristics of each unit, and linkages between units, if any. *GIA Section 6.4*	✓ Sensitivity analysis of boundary conditions and hydraulic and storage parameters, and justification for the conditions applied in the final groundwater model. *GIA Section 6.10*
✓ Representation of the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the development activities. *GIA Section 6.4*	✓ An assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios. *GIA Section 6.10*
✓ Incorporation of the various stages of the proposed development (construction, operation and rehabilitation) with predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps. *GIA Section 6.8*	✓ A programme for review and update of the models as more data and information become available, including reporting requirements. *GIA Sections 6.14 and 7.7.3* ✓ Information on the time for maximum drawdown and post-development drawdown equilibrium to be reached. *GIA Sections 6.9, 6.10 and 6.11*

<table>
<tr><th colspan="2">Impacts to water resources and water-dependent assets</th></tr>
<tr><td rowspan="6">✓ An assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts:
Description of any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.
The effects of dewatering and depressurisation (including lateral effects) on water resources, water-dependent assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance.
Description of potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units.
Consideration of possible fracturing of and other damage to confining layers.
For each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the development proposal, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.
GIA Section 6.9</td><td>✓ Description of the water resources and water-dependent assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.
GIA Sections 5, 6.8</td></tr>
<tr><td>✓ For each potentially impacted water resource, a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.
GIA Sections 6 and 7</td></tr>
<tr><td>✓ Description of existing water quality guidelines and targets, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.
GIA Sections 4 and 5</td></tr>
<tr><td>✓ An assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.
GIA Section 6.9.4</td></tr>
<tr><td>✓ Proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.
GIA Section 7</td></tr>
<tr><td>✓ Description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.
GIA Section 7</td></tr>
<tr><th colspan="2">Data and monitoring</th></tr>
<tr><td>✓ Sufficient physical aquifer parameters and hydrogeochemical data to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.
GIA Section 5</td><td>✓ Long-term groundwater monitoring, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.
GIA Section 5</td></tr>
</table>

✓ A robust groundwater monitoring programme, utilising dedicated groundwater monitoring wells and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time. *NGP Water Monitoring Plan*	✓ Water quality monitoring complying with relevant National Water Quality Management Strategy (NWQMS) guidelines and relevant legislated state protocols *NGP Water Monitoring Plan*
Surface water – Not Applicable to GIA	
Content deleted	
Water-dependent assets	
Context and conceptualisation	
✓ Identification of water-dependent assets, including: • Water-dependent fauna and flora supported by habitat, flora and fauna (including stygofauna) surveys. • Public health, recreation, amenity, Indigenous, tourism or agricultural values for each water resource. *GIA Sections 4 and 5*	✓ An estimation of the ecological water requirements of identified GDEs and other water-dependent assets. *GDE Impact Assessment (Appendix B)* ✓ Identification of the hydrogeological units on which any identified GDEs are dependent. *GDE Impact Assessment (Appendix B)*
✓ Identification of GDEs in accordance with the method outlined by Eamus et al. (2006). Information from the GDE Toolbox and GDE Atlas may assist in identification of GDEs. *GIA Section 4.6.1, and GDE Impact Assessment (Appendix B)*	✓ An outline of the water-dependent assets and associated environmental objectives and the modelling approach to assess impacts to the assets. *Adopted from Namoi subregion bioregional assessment (GIA Section 4)*
✓ Conceptualisation and rationale for likely water-dependence, impact pathways, tolerance and resilience of water-dependent assets. Examples of ecological conceptual models can be found in Commonwealth of Australia (2015). *GDE Impact Assessment (Appendix B)*	✓ A description of the process employed to determine water quality and quantity triggers and impact thresholds for water-dependent assets (e.g. threshold at which a significant impact on an asset may occur). *NGP Water Monitoring Plan*
Impacts, risk assessment and management of risks	
✓ An assessment of direct and indirect impacts on water-dependent assets, including ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs. *GIA Sections 6 and 7*	✓ Estimates of the impact of operational discharges of water (particularly saline water), including potential emergency discharges due to unusual events, on water-dependent assets and ecological processes. *NGP Managed Release Sudy*

✓ A description of the potential range of drawdown at each affected bore, and a clear articulation of the scale of impacts to other water users. *GIA Sections 6 and 7*	✓ An assessment of the overall level of risk to water-dependent assets that combines probability of occurrence with severity of impact. *GIA Sections 7*
✓ Indication of the vulnerability to contamination (for example, from salt production and salinity) and the likely impacts of contamination on the identified water-dependent assets and ecological processes. *GIA Sections 6 and 7*	✓ The proposed acceptable level of impact for each water-dependent asset based on the best available science and site-specific data, and ideally developed in conjunction with stakeholders. *NGP Water Monitoring Plan, and GIA Section 7*
☒ Identification and consideration of landscape modifications (for example, voids, onsite earthworks, roadway and pipeline networks) and their potential effects on surface water flow, erosion and habitat fragmentation of water-dependent species and communities. *Not addressed in GIA*	✓ Proposed mitigation actions for each identified impact, including a description of the adequacy of the proposed measures and how these will be assessed. *GIA Section 7*
Data and monitoring	
✓ Sampling sites at an appropriate frequency and spatial coverage to establish pre-development (baseline) conditions, and test hypothesised responses to impacts of the proposal. *NGP Water Baseline Report and Water Monitoring Plan*	✓ Monitoring that identifies impacts, evaluates the effectiveness of impact prevention or mitigation strategies, measures trends in ecological responses and detects whether ecological responses are within identified thresholds of acceptable change. *NGP Water Monitorng Plan*
✓ Concurrent baseline monitoring from unimpacted control and reference sites to distinguish impacts from background variation in the region (e.g. BACI design). *NGP Water Baseline Report*	✓ Regular reporting, review and revisions to the monitoring programme. ☒ Ecological monitoring complying with relevant state or national monitoring guidelines. *Not addressed in GIA*
Water and salt balance and water management strategy	
☒ Quantitative site water balance model describing the total water supply and demand under a range of rainfall conditions and allocation of water for mining activities (e.g. dust suppression, coal washing etc), including all sources and uses. *Not addressed in GIA*	☒ Estimates of the quality and quantity of operational discharges under dry, median and wet conditions, potential emergency discharges due to unusual events and the likely impacts on water-dependent assets. *Not addressed in GIA*

☒ Description of water requirements and onsite water management infrastructure, including modelling to demonstrate adequacy under a range of potential climatic conditions. *Not addressed in GIA*	☒ Salt balance modelling, including stores and the movement of salt between stores taking into account seasonal and long-term variation. *Not addressed in GIA*
Cumulative Impacts	
Context and conceptualisation	
✓ Cumulative impact analysis with sufficient geographic and time boundaries to include all potentially significant water-related impacts. *GIA Section 6.9.4*	✓ Cumulative impact analysis identifies all past, present, and reasonably foreseeable actions, including development proposals, programs and policies that are likely to impact on the water resources of concern. *GIA Sections 4.8, 5.5.6 and 6.9.4*
Impacts	
✓ An assessment of the condition of affected water resources which includes: • Identification of all water resources likely to be cumulatively impacted by the proposed development. • A description of the current condition and quality of water resources and information on condition trends. • Identification of ecological characteristics, processes, conditions, trends and values of water resources. • Adequate water and salt balances. • Identification of potential thresholds for each water resource and its likely response to change and capacity to withstand adverse impacts (e.g. altered water quality, drawdown). *GIA Sections 5 and 6*	✓ An assessment of cumulative impacts to water resources which considers: • The full extent of potential impacts from the proposed development, including alternatives, and encompassing all linkages, including both direct and indirect links, operating upstream, downstream, vertically and laterally. • An assessment of impacts considered at all stages of the development, including exploration, operations and post closure / decommissioning. • An assessment of impacts, utilising appropriately robust, repeatable and transparent methods. • Identification of the likely spatial magnitude and timeframe over which impacts will occur, and significance of cumulative impacts. • Identification of opportunities to work with others to avoid, minimise or mitigate potential cumulative impacts. *GIA Sections 6 and 7*
Mitigation, monitoring and management	
✓ Identification of modifications or alternatives to avoid, minimise or mitigate potential cumulative impacts *GIA Section 7.4*	✓ Identification of cumulative impact environmental objectives *Adopted from the NSW Aquifer interference Policy; GIA Section 2.2.5.1*
✓ Identification of measures to detect and monitor cumulative impacts, pre and post	✓ Appropriate reporting mechanisms *NGP Water Monitoring Pan*

development, and assess the success of mitigation strategies *NGP Water Baseline Plan, Water Monitoring Plan, and GIA Section 7.4*	✓ Proposed adaptive management measures and management responses *NGP Water Monitoring Pan, and GIA Section 7.6*
Subsidence – underground coal mines and coal seam gas	
✓ Predictions of subsidence impact on surface topography, water-dependent assets, groundwater (including enhanced connectivity between aquifers) and movement of water across the landscape *GIA Section 7.4.1*	✓ Description of subsidence monitoring methods, including use of remote or on-ground techniques and explanation of predicted accuracy of such techniques. *GIA Section 7.4.1 and 7.7.2* ✓ Consideration of geological layers and their properties (strength/hardness/fracture propagation) in subsidence modelling. *GIA Section 7.4.1*
Final landform and voids – coal mines (not applicable to NGP)	
Content deleted	
Acid-forming materials and other contaminants of concern (not applicable to NGP)	
Content deleted	
Hydraulic stimulation – coal seam gas (not applicable to NGP)	
Content deleted	

Appendix F - Groundwater Model Review

LAND AND WATER FLAGSHIP
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Review Narrabri Gas Project Groundwater Modelling Report

26 October 2015

Prepared for Santos

[Commercial-in-confidence]

Citation

CSIRO (2015) Review Narrabri Gas Project Groundwater Modelling Report. CSIRO Land and Water Flagship, Adelaide.

Copyright and disclaimer

Important disclaimer

Contents

1 Introduction

This report documents the scientific peer-review by CSIRO Land and Water of the Santos Regional Groundwater (MODFLOW) model of the Gunnedah Basin, created by CDM Smith, according to the groundwater model review principles outlined in the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

The key objective of the review is to assess the suitability of the above mentioned model to evaluate the potential impacts of water extraction for coal seam gas depressurisation on the surface water and groundwater resources in the Gunnedah Basin district.

Santos provided a draft of the groundwater model report together with all the model files on which the draft report was based. As per the conventional peer review process, an initial review was conducted and the main comments of this review were communicated to Santos in order to give Santos and CDM Smith the opportunity to address these comments.

The next section documents the main comments on the model and the responses of Santos / CDM Smith. The following section is the formal evaluation of the final model and report according to the review checklist from the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

2 Main Review Comments

2.1 Fit for purpose

The model objective are stated as (p. 6-1, section 6.1):

- *Estimate changes in hydraulic head in the target coal seams, and head and water table elevations in connected hydrostratigraphic units due to the proposed coal seam gas field development activities;*
- *In areas where drawdown is predicted, estimate the recovery time for hydraulic head to return to pre- coal seam gas development levels;*
- *Identify and quantify the potential groundwater loss or gain in each Water Sharing Plan zone due to intra- and inter-formational flows; and*
- *Identify those landholders who may potentially be impacted by coal seam gas activities and quantify the predicted impacts;*

The groundwater flow model presented is an adequate representation of the regional groundwater flow system in the Gunnedah Basin and the model is suited to make simulations to meet the above stated model objectives.

The reported impacts are a good summary of, and true to, the model simulated values. Considering the availability of data and the limitations of numerical modelling, the reported conclusions on the impacts of the proposed coal seam gas development of Santos on changes in water balance, pressure head and water table are justified.

2.2 Recharge to alluvium

CDM Smith estimated recharge long term average recharge to the alluvial aquifers through inverse modelling. In this approach, an observed head surface is imposed as a prescribed head boundary condition to the alluvial aquifers and the numerical model computes the fluxes that correspond to the hydraulic properties assigned to the aquifer. The prescribed head boundary is subsequently removed and replaced by the computed flux.

This method of recharge flux estimation is justified for the objectives of this model as it fully uses available head observations and represents long term average recharge conditions. The results correspond well to independently estimated values of recharge to the alluvial aquifers.

In the initial review it was pointed out that this recharge flux was not part of the sensitivity analysis and it therefore was not clear to what extent the assumption in estimating this recharge flux would affect the model predictions. It was advised to either quantitatively (through formal sensitivity analysis) or qualitatively (through discussion of the ramifications of the assumptions) address the potential impact of this boundary condition on the predictions of the model.

In reply to this comment, CDM Smith opted to add section 6.10.2 which contains a detailed discussion on the technical complexities of including the recharge boundary in the sensitivity analysis. The key arguments are:

- The recharge estimate is controlled by the hydraulic conductivity of the model. A sensitivity analysis of alluvial recharge on predictions therefore reduces to a sensitivity analysis of the hydraulic conductivity in the alluvial aquifers. Previous studies have shown that the impact of hydraulic conductivity on drawdown in the alluvium is limited.

- Outside of the alluvium, predictions of drawdown are not assumed to be highly sensitive to recharge as the main mechanism for recovery of drawdown is reduced evapotranspiration.

As reviewer, I agree with these arguments and consider the added section as an adequate and thorough qualitative assessment of the sensitivity of the prediction to the recharge boundary applied in this model.

2.3 Sensitivity Analysis

The sensitivity analysis applied is not comprehensive, i.e. not all parameters and parameter combinations are tested. However, the design and interpretation of the sensitivity analysis are justified as they focus on those parameter combinations that, from the understanding of the regional flow system, are expected to have the most effect on the predictions.

It was recommended to emphasize that the parameter combinations for the sensitivity analysis are not equally likely and that some represent extreme conditions. Santos and CDM Smith have added statements expressing such to sections 6.10.3 and 6.11.3.

2.4 Aquitard integrity

Vertical hydraulic conductivity is identified during the sensitivity analysis as the factor that affects the propagation of drawdown through the groundwater system and thus the predictions most. The review pointed out that the first draft of the model report did not discussed the potential of faults to compromise the aquitard integrity and thus the vertical hydraulic conductivity.

Santos and CDM Smith responded by adding section *4.5.11 Faulting Study* in which the results of a separate investigation into faults in the Gunnedah Basin. Of relevance for the assessment of aquitard integrity is the finding that the majority of faults mainly affect the Permian strata and to a lesser extent the Triassic strata. Surface faulting and displacement of Jurassic strata was found to be minor. This also implies that a considerable section of the aquitard sequence separating the target coal seams from the Pilliga Sandstone is largely unaffected by faulting.

3 Formal review checklist

Barnett *et al.* (2012) provide a detailed checklist to guide groundwater model review. Below all entries in this checklist are addressed and commented. Some entries in the checklist are not applicable to this model.

3.1 Planning

3.1.1 Are the project objectives stated?

Yes, the project objectives are to prepare a Groundwater Impact Assessment in support of the Environmental Impact Statement for the Narrabri Gas Project

3.1.2 Are the model objectives stated?

Yes, section 6.1 lists the objectives as:

- *Estimate changes in hydraulic head in the target coal seams, and head and water table elevations in connected hydrostratigraphic units due to the proposed coal seam gas field development activities;*
- *In areas where drawdown is predicted, estimate the recovery time for hydraulic head to return to pre- coal seam gas development levels;*
- *Identify and quantify the potential groundwater loss or gain in each Water Sharing Plan zone due to intra- and inter-formational flows; and*
- *Identify those landholders who may potentially be impacted by coal seam gas activities and quantify the predicted impacts;*

3.1.3 Is it clear how the model will contribute to meeting the project objectives?

Yes, table 6-15 describes the type of output and how this relates to the model objectives.

3.1.4 Is a groundwater model the best option to address the project and model objectives?

Yes, groundwater modelling is the only method to quantify the potential impact of groundwater abstraction associated with coal seam gas development

3.1.5 Is the target model confidence-level classification stated and justified?

Yes, the model confidence level is class 1, which is entirely justified considering

- the large spatial extent of the model domain
- the relative scarcity of data, especially long term monitoring data of the deeper water bearing layers
- the long response time of the groundwater system
- the unprecedented stresses simulated

At this point in time it is not possible to create a model with higher confidence level at this spatial and temporal scale.

3.1.6 Are the planned limitations and exclusions of the model stated?

The initial review highlighted that the report would benefit from a separate section that explicitly states the planned limitations and exclusions.

Santos and CDM Smith have added section 6.14 which lists the main limitations and exclusions of this model.

3.2 Conceptualisation

3.2.1 Has a literature review been completed, including examination of prior investigations?

Yes, a comprehensive and critical review of previous investigations is presented in chapters 4 and 5.

3.2.2 Is the aquifer system adequately described?

Yes

3.2.3 hydrostratigraphy including aquifer type (porous, fractured rock ...)

Yes

3.2.4 lateral extent, boundaries and significant internal features such as faults and regional folds

Yes

3.2.5 aquifer geometry including layer elevations and thicknesses

Section 6.4.2 describes the data sources and the results of the geological model extensively. For completeness, more detail on the interpolation algorithms or routines can be added.

Santos added details of the interpolation methodology to section 6.4.2 to address this comment. The added detail is an adequate and sufficient response.

3.2.6 confined or unconfined flow and the variation of these conditions in space and time?

Yes

3.2.7 Have data on groundwater stresses been collected and analysed?

Yes, sections 5.4 and 5.5 provide a succinct yet comprehensive overview of the stresses on the groundwater system

3.2.7.1 recharge from rainfall, irrigation, floods, lakes

Yes

3.2.7.2 river or lake stage heights

Yes

3.2.7.3 groundwater usage (pumping, returns etc)

Yes

3.2.7.4 evapotranspiration

Yes

3.2.7.5 other?

Yes – mine dewatering

3.2.8 Have groundwater level observations been collected and analysed?

Yes, section 5.4 provides an overview and interpretation of selected bore hydrographs, water table and potentiometric maps and density corrected plots of pressure evolution with depth to assess aquifer connectivity.

3.2.8.1 selection of representative bore hydrographs

Yes

3.2.8.2 comparison of hydrographs

Yes

3.2.8.3 effect of stresses on hydrographs

Yes

3.2.8.4 watertable maps/piezometric surfaces?

Yes

3.2.8.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?

Yes

3.2.9 Have flow observations been collected and analysed?

3.2.9.1 baseflow in rivers

Section 4.4.1 provides a high-level summary of flow statistics of the Namoi and tributaries with sufficient detail for this modelling project.

3.2.9.2 discharge in springs

Section 4.6.1 provides information on the location, source aquifers and discharge of springs and groundwater dependent ecosystems in the study area.

3.2.9.3 location of diffuse discharge areas?

Section 4.6.1 provides information on the location, source aquifers and discharge of springs and groundwater dependent ecosystems in the study area.

3.2.10 Is the measurement error or data uncertainty reported?

3.2.10.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)

Measurement uncertainty does not receive much attention in the report. For completeness, it is recommended to discuss measurement uncertainty with respect to:

- known limitations of the PINNEENA database, especially in the assignment of well screens to aquifers
- drill stem tests and how they compare to piezometric readings

Santos added details on the limitations of the PINNEENA database to section 5.4.1 and comments on the drill stem tests in section 5.4.2 to address these comments. The added detail is an adequate and sufficient response.

3.2.10.2 spatial variability/heterogeneity of parameters

Spatial variability of parameters is implicitly included in the discussions on the ranges of the hydrogeological parameters. Seeing the scarcity of data and the regional extent of the model, not much attention is devoted to spatial heterogeneity, which is entirely justified.

3.2.10.3 interpolation algorithm(s) and uncertainty of gridded data?

For completeness, more detail can be provided on the interpolation algorithms and routines used to create the layer elevations in the Leapfrog geological model and, more importantly, in the water table surface used in the inverse modelling of recharge.

Santos provided more detail on the interpolation methodology used in Leapfrog (section 6.4.2) and on the interpolation technique used for the water table interpolation (section 5.4.3). The added text is an adequate and sufficient response to the comments.

3.2.11 Have consistent data units and geometric datum been used?

Yes

3.2.12 Is there a clear description of the conceptual model?

Section 5 presents a comprehensive overview of the conceptual model. Section 5.6 provides a very good summary of the current understanding of the groundwater flow system and the processes and scales relevant for the impact assessment of depressurisation in the target coal seams.

3.2.12.1 Is there a graphical representation of the conceptual model?

Yes

3.2.12.2 Is the conceptual model based on all available, relevant data?

Yes

3.2.13 Is the conceptual model consistent with the model objectives and target model confidence level classification?

Yes

3.2.13.1 Are the relevant processes identified?

Yes, section 5.6.4 lists the crucial processes that affect the impact assessment.

3.2.13.2 Is justification provided for omission or simplification of processes?

Yes, throughout the report, both in sections 5 and 6, all model choices, including omission or simplification of processes, are justified and documented.

3.2.14 Have alternative conceptual models been investigated?

There is no formal comparison of alternative conceptual models.

3.3 Design and construction

3.3.1 Is the design consistent with the conceptual model?

Yes

3.3.2 Is the choice of numerical method and software appropriate?

3.3.2.1 Are the numerical and discretisation methods appropriate?

Yes

3.3.2.2 Is the software reputable?

Yes

3.3.2.3 Is the software included in the archive or are references to the software provided?

Yes

3.3.3 Are the spatial domain and discretisation appropriate?

3.3.3.1 1D/2D/3D

The 3D spatial domain is appropriate for the stated objectives

3.3.3.2 lateral extent

The lateral extent is mostly based on hydrogeological boundaries and most lateral boundaries are far from the target area and will have limited if any effect on the predictions.

3.3.3.3 layer geometry?

Section 6.4.3.2 and 6.4.3.3 provide a discussion on the translation of the Leapfrog geological model into a numerical grid. The chosen vertical discretisation is appropriate for the model objectives.

3.3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?

The local grid refinement from 5km to 1km in the project area is good compromise between providing local detail and maintaining a numerically and computationally tractable model.

3.3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?

The vertical discretisation is designed to properly handle the propagation of the depressurisation through the groundwater system and is well-suited for the model objectives.

3.3.4 Are the temporal domain and discretisation appropriate?

3.3.4.1 steady state or transient

The choice of a transient model with external forcing stresses constant in time, representing long term average conditions, is justified seeing the lack of long term monitoring data in the deeper hydrostratigraphic units and the long timeframe of predictions.

3.3.4.2 stress periods

Section 6.8 provides detailed information on the water production curves simulated in predictive mode, but it is not explicitly mentioned how these production curves are subdivided in stress periods.

Santos has added a new section, 6.8.4, in which the setup of stress periods is described. This is an adequate and sufficient response to the comment.

3.3.4.3 time steps

Section 6.8.8 provides details on the adaptive time stepping scheme implemented in MODFLOW-SURFACT. This scheme is appropriate for this model.

3.3.5 Are the boundary conditions plausible and sufficiently unrestrictive?

Section 6.4.3.7 provides a detailed discussion of the chosen boundary conditions. The chosen boundary conditions are in line with the conceptual model, plausible and chosen to minimally affect the predictions by placing them far from the development area.

3.3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?

Yes

3.3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?

Yes. The choice of each boundary condition is accompanied by an assessment of how the selected model boundary would affect the predictions. From these assessments it is clear that the risk of the boundary conditions affecting the predictions is sufficiently small not to warrant inclusion of the lateral boundary conditions formally in the sensitivity analysis. The diffuse recharge boundary conditions is a noteworthy exception to this, see next remark.

3.3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?

The method of estimating recharge through inverse modelling is justified for this steady state model with focus of the modelling on the impact of development in the deeper units of the groundwater system.

For completeness, on a technical level, it is worth adding to the discussion why groundwater evaporation and surface water groundwater interaction are still represented in the model as separated processes and not included implicitly in the inverse estimation of recharge.

Santos added detail to sections 6.4.4 and 6.4.6, including the explicit statement that evaporation is only assigned a non-zero value outside the Namoi alluvium. This is an adequate and sufficient response to this comment.

3.3.5.4 Are lateral boundaries time-invariant?

Yes, which is justified from the conceptual model and lateral position of the boundary conditions

3.3.6 Are the initial conditions appropriate?

3.3.6.1 Are the initial heads based on interpolation or on groundwater modelling?

The results of the steady state model are used as initial conditions for the predictive transient model.

Santos added in response to this comment that the simulated initial heads are very similar to the interpolated water table contours due to the inverse recharge estimation method (section 6.8.5). This is a relevant and justified addition to the model report.

3.3.6.2 Is the effect of initial conditions on key model outcomes assessed?

Not applicable as the initial conditions represent steady state long term average conditions in equilibrium with the hydraulic properties

3.3.6.3 How is the initial concentration of solutes obtained (when relevant)?

Not applicable

3.3.7 Is the numerical solution of the model adequate?

3.3.7.1 Solution method/solver

MODFLOW-SURFACT is a robust solver adequate for this kind of long term, regional model

3.3.7.2 Convergence criteria

The convergence criteria are adequate.

3.3.7.3 Numerical precision

The numerical precision is adequate.

3.4 Calibration and sensitivity

As no or very limited data is available that is able to constrain the model parameters crucial to the model predictions, i.e., the hydrogeological properties of the deeper hydrostratigraphic units, the choice is made not to carry out a formal calibration. While there is sufficient data to calibrate the properties of the shallow model layers, a formal calibration is not warranted as most of that data has been used in the inverse modelling of the diffuse recharge.

Section 6.5 does however show that, even without a formal calibration process, the regional steady state model is able to reproduce the observed groundwater head observation to a satisfactory degree for heads both inside and outside the Namoi alluvium. The reporting of the residuals through graphs and summary statistics is clear and appropriate.

3.4.1 Are all available types of observations used for calibration?

3.4.1.1 Groundwater head data

Not relevant

3.4.1.2 Flux observations

Not relevant

3.4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.

Not relevant

3.4.2 Does the calibration methodology conform to best practice?

Not relevant

3.4.2.1 Parameterisation

Not relevant

3.4.2.2 Objective function

Not relevant

3.4.2.3 Identifiability of parameters

Not relevant

3.4.2.4 Which methodology is used for model calibration?

Not relevant

3.4.3 Is a sensitivity of key model outcomes assessed against?

The scenario runs provide an exploration of the sensitivity of the model predictions to changes in vertical conductivity, storage and water production. As these are expected to be the most influential aspects of the model, the results of this sensitivity analysis can be considered an indicative yet adequate assessment of the validity of the model results.

3.4.3.1 Parameters

Yes – vertical hydraulic conductivity and storage parameters

3.4.3.2 boundary conditions

No, although these are assessed qualitatively through discussion in the report

3.4.3.3 initial conditions

Not relevant

3.4.3.4 stresses

Yes – different water production curves

3.4.4 Have the calibration results been adequately reported?

Not relevant

3.4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?

Not relevant

3.4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?

While this is not explicitly mentioned in the report, the discussion and representation of the modelled fluxes between layers illustrates that the model is capable of simulating the vertical gradients in the groundwater system.

3.4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?

Not relevant

3.4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?

Not relevant

3.4.6 Are the calibrated parameters plausible?

Yes – they represent the best estimates from local tests, literature and previous modelling

3.4.7 Are the water volumes and fluxes in the water balance realistic?

Yes, section *6.6 Steady State Water Balance* summarises and highlights the steady state water balance. The reported values are in line with water balance estimates from literature for this region.

3.5 Has the model been verified?

Yes – informally and qualitatively, mainly by comparison to regional estimates of water balance.

3.6 Prediction

3.6.1 Are the model predictions designed in a manner that meets the model objectives?

Yes – the predictions, maximum extent of drawdown, timing of maximum extent of drawdown, time series of exchange fluxes between WSPRA's, are adequate predictors of the impact of coal seam gas extraction.

3.6.2 Is predictive uncertainty acknowledged and addressed?

Yes – through sensitivity analysis

3.6.3 Are the assumed climatic stresses appropriate?

Not relevant

3.6.4 Is a null scenario defined?

Yes

3.6.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?

Yes

3.6.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?

Not relevant

3.6.5.2 Are well losses accounted for when estimating maximum pumping rates per well?

Not relevant

3.6.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?

Not relevant

3.6.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?

Yes

3.6.6 Do the prediction results meet the stated objectives?

Yes

3.6.7 Are the components of the predicted mass balance realistic?

Yes

3.6.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?

Yes

3.6.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?

Not relevant

3.6.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?

No

3.6.7.4 Is diffuse recharge from rainfall smaller than rainfall?

Yes

3.6.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?

No

3.6.8 Has particle tracking been considered as an alternative to solute transport modelling?

Not relevant

3.7 Uncertainty

The sensitivity analysis can be considered a qualitative uncertainty analysis, showing the extremes of the plausible ranges of parameter values. In this case, it is a valid alternative to a formal uncertainty analysis in which estimates of the probability of each prediction (corresponding to a particular plausible combination of parameter set and water production curve) are provided.

3.7.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?

Yes

3.7.2 Is the model with minimum prediction-error variance chosen for each prediction?

Not relevant

3.7.3 Are the sources of uncertainty discussed?

Throughout the model, assumptions and model choices are discussed in terms of their potential effect on the predictions.

3.7.3.1 measurement of uncertainty of observations and parameters

Yes

3.7.3.2 structural or model uncertainty

Yes

3.7.4 Is the approach to estimation of uncertainty described and appropriate?

Yes, see comment under heading 3.7

3.7.5 Are there useful depictions of uncertainty?

Not relevant

4 Conclusions

The regional groundwater MODFLOW model for the Gunnedah basin can be considered state of the art and is suited to assess potential impacts of water extraction for coal seam gas depressurisation on the surface water and groundwater resources in the Gunnedah Basin district.

An initial review based on the first draft of the groundwater model report and associated model files was carried out and Santos and CDM Smith were provided with the opportunity to address and comment on the issues raised during this review. Santos and CDM Smith have comprehensively and thoroughly addressed the comments of the reviewer.

References

Barnett, B.; Townley, L.; Post, V.; Evans, R.; Hunt, R.; Peeters, L.; Richardson, S.; Werner, A.; Knapton, A. & Boronkay, A. (2012) Australian Groundwater Modelling Guidelines. Waterlines Report no82, National Water Commission, Canberra

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FOR FURTHER INFORMATION

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Appendix G - Subsidence Assessment

Subsidence Assessment

Narrabri Gas Project

Prepared for
Santos NSW (Eastern) Pty Ltd

August 2016

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Extraction of coal seam gas has the potential to cause ground deformation at the ground surface in the form of subsidence due to mechanical compaction (due to depressurisation of the coal seams) and matrix shrinkage (due to gas desorption) at depth.

The IESC request that predictions of subsidence and effects from dewatering and depressurisation on surface water, water related assets, groundwater and movement of water across the landscape and possible fracturing of and damage to confining layers, should be assessed.

A baseline for ground motion across the project area has been formed from data gathered during the period from January 2007 to March 2011 using InSAR technology (Altamira, 2013). The majority of the survey area was deemed stable, exhibiting ground movement of less than 8 mm/year.

Subsidence estimates in the proposed Narrabri Gas Project area have been made using the *Linear Elastic Theory*' method and the *Compaction at a Specific Location* method as per the IESC guidance. This calculates subsidence at depth by mechanical compaction only. Subsidence through matrix shrinkage (gas desorption) could not be calculated.

Subsidence calculations for mechanical compaction suggest a total maximum subsidence of between 137 mm and 205 mm. This calculation is representative of subsidence expected at depth within the coal seams and hydraulically connected strata. This is likely to equate to negligible disturbance at the ground surface due to the large depth to the coal seams and the presence and thickness of a number of highly competent rock formations. The subsidence gradient or tilt was calculated at a 0.002 % change in slope.

The likelihood of impact to MNES and water resources (surface topography, water related assets, groundwater and movement of water across the landscape and possible fracturing of and other damage to confining layers) associated with subsidence arising from the proposed Narrabri Gas Project has been assessed as being **low to insignificant**.

The likelihood of impact to surface structures such as low height earthen dams is predicted to be **very low**. The predicted subsidence due to the Narrabri Gas Project are orders of magnitude less than mining induced subsidence (predicted between 2200 mm and 2400 mm at the nearby Narrabri Coal Mine) and only slightly larger than agricultural induced subsidence (predicted maximum of 167 mm; noting however that these occur over a significantly larger area).

1 Introduction

Santos NSW (Eastern) Pty Ltd (Santos) is proposing to develop natural gas from coal seams in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri.

The Narrabri Gas Project (the project) seeks to develop and operate a gas production field, requiring the installation of gas wells, gas and water gathering systems, and supporting infrastructure. The natural gas produced would be treated to a commercial quality at a central gas processing facility on a local rural property (Leewood), approximately 25 kilometres south-west of Narrabri. The gas would then be piped via a high-pressure gas transmission pipeline to market. This pipeline would be part of a separate approvals process and is therefore not part of this development proposal.

The project will target coal seam gas resources associated with Early Permian coal seams of the Maules Creek Formation and Late Permian coal seams of the Black Jack Group, located at depths ranging from 300 m to 1200 m below ground level in the northern portion of the Gunnedah Basin.

Extraction of coal seam gas has the potential to cause subsidence both at depth, from compaction of the coal seam and hydraulically connected strata, and at the ground surface, through settlement of the underlying compacted layers. Subsidence is the motion of a point either at or below the ground surface as it shifts downward relative to a datum such as sea-level. The opposite of subsidence is uplift, which results in an increase in elevation. Subsidence can have a number of causes such as dissolution of limestone (karstic systems), dissolution of soils by fluid flow in the subsurface, underground mining activities, petroleum extractions, elastic deformation owing to groundwater level fluctuations, or be related to geological events such as earthquakes.

The extraction of coal seam gas from a gas field, requires the initial pressure in the producing coal seams to be dropped (depressurised). As depressurisation of the coal seams proceeds, gas desorption commences and the combined water and gas pressure in the fractures/cleats and pores is reduced, thus increasing the vertical effective stress (i.e. the stress that is carried on the rock skeleton due to the weight of the overburden to the surface). An increase in the vertical effective stress may result in collapse of the cleat system and thus compaction of the coal seam and of hydraulically connected strata that are similarly depressurised. Secondly, subsidence within the coal seam may occur from a reduction in matrix volume as gas is desorbed for extraction.

The level of subsidence experienced at depth from depressurisation of the coal seam is directly proportional to the thickness and strength of the depressurised formations, and the reduction in coal seam pressure. The level of subsidence experienced at depth from desorption of gas is a function of the sorption behaviour of the coal seam gas only and not related to changes in overburden pressure (depressurisation).

Subsidence resulting from coal seam gas extraction detected at the ground surface (through settlement of underlying layers) depends on a number of factors including the thickness, strength and pressures of the coal seam overburden.

The process of subsidence at depth due to depressurisation of coal seam gas formations may take many years to become measurable at the surface following the onset of coal seam gas production. Furthermore, the complete expansion of the coal seam gas industry into new development areas may take several decades. Therefore, effective monitoring of ground movement and identification of surface subsidence potentially attributable to coal seam gas extraction requires a long term, regional scale ground motion monitoring technique. In line with this Santos has adopted interferometric synthetic aperture radar (InSAR) technology to detect ground movement and deformation across the entire extent of the Narrabri Gas Project Area. Santos commissioned a baseline subsidence assessment of the project area which utilised InSAR data from 2007 to 2011, the main outcomes of which are summarised in this report.

An assessment of potential subsidence at surface (through settlement of underlying formations) and depressurisation-induced subsidence at depth (within the coal seam and hydraulically connected strata) is required by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) for coal seam gas production projects.

This report details the methodology and estimation of the amount of potential subsidence at depth (within the coal seam and hydraulically connected strata) and at ground surface arising from the proposed depressurisation of the target coal seams for the Narrabri Gas Project. Secondly, this report presents an impact assessment on the likelihood of the predicted surface/subsurface subsidence to impact Matters of National Environmental Significance (MNES) and surface infrastructure.

1.1 Purpose of this technical report

This report aims to address the issue of subsidence in relation to the Narrabri Gas Project activities and assess potential subsurface and surface impacts that could occur. The report:

- Presents the IESC (2014) requirements with regards to subsidence relating to coal seam gas projects;
- Describes the mechanisms of potential subsidence at depth through the extraction of coal seam gas;
- Summarises how Santos has established a baseline for ground motion that was observed within the project area from 2007 to 2011 and prior to the onset of coal seam gas development using InSAR technology;
- Describes the methodology and calculates the maximum potential subsidence at depth (within the coal seam and hydraulically connected strata) that may be induced by proposed depressurisation of coal seam gas development beneath the project area;
- Describes the methodology of predicting subsidence at depth through degassing (desorption of gas for extraction) of the coal seam. Calculation of potential subsidence at depth related to degassing is outside the scope of this report.
- Considers the significance of the project-induced potential subsidence should it occur in the context of naturally-induced permanent or cyclical ground movements and potential subsidence at surface, produced through other industries, such as irrigators, active in the project area; and
- Presents the potential impacts of subsidence in the project area.

1.2 IESC requirements

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) requires that ‘the assessment of impacts should identify the potential impacts to water resources and water related assets from the proposal. The assessment should include but not be limited to:

> **Predictions of subsidence and effects** from dewatering and depressurisation (including lateral effects) on surface topography, water related assets, groundwater and movement of water across the landscape and possible fracturing of and other damage to confining layers.’

There are no direct requirements on the project for predicting, monitoring or managing subsidence in the New South Wales State Significant Development Secretary's Environmental Assessment Requirements, though there is a requirement to assess the likely impact of the development on soils and land capability of the site and surrounds.

2 Subsidence as a result of coal seam gas production

Coal seam gas is gas (methane) adsorbed to the macropores (cleats/fractures) and micropores (coal matrix) of the coal seam. In order to release the gas for production, the pore pressure within the coal seam needs to be decreased (depressurised) which is achieved by abstraction of groundwater. Reduction of pore pressure can cause subsidence within the coal seam and within over/underlying strata that are in hydraulic connection to the coal seam, due to the resultant increase in effective stress which has the potential to cause:

i. collapse of the cleat system, through removal of groundwater support, resulting in mechanical compaction of the coal seam and of over/underlying depressurised strata; and
ii. a reduction in matrix volume, associated with gas desorption (degassing), as gas that was previously sorbed to the solid phase of the coal is desorbed for extraction. This is a thermodynamic process termed shrinkage.

The assessment of subsidence within this report forms part of a groundwater impact assessment. As such, the calculations used to estimate subsidence of the coal seam and hydraulically connected strata within this report estimate the potential subsidence due to the process of mechanical compaction of the coal seam (i.e. from the removal of groundwater support).

The methodology to calculate potential subsidence at depth due to coal matrix shrinkage (degassing) is described in Section 4.2. The IESC (2014) state that matrix shrinkage is highly variable but can reach in excess of 1% of the coal seam thickness. However, the IESC (2014) also state that the process of subsidence due to degassing may not hold where a non-uniform distribution of depressurisation occurs. An estimation of potential subsidence associated with gas desorption (rather than removal of groundwater support) is not within the remit of a groundwater impact assessment. Therefore, the methodology of calculation of potential shrinkage has been included within this report for information only and no addition of subsidence related to shrinkage has been applied to reported estimates.

The amount of subsidence experienced at depth, within the coal seam and hydraulically connected strata, is mainly dependent on the geological sequence (e.g. type of lithology, fracture spacing, thickness of units and connectivity between the coal seam and over/underlying strata) and the required depressurisation.

The depressurisation of coal seams for gas extraction results in a uniform compaction of the coal seam. The uniform compaction at depth will likely be supported by competent overlying lithological units (e.g. sandstone and other sedimentary rock). The actual amount of subsidence transmitted to and observed at the surface will therefore be lower than that calculated for the target coal seam (IESC, 2014).

There is currently no confirmed subsidence resultant from coal seam gas development in Australia (IESC, 2014). Whilst some projects are at an early stage of development (and hence have experienced limited depressurisation), Santos' Fairview Gas Field has been producing gas for approximately 20 years. Table

2-1 presents the current predictions of depressurisation-induced subsidence (at depth, within the coal seams and interburden) for Australian coal seam gas projects.

Table 2-1: Currently available subsidence predictions for Australian coal seam gas projects (IESC, 2014)

Company	Gas Field	Maximum predicted subsidence at depth (mm)	Predicted subsidence at surface comment
Santos GLNG	Roma	280 (Walloon Coals)	-
	Arcadia	150 (Bandana Coals)	-
	Fairview	150 (Bandana Coals)	-
Australia Pacific LNG		850 (Walloon Coals)	Deformation is unlikely to be expressed at the surface (as land subsidence)
AGL Energy	Camden	'A few mm', 'negligible'	
Queensland Gas Company		Up to 180 in the north, 80 mm in the central gas fields, and up to 145 mm in the south (Walloon Coals)	Propagation to the surface considered unlikely.

Subsidence of the ground surface attributable to coal seam gas projects in the Powder River Basin, Wyoming, US, has been confirmed where a maximum surface subsidence between 40 mm and 60 mm was measured (IESC, 2014).

3 Baseline Subsidence Monitoring

3.1 Subsidence monitoring technique

Santos is using interferometric synthetic aperture radar (InSAR) technology to detect surface ground movement and deformation across the entire extent of the Narrabri Gas Project Area using Altamira Information whose core competence is radar imagery. InSAR is an aerial or satellite based radar technology used in geodesy and remote sensing. The method uses two or more synthetic aperture radar images to generate maps of surface deformation or digital elevation by analysing differences in the phase of the waves returning to the satellite. The satellite based geodetic survey is considered industry best practice and will identify cumulative subsidence for all contributing factors (such as agricultural extraction, seasonal variation, coal seam water extraction) to an accuracy of millimetres.

3.2 Subsidence baseline monitoring undertaken

Santos commissioned Altamira Information to undertake a baseline subsidence assessment using InSAR technology of an approximate area of 16,000 km^2 in the Gunnedah Basin (Altamira, 2013). The assessment utilised data from January 2007 to March 2011 comprising approximately 8 million data points. The assessment concluded:

- The density of measurement points was generally high except over agricultural fields where the density was low due to the effects of continual temporal changes resultant of intense agricultural activities;

- The majority of the survey area was deemed stable, exhibiting ground movement of less than 8 mm/year;
- There are several isolated areas showing ground movement over 16 mm/year associated with anthropogenic activities: irrigation ponds (likely associated with variations in pond water level between surveys) and exploration/appraisal well pads (likely associated with changes in ground levels from compaction during well pad construction);
- There are several patches showing ground movement over 16 mm/year associated with more natural causes of ground motion: riverbanks (where erosional and depositional processes occur) and areas next to the main N-S thrust fault system (the Hunter-Mooki-Goondiwindi Fault system) that flanks the Gunnedah Basin; and
- InSAR data are suitable to track the motion of the ground with suitable accuracy and precision for Santos' requirement to identify and monitor surface subsidence potentially attributable to coal seam gas extraction.

4 Methodology for subsidence prediction

The following section details:

- Two methodologies used to estimate depressurisation-induced potential subsidence at depth (within the coal seam and hydraulically connected strata/interburden) and the adopted parameters used in these methodologies; and
- The methodology to calculate potential subsidence at depth due to matrix shrinkage (degassing) suggested by the IESC (2014). Calculation of potential subsidence related to degassing is outside the scope of this report.

4.1 Mechanical compaction at depth (depressurisation)

An estimation of potential subsidence at depth through depressurisation-induced mechanical compaction of the coal seam and interburden has been made using two predictive methods:

- Linear Elastic Theory method (used in subsidence calculations for the Surat Basin, Queensland, such as Santos GLNG Coal Seam Gas Water Monitoring and Management Plan (CWMMP) and accepted by SEWPaC at the time of project approval); and
- The 'Compaction At A Specific Location' method (described in IESC, 2014).

The difference between the two methodologies is the parameter used to describe the deformation of the rock itself. The *Linear Elastic Theory* method uses Young's Modulus, an elastic property of the rock, to represent the rock type. *The Compaction at a Specific Locat*ion method considers the ratio of axial compression to lateral strain using Poisson's Ratio with Young's Modulus to calculate a coefficient of volume compressibility.

Both calculations assume:

- Ground conditions are considered uniform;
- Compaction is assumed to be one-dimensional; and
- Linear elastic ground compaction.

4.1.1 Linear Elastic Theory method

According to the *Linear Elastic Theory*, compression (ΔZ) of a given geological formation resulting from an increase in effective vertical stress within that formation is given by:

$$\Delta Z = Z_1.(P_{i2} - P_{i1})/E \qquad \text{(Equation 1)}$$

Where:	Z_1	=	thickness of the formation prior to compression (m);
	P_{i2} - P_{i1}	=	change in pore pressure resulting from depressurisation (equal to the increase in vertical effective stress) (Mpa); and
	E	=	Young's Modulus (Mpa)

With the compression being calculated for each formation experiencing drawdown and the total compression/subsidence for all formations combined.

4.1.2 Compaction at a Specific Location method

A methodology described in the IESC guidance (2014) states compaction (S) directly due to groundwater pressure changes in the geological unit at a given location (at the well) is given by:

$$S = \Sigma^{n}_{i=1}\ m_v.\Delta\sigma_i.H_i \qquad \text{(Equation 2)}$$

Where:	m_v	=	the coefficient of volume compressibility (Mpa^{-1})
		=	$(1-2\nu).(1+\nu)/E.(1-\nu)$
	ν	=	Poisons Ratio
	E	=	Young's Modulus;
	~~	~	the change in vertical effective stress (Mpa); and
	H	=	thickness of the formation prior to compaction (m)

4.1.3 Selection of parameters

The parameters used in the two methodologies described above, namely, Linear Elastic Theory (Section 4.1.1) and Compaction at a Specific Location method (Section 4.1.2), are detailed below along with the methodology/justification of selection.

<u>Unit thickness</u>

Values for the thicknesses of the coal seams and associated interburden are based on the geological and coal seam gas appraisal corehole, Dewhurst 7. Dewhurst 7 was selected as it encountered the greatest total thickness of coal seams in the project area. Since a greater thickness of coal will result in a higher estimated potential subsidence, this approach provides a conservative estimate of the maximum possible subsidence at depth that may occur for the project area as a whole.

The interburden thickness is the sum of the non-coal strata, both within each seam (where seams are split) and extending from the roof of the lower seam to the floor of the overlying the seam. For the purposes of these calculations, overlying strata considered to be in hydraulic continuity with the seam and extending upward to a designated capping layer have also been included in the value for interburden. A capping layer is considered to comprise a relatively lower permeability stratigraphic unit that will impede the vertical depressurisation from the coal seam to overlying units. A suitable capping layer was chosen based on lithology descriptions of cuttings and core from Dewhurst 7.

Adopted thicknesses are as follows:

- Hoskissons Interburden: 7.0 m
- Hoskissons Coal Seam: 10.5 m
- Maules Creek Coal Seams: 29.0 m
- Maules Creek Interburden: 69.6 m

A thickness of seven metres of the Black Jack Group directly overlying the Hoskissons seam was included in the interburden thickness. These strata are capped by a 1.6 m thick layer of siltstone.

The interburden of the Maules Creek seams comprise the total thickness of non-coal layers between each of the four coal seams (Rutley, Namoi, Parkes and Bohena), plus a 0.65 m thick layer of mudstone which directly overlies the Rutley Seam. Throughout the interburden of the Maules Creek seams there are varying thicknesses of siltstone and mudstone which would likely impede connection between the coal seam and overlying layers, however, including the whole thickness of the interburden between seams provides a conservative estimate of subsidence.

<u>Depressurisation and initial hydraulic head</u>

The maximum depressurisation, or drawdown, of confined hydraulic head in each coal seam is governed by the gas desorption characteristics of the coal seam. Previous calculations suggested depressurisation to 80 m above the top of the coal seams was required to allow gas desorption. For this assessment, the target residual hydraulic head is assumed to be to 50 m above the top of the coal seam gas bearing unit and is considered to be a conservative estimate in terms of maximum potential depressurisation.

The depths to the top of the seams included in this assessment have been taken from the geological log of corehole Dewhurst 7:

- Hoskissons Coal Seam: 692 m bgl
- Maules Creek Coal Seams:
    - Rutley Seam: 989 m bgl
    - Namoi Seam: 1010 m bgl
    - Parkes Seam: 1034 m bgl
    - Bohena Seam: 1055 m bgl

The magnitude of depressurisation or drawdown of hydraulic head is determined both by the required residual head above the target seam and the initial hydraulic head in the target formation (coal seam gas bearing unit). The initial heads applied in this assessment comprise:

- 72 m bgl for the Maules Creek Seams and interburden. Head taken from Dewhurst 7 data corrected for salt water (salt water head allows for a conservative estimate, freshwater corrected head is 101 m bgl).
- 16 m bgl for the Hoskissons Seam and Interburden. Head taken as an average of salt water corrected head of Bohena 12C (21 m bgl, located 12 km North West of Dewhurst 7) and Bibblewindi 11C (12 m bgl, located 10 km south west of Dewhurst 7).

<u>Young's Modulus (E)</u>

Values of Young's Modulus (E) are taken from IESC guidance (2014) which presents a range of E for certain Australian rock types. In each case the lowest value of E in the referenced range has been utilised to provide a conservative estimate. Lithology of interburden was determined from descriptions of cuttings and core in Dewhurst 7.

- Young's Modulus for coal: 2 GPa
- Young's Modulus for siltstone/sandstone: 19 GPa (lowest in sandstone range).
- Young's Modulus for mudstone: 10 GPa

Poisson's Ration (ν)

Literature values for Poisson's Ratio (˜) show it to be in the order of 0.10 to 0.25 for crystalline rock and of 0.20 to 0.45 for soils (ICE, 2012). Typical values for coal have been reported as between 0.31 and 0.39 (Greenhalgh and Emerson, 1986; Chi an Yuwei, 2013).

A value of 0.25 is often used for most rocks (IESC, 2014; Greenhalgh and Emerson, 1986). In order to provide a conservative estimate, initial calculations have assumed ˜ = 0.25 for all units.

A second calculation using ˜ = 0.35 for the coal seams only, was undertaken as a sensitivity analysis. An increased Poisson's Ratio reduces the amount of subsidence predicted.

4.2 Matrix shrinkage (degassing)

The IESC (2014) provides a method for predicting the amount of subsidence at depth due to degassing (desorption of gas) of the coal seams resulting in matrix shrinkage. The methodology is detailed below for information only as a prediction of subsidence relating to desorption is outside the remit of this report.

Assuming the geological materials are significantly constrained in the horizontal direction, shrinkage may be estimated considering the vertical compression of the coal. The following equation can be used, where the linear vertical strain (i.e. the change in the height of the coal seam) due to desorption of gas is defined as:

$$\varepsilon_{sh} = S_{max} P_p / P_L + P_p$$ (Equation 3)

Where:

Where:	ε_{sh}	=	the desorption-induced strain
	S_{max}	=	is the strain at infinite pore pressure
	P_p	=	is the current pore pressure
	P_L	=	the pore pressure at which strain is equal to one-half of the current S_{max}

The parameter values are measured by conducting laboratory tests on coal samples. These parameter values are not available for the Maules Creek Formation or the Hoskissons Formation.

4.3 Subsidence gradients

In terms of predicting potential impacts of estimated subsidence, it is not so much the absolute value of subsidence but the differential settlement at the surface which is of greatest potential impact. In the short term, the field will be developed progressively with the surface expression varying temporarily and spatially. In the long term, subsidence over the project area is anticipated to be largely uniform.

In order to calculate the maximum predicted tilt, the subsidence estimates for the Maules Creek seams and interburden and the Hoskissons seam and interburden are divided by the (minimum) lateral distance between the project area and the predicted all-time maximum extent of drawdown for that unit (CDM Smith, 2016).

This method assumes the entire project area will be impacted by the maximum subsidence reported, providing a worst case estimate of tilt.

5 Results of subsidence predictions

The following sections present the range of subsidence estimates and gradients calculated by the methodologies presented in Section 4.

5.1 Estimated subsidence at depth

Estimates from the three calculations (*Linear Elastic Theory* and two calculations of *Compaction at a Specific Location* using different Poisson's Ratios) are presented in Table 5-1. The estimates provide a probable worst case range of depressurisation-induced (mechanical compaction) subsidence at depth (within the coal seams and interburden) of between 137 mm and 205 mm. This range is the total maximum depressurisation-induced subsidence (from mechanical compaction) expected at depth, within the coal seams and associated interburden, at a time when both coal seam gas bearing units are depressurised to 50 m above the top of the coal seam.

Table 5-1: Subsidence Estimates for the Narrabri Gas Project at the location of Dewhurst 7

Unit	Subsidence Prediction at Depth (within the coal seam and interburden) (mm)		
	Linear Elastic Theory (Eq. 1)	Compaction At A Specific Location (Eq.2).	
		Poisson's Ratio of: 0.25 for all	Poisson's Ratio of: 0.35 for coal; and 0.25 for interburden
Hoskissons Coal Seam & Interburden	37	30	24
Maules Creek Coal Seam & Interburden	168	140	113
Total	205	170	137

5.2 Estimated subsidence at surface

The calculated subsidence estimates (Table 5-1) are representative of the compaction expected at depth within the coal seams and hydraulically connected strata. Given that the target coal seams are several hundred metres below the ground surface (between 300 m bgl and 1200 m bgl) and sit within a sequence of varying lithologies containing a significant thickness of competent rocks, including the Porcupine Formation, Brigalow Formation, Digby Formation, Napperby Sandstone, Garrawilla Volcanics and Pilliga Sandstone, the considerable depth of burial, and small amount of predicted subsidence due to compaction of the coals at depth, the subsidence at surface is likely to be far less than the maximum estimate of subsidence at depth (205 mm).

5.3 Subsidence gradients

The subsidence gradient has been calculated by measuring the shortest distance from the eastern side of the project area, which is the area considered to experience maximum drawdown and therefore the maximum amount of subsidence, to the maximum all-time extent of drawdown of hydraulic head (predicted by the numerical modelling conducted as part of the Groundwater Impact Assessment) (CDM Smith, 2016). The distances used within the calculation are 6.2 km (Hoskissons seam) and 7.8 km (Maules Creek seams). Predicted gradients for the Hoskissons and Maules Creek seams and interburden are:

- Hoskissons Seam: 0.004 mm/m to 0.06 mm/m
- Maules Creek Seams: 0.01 mm/m to 0.02 mm/m

The calculated maximum tilt equates to effectively 0.002% change in gradient.

6 Non coal seam gas related ground movements

To provide some context to the subsidence predictions as associated with coal seam gas extraction of the Narrabri Gas Project, anticipated values of subsidence related to natural ground movements, agricultural processes and historical use of the Great Artesian Basin (GAB) aquifers are briefly outlined below.

6.1 Solid Earth Tide

Much like the oceans, the Earth's surface is cyclically displaced by lunar and solar gravitation. This motion is termed the solid Earth tide and can account for natural vertical displacements of the earth surface of up to approximately 300 mm (Phillips *et al.,* 1999) or 400 mm (Watson *et al.*, 2006) at semi-diurnal and diurnal frequencies. The total maximum subsidence predicted associated with the Narrabri Gas Project is 205 mm at depth, 100 mm less than natural variations of the Earth surface that occur on a semi-diurnal and diurnal frequency.

6.2 Agriculture

Agricultural processes continually impact the level and form of ground surface. Groundwater extraction for agricultural and irrigation purposes in the San Joaquin Valley, California, has caused approximately 8000 mm of subsidence within 50 years, representing one of the largest alterations of land surface attributed to humankind (IESC, 2014).

The subsidence baseline of the Narrabri Gas Project Area undertaken by Altamira (2013) identifies areas of surface subsidence located at the edge of agricultural fields of up to 80 mm (data between 2007 and 2011). Altamira state that detailed InSAR measurements cannot be retrieved over fields due to extensive agricultural activity, meaning land deformation due to agricultural processes is not monitored.

An estimation of subsidence that could have arisen from abstraction from the Namoi Alluvium of three registered groundwater bores located within the Namoi catchment is presented in Table 3. The subsidence estimates were calculated using the *Linear Elastic Theory* method (Section 4.1.1) which was shown to produce the most conservative estimate of subsidence in Section 5 of this report. Thickness and lithology of the alluvium was taken from the relevant bore logs. The bore logs detail the Namoi

Alluvium to comprise unconsolidated sands, gravels and sandy clays. Young's Modulus for the alluvium was taken as 10 Mpa (the most conservative value for Young's Modulus of soils presented in ICE, 2012, (range was 10 Mpa to 100 Mpa)). The drawdown amount was taken from hydrographs presented in the Namoi Catchment Study (Schlumberger Water Services, 2012).

The maximum predicted subsidence was 167 mm (GW021412). This predicted subsidence for the Namoi Alluvium is in the same order of magnitude calculated for the subsidence at depth associated with the Narrabri Gas Project. Additionally, subsidence impacting the Namoi Alluvium will be manifest at the surface as the unit shallow and overlain by units of clay only.

Table 6-1: Subsidence Estimates for the Namoi Alluvium and Pilliga Sandstone as a result of historical decline in head

Registered Bore	Unit (Location)	Thickness (m)	Drawdown (m)	Timeframe	Subsidence prediction Linear Elastic Theory (Eq.1) (mm)
GW030232	Upper Namoi Alluvium (Approx. 50 km SE of Narrabri)	13	5	36 years (1972-2008)	61
GW021412	Lower Namoi Alluvium (Wee Waa)	43	4	40 years (1968-2008)	167
GW025144	Lower Namoi Alluvium (Barren Junction)	6	13	40 years (1968-2008)	74
GW004399	Pilliga Sandstone (Approx. 50 km NW of project area)	110	31	90 years (1900-1990)	1.8

6.3 Historical depressurisation of the Great Artesian Basin aquifers

The aquifers of the Great Artesian Basin have historically been exploited to provide local water supply, predominately used for stock watering. Hydrographs for artesian bores in the Pilliga Sandstone presented in the Namoi catchment study (Schlumberger Water Services, 2012) show a maximum head decline of approximately 80 m from 1900 to 1990.

An estimate of subsidence due to the decline in head in one bore sourced from the Pilliga Sandstone (GW004399) was calculated using the *Linear Elastic Theory* method. GW004399 was selected as the full thickness of the Pilliga Sandstone was proven in drilling and detailed on the bore log. A Young's Modulus of 19 Gpa was used, commensurate with the value used to calculate subsidence within sandstone units of the coal seam interburden in Section 5.

The total subsidence corresponding to a 30 m decline in groundwater levels within the bore was 1.8 mm (Table 3). These minimal subsidence values from a relatively large decline in head adds weight to the potential bridging impact of competent units such as the Pilliga Sandstone.

6.4 Narrabri Coal Mine (Whitehaven)

As noted in Section 1.1, subsidence can occur through various natural and anthropogenic mechanisms. In addition to the baseline ground movement assessed by Altamira (2013), subsidence is also predicted to occur at the nearby Whitehaven Narrabri Coal Mine, which potentially may interact cumulatively with predicted subsidence related to coal seam gas activities.

Stage 2 of the underground Narrabri Coal Mine is proposed to extract 26 longwall panels from the Hoskissons Seam. Maximum subsidence for the longwall panels has been estimated between 2200 mm and 2400 mm, reduced to a minimum of 800 mm where the Garrawilla Volcanics have a high enough strength to reduce the subsidence (Ditton Geotechnical Services, 2009). The maximum tilt estimated for the longwall mining was 51 mm/m.

A maximum cumulative subsidence from stage 2 works at the Narrabri Coal Mine and the Narrabri Gas Project is therefore predicted to be 2600 mm (conservatively 205 mm associated with the extraction of coal seam gas, equating to 7 % of total predicted cumulative subsidence).

A maximum cumulative tilt from the stage 2 works at Narrabri Coal Mine and the Narrabri Gas Project is therefore predicted to be 51.1 mm/m (0.1 mm associated with the extraction of coal seam gas, equating to 0.2 % of total cumulative tilt).

7 Potential impacts due to predicted coal seam gas related subsidence

Subsidence (at the surface) can have potential impacts on water resources and infrastructure depending on the sensitivity of such values and the severity of the subsidence. There is currently no reference to adverse impacts arising from subsidence due to coal seam gas extraction (IESC, 2014). However, an assessment of the likelihood of potential impacts occurring as a result of predicted subsidence associated with the Narrabri Gas Project is made in the following section.

The IESC (2014) requirement for predictions of subsidence and effect associated with coal seam gas projects (Section 1.2) focusses on potential impacts to water resources/Matters of National Environmental Significance (MNES).

The IESC Knowledge Report (IESC, 2014) also discusses potential impact to surface infrastructure, including buildings, dams, roads and pipelines. There is no direct IESC (2014) requirement to assess impacts to surface infrastructure.

The New South Wales State Significant Development Secretary's Environmental Assessment has a requirement to assess the likely impact of coal seam gas development on soils and land capability of the site and surrounds (Section 1.2).

Potential impacts to water resources and surface infrastructure as a result of predicted subsidence are discussed in the following section. Potential impacts are considered based on the following:

- the predicted maximum subsidence at depth (within the coal seam and hydraulically connected strata) associated with depressurisation is **205 mm**;
- the predicted maximum tilt (at ground surface) arising from depressurisation-induced subsidence is **<0.02 mm/m** or **0.002 %.**
- the thickness of successive competent strata overlying the coal seams (impeding vertical propagation of subsidence to the surface), is 300 m to 1200 m; and
- the predicted subsidence at surface is likely to be far less than the predicted maximum subsidence at depth (<205 mm).

7.1 Water resources

The maximum depressurisation-induced subsidence predicted at the surface (<250 mm) and maximum tilt (0.002 % change) is unlikely to impact surface hydrology networks due to their small magnitude.

The main groundwater resources in the project area are the shallow Pilliga Sandstone and alluvium. These shallow formations are unlikely to be affected by the predicted subsidence at depth due to the unlikely propagation of subsidence to the surface (through 300 m to 1200 m thickness of overburden).

Potential groundwater dependent ecosystems (GDE) identified to date, such as Hardy's and Eather Springs, are sourced by the alluvium and Pilliga Sandstone and are therefore unlikely to be impacted.

Applying the MNES Significant Impact Guidelines – Version 1.1 (Commonwealth of Australia, 2009) the potential impacts to MNES/water resources arising from predicted depressurisation-induced surface subsidence are assessed as being **low to insignificant**.

7.2 Surface infrastructure

The main reason for surface subsidence to impact infrastructure such as drainage channels, roads, power lines and dams is the generation of large surface gradients and tilts arising from differential settlement of underlying formations. The Impacts of surface subsidence need to be assessed on a case by case basis. However, examples cited in the IESC Knowledge Report (IESC, 2014) suggest assessment criteria for surface infrastructure that include:

- **Drainage channels/stormwater systems:** require case by case inspection especially where tilt is above 4mm/m *(maximum predicted tilt is < 0.02 mm/m)*;
- **Roads:** acceptable settlement suggested as 0.3 % in 40 years for concrete pavements measured over 10 m half cord length or 0.5 % in 20 years for flexible pavements;
- **Power lines:** generally accepted a tilt of below 20 mm/m in the area of the pole/power line will not pose significant problems *(maximum predicted tilt is < 0.02 mm/m)*; and
- **Dams:** General criteria for assessment of the effect of subsidence on the performance of dams are not available. Dams within the project area are likely to be low height earthen dams which will be most impacted by large tilts in differential settlement *(maximum predicted tilt is < 0.02 mm/m)*.

Based on the above example assessment criteria the likelihood of impact to surface infrastructure is determined to be **very low**.

8 Conclusions

The report concludes the following:

- Extraction of coal seam gas has the potential to cause ground deformation at the ground surface in the form of subsidence due to mechanical compaction (due to depressurisation of the coal seams) and matrix shrinkage (due to gas desorption) at depth.
- The IESC request that predictions of subsidence and effects from dewatering and depressurisation on surface water, water related assets, groundwater and movement of water across the landscape and possible fracturing of and damage to confining layers, should be assessed.
- A baseline for ground motion across the project area has been formed from data gathered during the period from January 2007 to March 2011 using InSAR technology (Altamira, 2013). The majority of the survey area was deemed stable, exhibiting ground movement of less than 8 mm/year.
- Subsidence estimates in the Narrabri Gas Project Area have been made using the *Linear Elastic Theory*' method and the '*Compaction At A Specific Location'* method as per the IESC guidance. This calculates subsidence at depth by mechanical compaction only. Subsidence through matrix shrinkage (gas desorption) could not be calculated.
- Subsidence calculations for mechanical compaction suggest a total maximum subsidence of between 137 mm and 205 mm. This calculation is representative of subsidence expected at depth within the coal seams and hydraulically connected strata. This is likely to equate to negligible disturbance at the ground surface due to the large depth to the coal seams and the presence and thickness of a number of highly competent rock formations.
- The subsidence gradient or tilt was calculated at a 0.002 % change in slope.
- The likelihood of impact to MNES and water resources (surface topography, water related assets, groundwater and movement of water across the landscape and possible fracturing of and other damage to confining layers) associated with subsidence arising from the Narrabri Gas Project has been assessed as being **low to insignificant**.
- The likelihood of impact to surface structures such as low height earthen dams is predicted to be **very low**.
- The predicted subsidence due to the Narrabri Gas Project are orders of magnitude less than mining induced subsidence (predicted between 2200 mm and 2400 mm at the nearby Narrabri Coal Mine) and only slightly larger than agricultural induced subsidence (predicted maximum of 167 mm; noting however that these occur over a significantly larger area).

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