BIOREGIONAL ASSESSMENT OF THE NAMOI RIVER CATCHMENT PHASE 1

Prepared for
Namoi Catchment Management Authority

23rd September 2012

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Abbreviations and Acronyms

ABBREVIATION	DESCRIPTION
APLNG	Australia Pacific Liquid Natural Gas
CAP	Catchment Action Plan
CHPP	Coal handling processing plant
CMA	Catchment Management Authority
CSG	Coal seam gas
DSEWPaC	Commonwealth Department of Sustainability, Environment, Water, Population and Communities
DIWA	Directory of Important Wetlands in Australia
GDA	Geodatum Australia
GL	Gigalitres
GDE	Groundwater-dependent Ecosystem
GNR	Geographical Names Register
LWM	Longwall Mining
MDBA	Murray-Darling Basin Authority
ML	Megalitres
ND	Undated reference
NOW	NSW Office of Water
NWC	National Water Commission
OCM	Open-cut Mine
RAMSAR	The Convention on Wetlands of International Importance
RCI	River Condition Index
QGC	Queensland Gas Company Pty Ltd
QLD DERM	Queensland Department of Environment and Resource Management
WAIT	Commonwealth Water Asset Information Tool

Executive Summary

This report documents the findings of Phase 1 of the Bioregional Assessment of the Namoi catchment. The report was commissioned by the Namoi Catchment Management Authority, and funded by the Commonwealth Department of Sustainability, Water, Environment, Population and Communities.

The scope of the study was to undertake a desktop analysis to document the type and location of water assets of the Namoi catchment, and their potential vulnerabilities to proposed coal seam gas and coal mining projects. Key deliverables of the study were to: populate the Water Access Information Tool (a MS Access Database developed by the Commonwealth Government); design and documentation of a framework for determining the vulnerability of water assets to coal mining and coal seam gas extraction activities; identify data and knowledge gaps, and collation of spatial datasets associated with natural hydrological features in the catchment.

Assessment was restricted to coal seam gas extraction and coal mining activities within the specified area. Mitigation strategies were not examined but vulnerabilities are identified and the potential impacts of coal seam gas and coal mining described in relation to their ecological and physical impact, and the geographical extent and impact zone of those impacts.

A total of 2298 water assets from over 50 spatial datasets were identified in the Namoi catchment, comprising floodplains, groundwater aquifers, groundwater-dependent ecosystems, watercourses (streams and rivers), waterholes, wetlands and other assets (e.g. caves and waterfalls). The vulnerability of each water asset was determined using a matrix which cross-referenced their sensitivity to potential impacts arising from coal seam gas extraction and coal mining activities, with their inherent resilience (i.e. the level of disturbance an asset could experience without experiencing changes in its structure and function). The resultant vulnerability categories for each asset was then reviewed against their proximity in the Namoi catchment to current and predicted coal industry activities.

This report collates an array of different existing spatial datasets and presents them in a format that can be interrogated to identify the potential impacts of coal industry activities on water assets in the Namoi catchment. However, key knowledge gaps exist in relation to the condition, sensitivity and resilience of assets, their socio-cultural and economic values, and the full cumulative environmental impacts arising from coal industry activities. Recommendations for subsequent phases of this study include: greater involvement from coal industry representatives to refine our understanding of the location of future coal seam gas and extraction activities; including all biodiversity in the analyses, rather than only water assets, and including consideration of the cumulative environmental impacts of all activities in the catchment (e.g. agriculture).

Note that this report is not a replacement for reading the individual items listed in the attached electronic databases but it does provide a summary and synthesis; it should be used as a guide to inform the Bioregional Assessment and further investigations.

1 Introduction

1.1 BACKGROUND

On 21 November 2011, the Prime Minister announced the establishment of a new Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining that will provide scientific advice to Governments in relation to coal seam gas (CSG) and coal mining proposals that are likely to have significant impacts on water resources.

A key role of the Committee is to scope and advise on Bioregional Assessments in areas where CSG and/or large coal mining developments are underway or planned. The Bioregional Assessments involve undertaking a scientific analysis of the ecology, hydrology and geology of an area for the purpose of assessing the potential risks to natural water resources in the area arising from the direct and indirect impacts of CSG or large coal mining development.

The Bioregional Assessments are divided into Phases. Phase 1 involves data collation on water assets in the Namoi catchment, and an analysis of their vulnerability to CSG and coal mining activities. Knowledge gaps in relation to the hazards and risks to regional water resources associated with CSG and coal mining development is also included. A core outcome of Phase 1 is facilitating data exchange and knowledge sharing between the Commonwealth and regional natural resource management groups.

1.2 PROJECT PURPOSE AND OBJECTIVES

The purpose of this project was to determine the vulnerability of natural water assets in the Namoi catchment to CSG extraction and coal mining activities.

The objectives of Phase 1 of the Namoi Bioregional Assessment project were to:

- source and collate spatial datasets associated with natural hydrological features in the catchment;
- compile an inventory of individual water assets from the above spatial datasets, and other sources;
- research the environmental, economic and socio-economic values of water assets in the catchment;
- identify data and knowledge gaps in the water asset data and vulnerability assessment with respect to coal mining and CSG extraction;
- design and document a framework for determining the vulnerability of water assets to coal mining and CSG extraction in the catchment, and
- populate the Department of Sustainability, Environment, Water, Populations and Communities (DSEWPaC) Water Asset Information Tool (WAIT) template.

1.3 CAVEATS

A key driver in defining the scope of the project was the limited timeframe to undertake the project. While as much data and information as possible on water assets was included in the analyses, only existing and freely available resources were included to accommodate the delivery schedule. This meant that:

- some spatial data that are known to be available were not able to be sourced/included in time;
- no new data were created - only existing data were used in spatial and other analyses;
- only data that could be readily accessed (and quickly modified) to suit the purposes of the project were included in the spatial database, and contributed to the vulnerability analyses;
- where knowledge gaps existed, the vulnerability analyses was supported by generic rather than specific rule sets, and was guided by specialist knowledge.

1.4 STRUCTURE OF THE REPORT

This report is separated into the following sections:

- Section 2 provides a broad outline of the impacts of CSG and coal mining on water assets. This section provides the context for asset value and vulnerability in relation to CSG and coal mining.
- Section 3 outlines the approach to literature and data collation, storage and management.
- Section 4 identifies major gaps in the spatial data, and prioritises future data collection.
- Section 5 presents the Vulnerability Categorisation Framework that was applied to water assets in the Namoi catchment.
- Section 6 covers the approach used to database information about natural water assets.
- Section 7 lists recommendations for future work.

2 Mining Methods and Impacts

2.1 COAL SEAM GAS

2.1.1 Background

Coal seam gas (CSG) is naturally occurring methane gas (CH_4) found in underground coal seams (Geoscience Australia 2010). Methane gas is trapped by molecular bonding (adsorption) on the internal surfaces of micropores (cleats) within the coal, and water generated pressure captures it within the coal seam. In essence, the coal seam acts as the source, reservoir and seal for this type of gas deposit (Atkinson 2002).

Reserves of CSG in Australia are known from the Bowen and Surat basins in Queensland, and the Sydney, Gunnedah, Clarence-Moreton and Gloucester basins in New South Wales. Exploration is proposed or currently occurring in other coal basins including the Galilee, Arckaringa, Perth and Pedirka Basins.

The volume of the CSG resource in the eastern part of Australia is considerable, and the economic feasibility of extracting the resource is increasing. The recent escalation of CSG exploration and production activities in conjunction with uncertainty about potential impacts to land security, groundwater, surface water, productive soils and other environmental issues has generated concern from farmers, environmental groups and the scientific community.

This section describes information from existing literature about the process of CSG exploration and production, and its potential impacts to the Namoi catchment natural resources, to inform development of the vulnerability categorisation framework.

2.1.2 Current Coal Seam Gas Production in Queensland and NSW

CSG has been produced in Queensland from the Bowen Basin since 1997 and in the Surat Basin since 2005. Exploration is also occurring in other Queensland basins, northern NSW, and other parts of Australia where there are known coal deposits (GISERA 2012a).

Queensland's CSG industry has grown rapidly over the past 15 years — the annual number of wells drilled increasing from 10 in the early 1990s to almost 600 in 2010–11. Many Queensland basins are highly prospective for CSG and production in the Bowen (Permian Coal Measures) and Surat (Jurassic Walloon Coal Measures) basins represents more than 79 percent of the total gas produced in the state (DEEDI 2012).

AGL currently produces gas to the NSW domestic market from its Camden Gas Project in the Sydney Basin. The Camden Gas Project provides approximately five percent of NSW's gas supply.

CSG exploration and appraisal activities in NSW are currently occurring in the Gunnedah, Gloucester and Clarence Morton Basin.

2.1.3 Differences Between Coal Seam Gas and Conventional Gas

Natural gas in Australia has traditionally been extracted from conventional gas fields. In a conventional gas field, the gas has been generated over geologic time from organic material trapped in a source rock which has then migrated into a trapping reservoir which typically has high porosity and permeability. Compared to CSG, conventional gas reservoirs are generally at greater depth, the gas flows to surface at higher pressure and there is very little water associated with the gas production. Conventional gas reservoirs are generally discrete structures compared to the regionally extensive coal seams, and typically fewer wells are required to develop a conventional gas resource (APLNG 2010).

CSG development differs significantly from developing conventional natural gas. To produce gas from a coal seam, normally the water associated with the gas in the reservoir must first be withdrawn using an artificial lift (pump) installed in the well at the depth of the coal seam being targeted. This reduces the pressure within the coal seam and liberates the adsorbed gas from the coal (APLNG 2010).

2.1.4 CSG Extraction

Target coal seams for CSG production are typically 200 m to 1000 m below the ground surface. CSG is held to the coal surface under water pressure. CSG is extracted by drilling wells and pumping the formation water from the coal seam, enabling the CSG to be released (desorbed) from the coal micropores and cleats, and allowing the gas and 'produced water' to be carried to the surface. This reduces the pressure in the coal seam and allows the gas to flow from the surfaces of the coal. At the surface, water and gas are separated by gravity in the 'separator', a cylinder of varying sizes depending on the water production rate of the coal seam. The gas is piped to a gathering network, and then to the consumer (Figure 1, Plate 1).

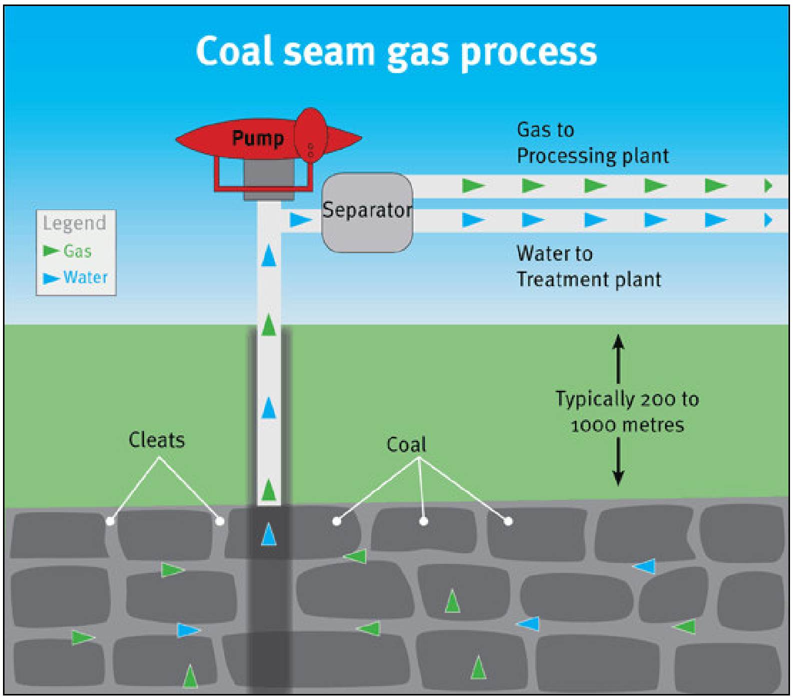

Figure 1. Schematic of the coal seam gas extraction process (Source: DERM 2012a).

Plate 1. A typical coal seam gas extraction wellhead.

2.1.5 CSG Field Development

Development of a CSG field typically includes the following series of activities (URS 2009):

1. Exploration – including geophysical surveys and drilling of exploration wells
2. Appraisal – drilling and testing of appraisal wells (also called pilot wells)
3. Development, including drilling and completion of wells (wells drilled to enable gas production), and construction of centralised compression and water treatment facilities, gas and water gathering networks and other related infrastructure
4. Production and operation
5. Rehabilitation and decommissioning.

A CSG production field typically includes the following infrastructure and facilities:

- CSG wells and associated infrastructure (e.g. telemetry, generator, water transfer tank)
- Water and gas gathering pipe networks, and gas export pipelines
- Water treatment facilities (e.g. storage ponds, reverse osmosis plants, brine storage and injection)
- Gas treatment and compression facilities including filtration, compression, cooling and dehydration process items
- Power supply networks (above and below ground)
- Field infrastructure such as access tracks, storage warehouses, workers accommodation camps, offices and telecommunications.

2.1.6 Water Production and Management

As depicted in Figure 2, water production is higher in the initial stages of CSG appraisal and production, and decreases as the gas production increases. However, the actual production rates and times within and between coal measures vary considerably.

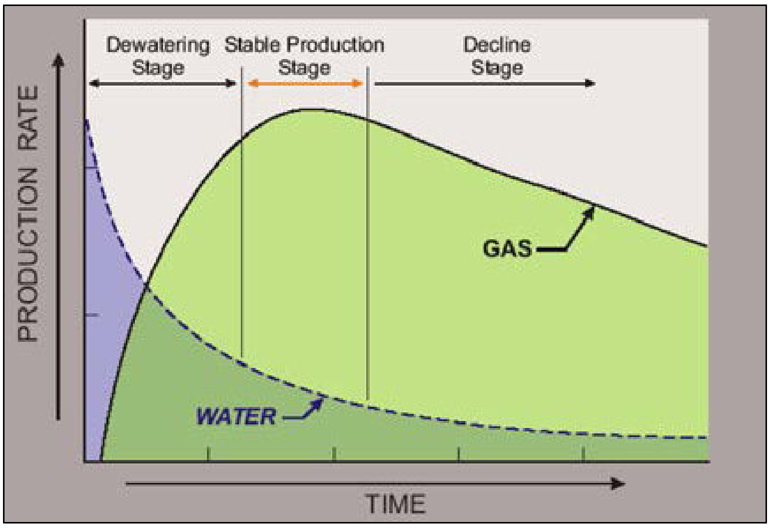

Figure 2. Conceptual coal seam gas and water production curve.

Current projections indicate the Australian CSG industry could extract in the order of 7500 gigalitres (GL) of co-produced water from groundwater systems over the next 25 years, equivalent to approximately 300 GL/yr. In comparison, the current total extraction from the Great Artesian Basin is approximately 540 GL/yr (NWC 2012).

From their CSG production experience in the Surat Basin, Queensland Gas Company Pty Ltd (QGC) indicated that initial water quantities extracted from a well ranged from 0.4 megalitres per day (ML/day) to 0.8 ML/day before decreasing to about 0.1 ML/day over a period of six months to a few years (NWC 2011). At the Fairview field in the Bowen Basin, Santos reported an average initial daily water production rate of 0.20 ML/day/well, which decreased to 0.02 ML/day/well after 12 years (NWC 2011) (Figure 3). Exploration and appraisal activities in the Gunnedah Basin are on-going, however current water production estimates reported by Santos (Santos 2011) appear to be similar to the water production rates in the Bowen Basin.

Historically the produced water was either directly discharged to grade (surface or streams) or stored in evaporation ponds. More recently the CSG industry has developed water treatment facilities so the produced water can potentially be used. CSG projects in QLD now typically temporarily store the produced water in transfer ponds prior to being treated (e.g. amended and / or desalinated). Following water treatment, a permeate (clean water) and a brine (salty water) stream is produced.

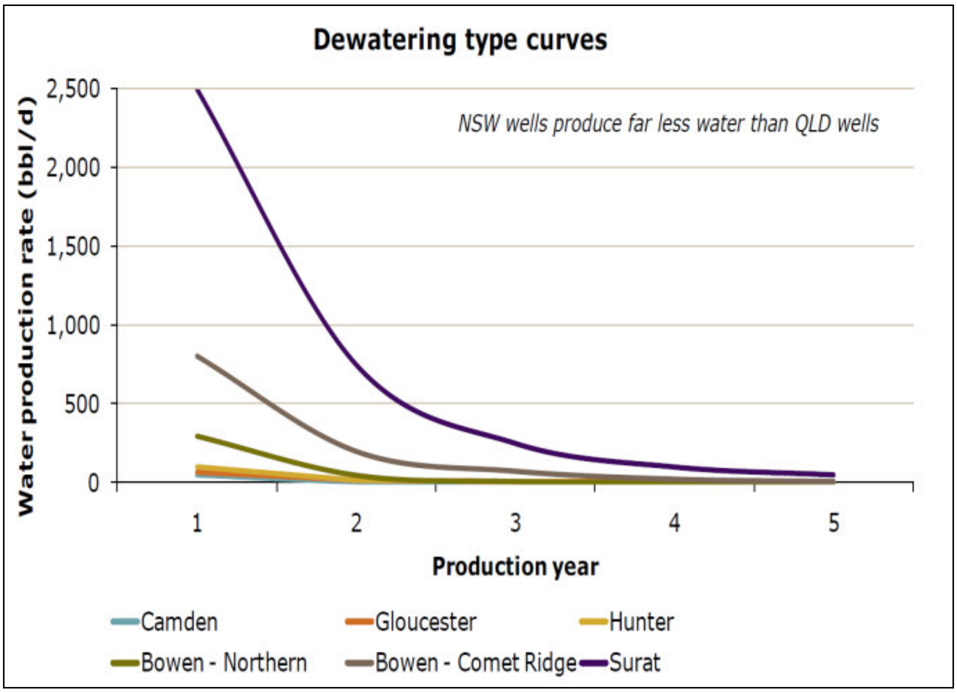

Figure 3. Relative water production from Australian CSG development areas (Source: Dart Energy ND).

Current management of brine in Australia includes re-injecting into a deep isolated rock formation, or temporary storage and disposal to a licensed facility. Trials are currently underway in Queensland for the crystalisation and commercial production of salt from the CSG brine.

Current management of permeate in Australia includes trials for irrigation of fodder and hardwood, re-injection into town water supply groundwater system, discharge to surface waters, and for operational activities such as dust suppression.

The QLD DERM Guideline: Preparing an Environmental Management Plan for Coal Seam Gas Activities (DERM 2010) sets out the preferred and non-preferred management options for CSG water. These are:

- Category 1 – preferred management options include:
    - injection where detrimental impact unlikely
    - untreated use where detrimental impact unlikely
    - treatment to an agreed standard for agricultural, industrial and potable uses
- Category 2 – non-preferred management options include:
    - disposal via evaporation dams
    - disposal via injection where a detrimental impact is likely
    - disposal to surface waters
    - disposal to land.

2.1.7 Hydraulic Fracturing, Cavitation and Multi-lateral Drilling

In some cases the coal permeability is low and gas production is small (i.e. sub-economic). In these cases, hydraulic fracturing (commonly referred to as 'fraccing') or cavitation may be used to further assist the flow of gas through the coal to the producing well (GISERA 2012b). A new technology is currently being developed in the Gunnedah Basin called 'multi-lateral drilling', which serves as an alternative to hydraulic fracturing and cavitation. This method may increase gas flow and reduce the surface infrastructure requirements for CSG production. These methods are further discussed below.

Hydraulic Fracturing

Hydraulic fracturing involves pumping treated fluid containing sand grains into coal cleats at a high rate and pressure to form and extend a fracture in the coal reservoir. It works to enhance recovery by enlarging fractures through which oil and gas, including coal bed methane, can be drawn to a well and pumped to the surface. It involves pressurised injection of water, chemical additives, and proppants into a geologic formation, inducing fractures in the formation that stimulate the flow of natural gas or oil, thus increasing the volume of gas or oil that can be recovered from coal beds, shales, and tight sands - the so-called 'unconventional' reservoirs (US EPA 2011).

Most hydraulic fracturing fluids are water-based fluids that are designed to create pressure to propagate the fracture, and to carry the proppant into the fracture. Proppants are solid materials that are used to keep the fractures open after pressure is reduced in the well, the most common proppant being sand (Carter *et al.* 1996). Water-based fluids containing sand have become the predominant type of fracturing fluids, although fluids can also be based on oil, methanol, or a combination of water and methanol. After fluids are injected to expand fractures within a coal seam, large quantities of ground water and some of the injecting fracturing fluids are pumped back out of the well to facilitate the production of the gas.

In addition to proppants and water, hydraulic fracturing fluids often contain chemical additives. The types and concentrations of chemical additives vary depending on the conditions of the specific well being fractured, and are selected to create a fracturing fluid tailored to the properties of the formation and the needs of the project (US EPA 2011).

The process of coal seam hydraulic fracturing typically involves the following series of tasks (Golder Associates 2010):

- Well casing perforation (access hole in the steal well casing pipe are created to allow access to the coal seam groundwater and CSG)
- Acid Injection (to open up the coal seam cleats where they are filled with natural calcite)
- 'Pad Volume' injection (hydraulic fracturing fluid) which comprises a mix of water, guar gum, sand and stabiliser chemicals injected to fracture the seam
- 'Slurry Volume' injection (hydraulic fracturing slurry plus beach sand) which includes the addition of sand to prop open the fracture followed by the addition of a breaker
- 'Flush Volume' injection (water only) to force the remaining hydraulic fracturing fluids, contained in the well casing, into the coal seam to complete the hydraulic fracturing process
- 'Flow-Back' pumping involves the extractive pumping of a volume of fluids equivalent to around 110 percent of the total volume of hydraulic fracturing fluids previously injected (as described above) and aims at recovering the majority of the hydraulic fracturing fluids injected. The remaining mobile components will largely be recovered and treated as part of the production pumping of CSG
- Well stabilisation dosing to preserve the hydraulic fracturing job for the period between well completion and operational gas production.

Cavitation

Cavitation is an alternative technology for well completion that may be utilised when other well completion methodologies are not suitable. Cavitation uses air pumped at high pressure to penetrate the coal cleats and occurs underground within the formation. The pressure is held on the well bore for a given amount of time. It is then released suddenly, causing the coal to fail and slump into the well bore. The failed coal is flowed to the surface, leaving a cavity in the coal reservoir sections and a zone of increased permeability around the cavity within the coal formation (APLNG 2010).

Multi-Lateral Drilling

Multi-lateral wells target several coal seams through a single well bore at the surface, with a horizontal leg drilled laterally within each seam for a distance of several kilometres (Figure 4). Using multi-lateral wells enables a large reservoir area to be drained with fewer surface installations (Dart Energy ND). This drilling technology is currently being used throughout Australia and is being trialled in the Gunnedah Basin.

Multi-lateral drilling can also have an added benefit of minimising, or even eliminating, the need for hydraulic fracturing. However, ultimately geological variables will dictate the CSG extraction method used in each area.

2.1.8 Typical Chemicals Used in Drilling, Completion and Stimulation

Generally, drilling of a well will utilise approximately 200 m^3 (0.2 ML) of drilling mud comprised mainly of water and bentonite. Water from the drilling mud are separated from the drill cuttings and stored for treatment. The rill cuttings brought to the surface are rehabilitated *in-situ* (APLNG 2010).

Additional chemical additives are typically blended into the drilling and completion fluids to assist the drilling process. Biocides are used to limit the growth and spread of bacteria that may cause fouling. Corrosion inhibitors limit potential for corrosion and failure of well completions, thus maintaining the integrity of the wells (APLNG 2010).

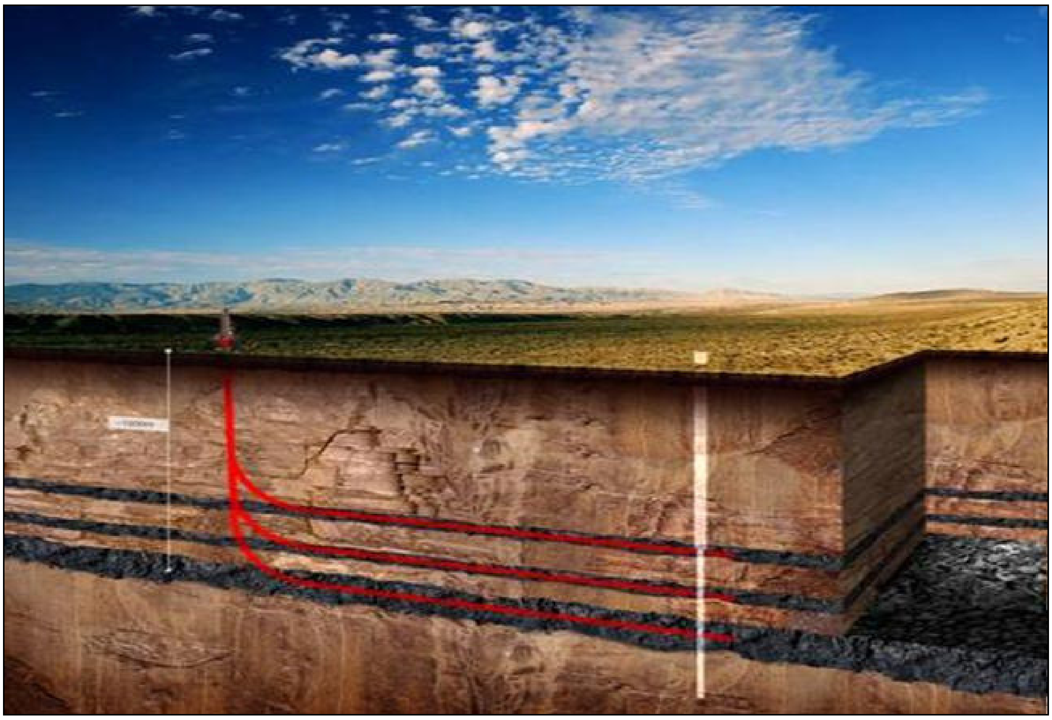

Figure 4. Multi-lateral drilling (Source: Dart Energy ND).

Well completion, involving hydraulic fracturing, will typically utilise about 1600 m^3 (1.6 ML) of fluid, predominately water, containing inert proppant solids (typically glass beads, sand and/or silica in composition). This fluid remains in-situ to assist in maintaining the flow of CSG. The well completion fluids used for fracturing the coal seam are pumped from the well during development, returned to the surface, and treated through a water treatment plant (APLNG 2010).

The additives and use of typical components of hydraulic fracturing fluid are (DERM 2012b):

- Acid (such as hydrochloric acid) – removes cement and drilling mud from casing perforations prior to hydraulic fracturing fluid injection
- Activator (such as 2-butoxyethanol) – used to initiate foaming
- Gelling agents and binders (such as guar gum) – these are used to increase the viscosity of the hydraulic fracturing fluid and allow more sand to be carried into the fractures
- Cross linker (such as boric acid) – used to change the viscous fluid into a pseudo-plastic fluid enabling more proppant to be carried
- Proppant (such as sand or quartz) – to hold the fracture faces apart
- Breakers (such as ammonium persulphate) – these are used to break down the fracturing gel and enable release of the proppant into fractures; they also enhance the recovery of the hydraulic fracturing fluid
- Buffers, stabilizers and solvents (such as potassium carbonate) – maintain the stability of the fracturing fluid, immobilise clays and enhance pre-fracture
- Microbial control (such as sodium hypochlorite) – inhibits growth of organisms which could contaminate the gas resources and the hydraulic fracturing fluid
- Surfactants (such as orange oil) – reduce the surface tension thereby aiding fluid recovery
- Clay management (such as choline chloride) – used to minimise clay swelling in the vicinity of the well and in the formation
- Corrosion inhibitor and oxygen scavenger (such as fumaric acid) – used to prevent corrosion of well equipment.

2.1.9 Potential Impacts of Coal Seam Gas Developments

The social and economic impacts of coal seam development on land users, neighbours and local communities in adjacent towns and rural areas can be both positive and negative, and include (Corkery 2009, NWC 2012):

- potential for growth in retail, commercial and industrial developments
- alteration of social activities or employment due to employment generation and capital expenditure
- amenity impacts on neighbouring properties
- change in property values (can be an increase and or decrease in value depending on location)
- disruption of current land-use practices and the local community through infrastructure construction, land access, and ongoing operational maintenance activities
- increased pressure on local services and infrastructure (from the increased workforce).

The environmental impacts of coal seam development vary according to the hydrogeology, topography, and current land use. A summary of the potential environmental impacts of coal seam gas developments is provided at Table 1.

Table 1. Summary of potential environmental impacts of coal seam gas developments (Sources: APLNG 2010, Santos TOGA ND, APLNG 2012, NWC 2012).

Affected Resource	Potential Impacts On:
Water	- Connected surface and groundwater systems from the extraction of large volumes of water. Some systems may already be fully or over-allocated. - Other water users and natural hydrogeological systems due to depressurisation of the coal seam, including changes in pressures of adjacent aquifers with consequential changes in water availability, reductions on surface water flows in connected systems and subsidence potentially affecting surface water systems, natural ecosystems, and current land use (e.g. irrigation and grazing lands) - Water quality and hydrology through the unmanaged release of produced water or brine water - Surface water quality from overly treated, 'clean water' pollution of naturally turbid water systems. - Surface water quality from unmanaged erosion and sediment migration from construction areas, access roads and other disturbed areas - Connection and cross-contamination between aquifers, with potential impacts on groundwater quality through enhanced stimulation techniques such as hydraulic fracturing - Groundwater quality and hydrogeology from reinjection of treated waste water or brine into other aquifers - Natural aquatic and groundwater ecosystems, including threatened species of fish, macroinvertebrates, and stygofauna
Terrestrial Ecology, Land, Air and Sensitive Receivers	- Natural terrestrial ecological systems, including threatened species and ecosystems - Existing landuses such as agriculture, viticulture, and conservation - Soils due to infiltration and unmanaged spills or leaks of produced water - Contamination of soils from unmanaged spills and leaks of fuels, chemicals or regulated wastes - Contamination of soils due to unmanaged spills of effluent from accommodation camps - Air quality from increased emissions from combustion activities (compressor engines, electricity generators, heating/drying units, trethylene glycol unit burners, flares), vehicle emissions, non-combusted hydrocarbon and coal seam gas emissions, windblown salt, water vapour, odour, and greenhouse gases - Increased dust and other particulates at sensitive receptors - Increased noise levels at sensitive receptors - Aboriginal or non-Aboriginal heritage sites or items

2.2 COAL MINING

2.2.1 Background

Coal mining can be separated into two major techniques, open cut and underground.

Open Cut Mining

Open cut mining involves removed of overlaying surface soil, bed rock (overburden) and the removal of the coal seam or seams (NSW Mineral Council Ltd ND). The coal seam is first fractured and then transported using trucks or conveyors to a preparation plant, or the location of the end use (World Coal Association 2010).

Underground Mining

There are several variations of underground mining, however the common feature for all forms of underground mining is the creation of tunnels extending from the surface into the coal seam and the use of machinery to extract the coal.

Some of the common underground mining methods include bord and pillar, longwall and highwall mining. Bord and pillar was commonly used until the introduction of longwall, as the process of leaving behind pillars (that are uses as support for the mine) is not as efficient as longwall (NSW Mineral Council Ltd ND). Longwall mining uses mechanised shears to cut coal away while hydraulic-power supports hold the roof of the mine (NSW Mineral Council Ltd ND). Following the remove of each slice of coal the hydraulic-power supports are progressively moved forward and the roof is collapsed behind them.

Highwall mining is a relatively new method, introduced in the 1990s. It involves the use of remote controlled mining machines (NSW Mineral Council Ltd ND). This method is commonly used to mine areas left behind from previous mining or when difficult geological conditions restrict the use of other mining methods (NSW Mineral Council Ltd ND). The two main types of highwall mining are continuous highwall, and auger mining (NSW Mineral Council Ltd ND).

2.2.2 Current Coal Mining Production in NSW

Coal is the major mineral resource mined in NSW. The coalfields of the Sydney-Gunnedah Basin contain almost all of the coal reserved in NSW, with smaller quantities in the Gloucester and Oaklands Basins. Recoverable coal reserves in NSW are over 12 billion tonnes. These reserves are contained in 63 operational coal mines and 30 coal mine development projects (NSW Mineral Council Ltd ND).

Open cut mining currently accounts for 65 percent of raw coal production in NSW (NSW Mineral Council Ltd ND). Productivity in the NSW coal industry has increased by 25 percent in the past ten years (NSW Trade & Investment ND).

2.2.3 Coal Mining Field Development

Infrastructure required for open cut or underground coal mining is similar and typically includes:

- coal handling and processing plant (CHPP)
- mine waste rock and coarse reject storage and management facilities
- coal product rail loading infrastructure and rail line
- water management infrastructure (storage ponds, sediment basins, drains, diversions, sumps, production and dewatering bores)
- mine administration offices
- toilets and shower facilities
- crib hut
- hardstand and laydown area
- bunded fuel bay
- on-site diesel power generators
- first aid building
- maintenance workshop
- wash bay
- light vehicle parking facilities
- communication, power and water reticulation
- access roads/rail.

2.2.4 Potential Impacts of Coal Mining

Mining and associated activities have the potential to cause a number of environmental impacts if not managed correctly (Environment Australia 2002). The following is a list of typical unmitigated impacts associated with coal mining (Environment Australia 2002, Corkery 2009, Bailey 2011):

- Potential surface water contamination through erosion by wind and water (may increase sediment loads and decrease water quality in streams) and dirty water runoff entering local water ways (runoff from haul roads and un-vegetated spoil)
- Potential groundwater and surface water contamination from salt and toxic elements that can mobilise, and chemical spills such as fuel, entering the groundwater through underground seepage
- Potential changes to surface and groundwater flows and levels
- Potential soil impacts, including salinisation, acidification, pollution, compaction, loss of soil structure, loss of productive topsoil and contamination from waste. This can lead to reduced production or loss of agricultural land
- Potential air quality impacts from dust pollution with emission from crushing plants, machinery, roads and mine traffic, uncovered coal and from gas emissions from processing and mine openings
- Potential impacts from failure of engineered structures such as tailings dams (i.e. release of highly contaminated wastes into the environment)
- Potential for acid rock drainage from tailings, ore and waste dumps and old mining areas
- Potential impacts to flora through vegetation clearing and indirect losses through spread of weeds
- Potential impacts to fauna through vegetation clearing (loss of habitat) and through habitat fragmentation

- Potential impacts on adjacent areas due to the development of camps, towns, roads, railways and services required for the mining project
- Potential for invasion of weed species and feral animals
- Potential increase in traffic on public roads
- Potential impacts from the construction of new roads and rail networks for transportation of coal
- Potential for damage to Aboriginal or non-Aboriginal heritage sites or items.

Impacts that are exclusive to underground mining are typically associated with subsidence. Some impacts that are exclusive to underground mining include, but are not limited to (Corkery 2009, NSW Government 2008):

- Potential impacts on groundwater aquifers, and surface water flow paths due to cracking cause by subsidence
- Potential impacts infrastructure located in the subsidence zone
- Reduced availability of groundwater as a result of fracturing hydrogeological flow paths
- Potential development of new drainage paths in subsidence zones, potentially increasing erosion in these areas (see issues of soil erosion listed above)
- Potential loss of groundwater connectivity and potential reduction in groundwater quality and quantity due to drainage of aquifers into the mine workings.

Mining developments have the same potential positive and negative social and economic impacts on land users, neighbours and local communities, as coal seam gas developments (Environment Australia 2002). Hence, the social and economic impacts on surrounding towns, and communities include (Corkery 2009, NWC 2012):

- Potential for growth in retail, commercial and industrial developments
- Alteration of social activities or employment due to employment generation and capital expenditure
- Amenity impacts on neighbouring properties
- Change in property values (can be increase and or decrease in value depending on location)
- disrupting current land-use practices and the local community through infrastructure construction, land access, and ongoing operational maintenance activities
- Implication of the increase workforce on the need for services and infrastructure.

3 Data Collation

Data and information on assets, their type, location, condition and landscape context, and on current and predicted coal mining and coal seam gas extraction activities was sourced and collated using three approaches: 1) a literature review, 2) a spatial data search, and 3) a workshop with CMA and other invited stakeholders.

3.1 LITERATURE REVIEW

The aims of the literature review were to:

1. review studies on the location and character of water assets in the target area to inform the assessment of asset class sensitivity and resilience
2. review studies on impacts of coal mining and coal seam gas extraction on water assets to inform the assessment of asset class sensitivity and resilience
3. characterise the current pressures on water assets in the catchment with respect to coal and coal seam gas extraction and future development pressure of these industries.

Key literature sources interrogated were scientific papers and theses, the NOW (2012) Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources, Floodplain Management Plans, local Government plans and reports (i.e. Local Environment Plans, State of the Environment reports, and biodiversity strategies), the Proposed Basin Plan (MDBA 2012), and Namoi Valley Sustainable Rivers Audit report (Davies *et al*. 2008). A list of key literature sources reviewed during this task is provided at Appendix B.

A number of key local stakeholders were also contacted for advice on water assets, and on the type and availability of data and other information.

The results of the literature review were entered into an excel spreadsheet initially, then imported into the WAIT database to supplement information on values of individual assets. The full bibliography is included at the end of this report.

3.2 SPATIAL DATA REVIEW

3.2.1 Data Acquisition and Initial Review

Initially the Geographical Names Register (GNR) of NSW was refined spatially and by class to create a preliminary list of water assets within the catchment. The spatial accuracy of the GNR was assessed against the NSW Mosaic Topographic Map and Google Earth, then each water asset was assigned a unique identity and loaded into the WAIT database. Additional datasets, provided by Namoi CMA and sourced by ELA, were individually assessed based on the named water assets listed, their spatial accuracy and available metadata. Each dataset was spatially joined with the preliminary list developed from the GNR. Waters assets that were already listed in the WAIT database were assigned the existing unique identity and any additional named water assets that were found were allocated a new unique identity and loaded into the WAIT database. In addition, ELA reviewed topographic maps and Google Earth for named natural water assets, in an attempt to pick up any assets pertinent to this study that were not included in digital layers.

3.2.2 Data Management Approach

ELA collated spatial layers containing water assets into a geodatabase using ArcGIS v10.0 with standard Datum on GDA 94. The feature datasets of the geodatabase were imported as per the following water assets in the catchment:

- groundwater (type, depth, connectivity, drawdown, recharge/discharge, current use
- surface water network (rivers, streams, floodrunners)
- riverine condition data (e.g. River Styles)
- local and regional catchments, including floodplain extent
- groundwater dependent ecosystems, including wetlands and mound springs
- RAMSAR sites
- water infrastructure (farm storages, irrigation channels, bores)
- recreational and tourism assets (e.g. iconic swimming holes, hot springs)
- key habitats/populations (waterbirds, fish, invertebrates, stygofauna).

Each named water asset within the geodatabase was assigned the unique WAIT identity number. The layers were then combined into a composite polygon layer and priority assigned to the mapping source that provided the best spatial definition of each asset. The asset class (Table 3) was assigned to each asset in the composite layer before analysis was undertaken.

Each spatial dataset in the geodatabase was also allocated a reference number and indexed in an Excel spread sheet. The reference number for each spatial layer was also loaded into the notes field of WAIT so that the two databases and the spread sheet could be cross referenced (Figure 5).

Supporting documentation that was provided with the spatial datasets (e.g. reports and metadata), was loaded into a directory structure that mirrored the geodatabase scheme and also included the spatial dataset reference number (Figure 5).

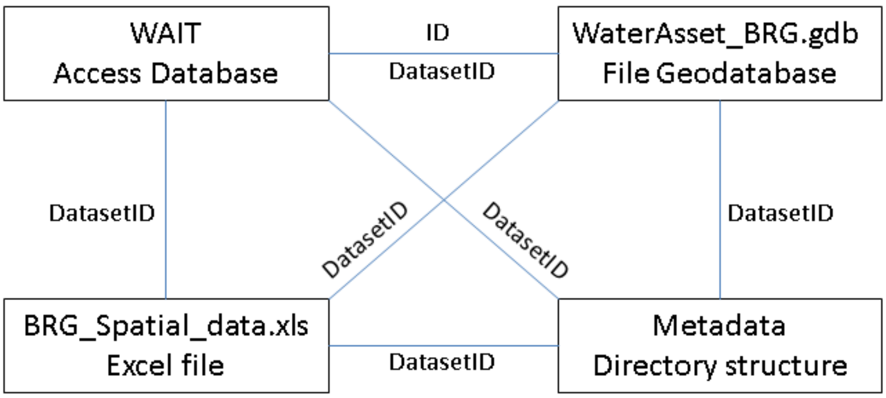

Figure 5. Data management and linkages

3.2.3 Results

A total of 2298 water assets were identified for Namoi CMA in the WAIT from various spatial datasets. Table 2 lists all datasets uploaded to the geodatabase, including the information provided by Namoi CMA, the Geographical Names Register of NSW, the Digital Topographic Database and the Geofabric database.

Table 2. List of spatial datasets loaded into the geodatabase.

Description	Metadata	Unique Ids assigned	Source
Namoi Sub-catchments. Subset of NSW wide layer	no	yes	Namoi CMA
Geographical Names Register. Subset of NSW wide layer	yes	yes	NSW Land and Property Information
Namoi Local Catchments	yes, in geodatabase (ArcCatalog)	yes	Namoi CMA
Geofabric AHGFAquiferBoundary. Subset of National layer	yes	yes	Bureau of Meteorology
MER 2008 Groundwater Management Areas	no	yes	NSW Office of Water
Groundwater Dependent Ecosystems	yes	yes	NSW Office of Water
Priority wetlands	yes	partially	Namoi CMA
River Assessment Units	yes, in geodatabase (ArcCatalog)	yes	Namoi CMA
River Condition Index values	yes	yes	NSW Office of Water
River Condition Index risk	yes	yes	NSW Office of Water
River Condition Index priorities	yes	yes	NSW Office of Water
River Condition Index River Condition	yes	yes	NSW Office of Water
Namoi_MER_theme_2_all_wetlands_220509_014	yes	yes	NSW Office of Water
River Styles	yes	yes	NSW Office of Water
River Condition Index River Catchments	yes	yes	NSW Office of Water

Description	Metadata	Unique Ids assigned	Source
MER Riverine Water Quality Condition Assessment	yes	no	NSW Office of Water
MER Riverine Water Quality Trend Data 2005-2008	yes	no	NSW Office of Water
Key Fish Habitats in Floodplain Wetlands	yes	n/a	Department of Primary Industries
Key Fish Habitats in Reservoirs	yes	n/a	Department of Primary Industries
Key Riverine Fish Habitats	yes	n/a	Department of Primary Industries
LPI hydro lines	yes	yes	NSW Land and Property Information
LPI hydro point	yes	yes	NSW Land and Property Information
LPI hydro area	yes	yes	NSW Land and Property Information
Geofabric Surface Cartography AHGF Hydro Area	yes	yes	Bureau of Meteorology
Geofabric Surface Cartography SLAKE AHGF Waterbody	yes	n/a	Bureau of Meteorology
Geofabric Surface Cartography AHGF Waterbody	yes	yes	Bureau of Meteorology
Geofabric AHGF Water table aquifer. Subset of National layer	yes	yes	Bureau of Meteorology
Namoi Floodplains	yes		yes
Towns	no	yes	NSW Land and Property Information
Potential Groundwater Dependent Ecosystems	yes	yes	SKM (2009)
Agricultural bores	no	n/a	Namoi CMA

Description	Metadata	Unique Ids assigned	Source
State Wide Geology	yes	n/a	Department of Mineral Resources
Cadastre (subset)	yes	n/a	NSW Land and Property Information
State Forests	no	n/a	Forests NSW
National Parks	yes	n/a	Office of Environment and Heritage
NSW Landuse	yes	n/a	Office of Environment and Heritage
NamDistributedRiverStressAnMean Line	no	n/a	NSW Office of Water
NamEntitlementEstimate	no	n/a	NSW Office of Water
NamEstimatedAnnMedianFlow	no	n/a	NSW Office of Water
Namoi Depth to Water Table	yes	n/a	Namoi CMA
Coal Seam Mine potential	no	n/a	NSW Department of Trade & Investment
Coal Exploration Potential Underground	no	n/a	NSW Department of Trade & Investment
Coal Exploration Potential Underground and or Shallow	no	n/a	NSW Department of Trade & Investment
Coal Exploration Potential Underground Possible Shallow	no	n/a	NSW Department of Trade & Investment
NSW Barriers to fish	yes	n/a	Department of Primary Industries
GDEs identified in water sharing plans	no	yes	NOW
Vegetation Map	yes	yes	Namoi CMA
GeoFabric AHGF Waterbody Reservoir	yes	n/a	Bureau of Meteorology
GeoFabric AHGF Dams	yes	n/a	Bureau of Meteorology

Each of the 2298 natural assets identified were assigned an asset class to facilitate the vulnerability analysis. The number of water assets in each class is listed in Table 3.

Table 3. Asset classes used in the vulnerability assessment.

Asset Class	Number of Assets
Catchments	688
Floodplains	27
Groundwater aquifers	35
Groundwater Dependent Ecosystems	212
Watercourses (streams and rivers)	1095
Waterholes	12
Wetlands	229
ALL	2298

4 Data Gap Analysis

4.1 LIST OF DATA GAPS

While the final list of named assets is comprehensive, information about the condition, management and landscape context of assets (e.g. values) were often absent, and prevented a confident assignment of asset vulnerability. In particular, major gaps in the Namoi Catchment were:

- Asset condition – the condition of some assets, particularly wetlands and springs (subset of GDEs), has not been adequately quantified in the catchment.
- Aquifer/stream connectivity – the relationship between surface and groundwater flow were not manifest in spatial data to the extent that any meaningful assessment of vulnerability could be undertaken.
- Namoi-specific socio-economic values

4.2 PRIORITIES FOR FUTURE DATA COLLECTION

The potential for coal mining and CSG extraction was based on government-developed mapping of the coal basins within each catchment. We acknowledge that assessment of accessible and viable resource potential needs to consider various factors such as depth, thickness, and quality of coal, however the level of information on these aspects varies across the state. This information was not available for the Namoi catchment, and was explicitly outside the scope of this study to generate new data.

The resource potential mapping is expected to improve over time in each catchment as more work is undertaken, which will assist with refining the areas shown for Phase 1 of this Bioregional Assessment. It is recommended that the Namoi CMA consider geological modelling and industry consultation to develop more refined resource extraction likelihood maps to inform future vulnerability analyses.

The current best practice example in NSW is the Namoi Catchment Water Study. As part of this study potential coal mining and coal seam gas developments were mapped using over a 100 year period in the Namoi Catchment area through geological mapping, modelling and industry consultation.

5 Vulnerability Framework

5.1 BACKGROUND

Once the literature and spatial data on natural water assets in the Namoi catchment were compiled, and spatial data integrated into a geodatabase, a vulnerability class was assigned to each water asset in relation to the potential impact of coal mining or CSG extraction on flow pattern, habitat, water quantity and water quality. This section of the report outlines the vulnerability categorisation framework used as the basis for the vulnerability assignment.

5.2 CONTEXT

The primary impacts of coal mining and CSG extraction are:

- Removal of surface vegetation (habitat) – consolidated clearing (i.e. open cut mines) or fragmented clearing (CSG and longwall coal mining)
- Groundwater drawdown (water quantity) – lowering of water table can lead to change in gradients and flow direction, and may reduce overall water availability
- Groundwater contamination (water quality) – vertical connections; extracted ground water chemistry
- Changes to surface water flow (water quantity, flow pattern) – interception of rainfall; treated water release
- Surface water contamination (water quality) – polluted water spill, surface subsidence.

These may result in secondary impacts including loss of agricultural potential and loss of natural habitat and ecosystem function. The extent to which an asset is susceptible to the impacts of coal mining or CSG extraction is dependent on the:

- underlying coal resource potential
- current condition of the asset
- value of the asset (ecological and socio-economic)
- resilience of asset to change/modification.

5.3 WATER ASSET CLASSES

Water assets were separated into six broad asset classes for the purpose of vulnerability assignment. These classes were:

- groundwater aquifers (alluvial and other aquifers, Great Artesian Basin)
- floodplains
- groundwater dependent ecosystems (e.g. mound springs, river red gum forests)
- local catchments (i.e. contributing areas of streams 3rd order and greater)
- watercourses (e.g. rivers, streams, creeks, floodrunners)
- wetlands (e.g. lakes, lagoons, billabongs, sedgelands, swamps)

These classes were delineated because sensitivity and resilience measures used in the vulnerability framework are not common to all natural water assets, but are common to assets within each class.

5.4 BROAD FRAMEWORK

Vulnerability is a function of an asset's *sensitivity* and its *resilience*. Sensitivity is the degree to which an asset is affected by 'pressures' (in this case activities associated with coal mining and CSG extraction), and resilience is the amount of change a system can undergo (i.e. its capacity to absorb disturbance), and remain within the same regime that essentially retains the same function, structure and feedbacks (Walker and Salt 2006). Determining an asset's capacity to absorb change or disturbance without moving to a new state often involves identifying thresholds (i.e. 'tipping points' from one stable state to another). Thresholds are typically related to core structural and functional elements of ecosystems, such as wetting-drying periods in wetlands, lateral and longitudinal connectivity in rivers, and carbon exchange between floodplains and rivers.

A rating for vulnerability was derived from a matrix that cross-references levels of asset sensitivity to levels of asset resilience (Table 4). The lower the sensitivity and higher the resilience of an asset to the effects of coal or CSG extraction, the lower its vulnerability.

Table 4. Asset vulnerability as a function of asset sensitivity and asset resilience.

	Resilience		
Sensitivity	High	Medium	Low
High	*Medium*	*High*	*High*
Medium	*Low*	*Medium*	*High*
Low	*Low*	*Low*	*Medium*

To achieve the comparison in Table 4, sensitivity and resilience levels were generated for each asset using a set of values relevant to each asset class (Table 5). Where possible, the resilience assessment of relevant assets was adopted or derived from the current Namoi Catchment Action Plan (2010-2020; the 'CAP' – Namoi CMA 2011). The CAP was developed using resilience thinking to identify critical thresholds that are immediate priorities for natural resource management in the Namoi catchment, and was based on extensive scientific research and community consultation. Targets and actions to ensure these critical thresholds are not crossed were also developed and used in the CAP. The thresholds and targets are therefore directly applicable to this study.

The following list of critical thresholds and targets listed in the Namoi CAP were considered in the vulnerability analysis where data supported their inclusion:

- Woody vegetation cover at 30% in cleared sub-catchments and 70% in intact sub-catchments.
- Area of endangered or vulnerable community.
- Surface water flow at 66 percent of pre-development flow with a sensitivity to natural frequency and duration.
- Geomorphic condition is good (against benchmark condition).
- Alluvial aquifers are not drawn down below long term historical maximum draw down levels.
- Groundwater is within 30 m of surface where there are identified groundwater dependent ecosystems.

Table 5. Values used to determine asset sensitivity and resilience

Effect	Asset Class	Values Considered in Assigning Sensitivity	Values Considered in Assigning Resilience
Flow pattern	Groundwater aquifer	Connectivity (SWS 2011, 2012; Badenhop *et al.* 2012)	Level of drawdown recovery (Badenhop *et al.* 2012)
	GDE	Degree of connectivity Depth to watertable	Level of regulation
	Local catchment	Stream density (km/km^2)	Naturalness of flow regime
	Watercourse	Continuity of native riparian vegetation RCI Geomorphic Condition (Lambert and Short 2004; Healey *et al.* 2012)	Adjacent land use Stream order
	Floodplain	Naturalness of inundation regime (based on level of upstream regulation)	Percent native vegetation Land use
	Wetland	Adjacent vegetation	Size Level of upstream regulation

Effect	Asset Class	Values Considered in Assigning Sensitivity	Values Considered in Assigning Resilience
Habitat	Groundwater aquifer	Stygofauna diversity and hotspots (based on expert knowledge and cited literature)	Size
	GDE	Vegetation type	Depth to water table
	Local catchment	Threatened ecological communities Biodiversity richness (vegetation types and threatened species)	Percent native vegetation cover
	Watercourse	Riparian zone condition (use RCI data – fish, macroinvertebartes, riparian vegetation – Healey *et al*. 2012) Proportion of reach vegetated	Surrounding land use Risk to instream value (RCI data – Healey *et al*. 2012)
	Floodplain	Threatened ecological communities Biodiversity richness (vegetation types and threatened species)	Percent native vegetation cover
	Wetlands	Legal status (e.g. DIWA and/or Ramsar) % cleared (represenatativeness) Area native vegetation % native vegetation within 200 m	Total area (ha) Adjacent land use

Effect	Asset Class	Values Considered in Assigning Sensitivity	Values Considered in Assigning Resilience
Water quantity	Groundwater aquifer	Connectivity (SWS 2011, 2012; Badenhop *et al.* 2012), and identified % recharge area (Badenhop *et al.* 2012)	Size Status (recovering or not) (Badenhop *et al.* 2012) Density of bores (no/km^2)
	GDE	Degree of connectivity of aquifer	Size Depth to water table
	Local catchment	Naturalness of flow (level of water entitlement)	River Condition Index (Hydrologic Stress) (Healey *et al*. 2012)
	Watercourse	Naturalness of flow (level of regulation) Adjacent land use	Level of water entitlement Stream order
	Floodplain	Area of reservoirs/number of farm dams	Naturalness of inundation regime (based on level of upstream regulation)
	Wetland	Naturalness of the wetting/drying regime (i.e. regulated or not)	Wetland size

Effect	Asset Class	Values Considered in Assigning Sensitivity	Values Considered in Assigning Resilience
Water quality	Groundwater aquifer	Aquifer type (alluvial or non-alluvial) Density of agricultural bores	Size
	GDE	Land use (polygons)/adjacent land use (points)	Size
	Local catchment	Land use	Volume of runoff (medium flow)
	Watercourses	Riparian zone condition (use RCI data – fish, macroinvertebartes, riparian vegetation – Healey *et al*. 2012) Proportion of reach vegetated	Adjacent land use Stream order Regulated (yes/no)
	Floodplains	Current land use	Size Percent native vegetation
	Wetlands	Condition (% surrounding vegetation – 200m buffer) Distance to nearest watercourse	Size Adjacent land use

Appendix A provides some details around the rules used for spatial assignment of sensitivity and resilience to each asset.

5.4.1 Assumptions

Given the timeline for the project, and the lack of information available on some water assets, and ecological responses to coal seam gas extraction and coal mining activities, a number of assumptions were necessary to complete and implement the vulnerability framework:

- As a rule the vulnerability asset framework is supported by generic rather than specific understanding of riverine, wetland and floodplain assets in the Namoi catchment
- Vulnerability ratings are relative, not absolute
- The number and type of values used to assign asset sensitivity and resilience were limited by the availability of existing spatial data to describe the target asset. It is acknowledged that there are likely several important descriptors for qualifying water asset responses to pressure from coal seam gas extraction and coal mining, but if they were not available in a compatible spatial format they could not be used in the assessment
- In completing the vulnerability framework it was also assumed that the more degraded an asset's current condition, the less sensitive it would be to further impacts. Conversely, it was assumed the assets in the best current condition were most resilient to change
- It was assumed that where pressure from coal seam gas extraction and coal mining did not involve total physical loss of the asset, the pressure would never equate to a total change in condition of the asset; that there would always be some component of the current structure and function retained (e.g. no permanent wetland ever became permanently dry).

5.5 REVISION OF VULNERABILITY CATEGORIES

The vulnerability ratings assigned to assets using the generic spatial rules shown in Table 5 were revised, if necessary, through application of four subsequent activities:

- Targeted literature review
- Expert workshop
- Special considerations
- Spatial check against coal resource potential

5.5.1 Literature review

As much literature as possible was sourced and reviewed for this project, and if relevant, information was used to re-assign values and sensitivities to particular assets for particular effects. A full bibliography is presented in Appendix B, and an example of literature review is presented in Appendix C for habitat value of aquifers (based on stygofauna potential).

5.5.2 Stakeholder Workshop

A stakeholder workshop was held at the CMA office in Tamworth on the 31st August 2012, at which Namoi CMA staff were able to revise the vulnerability rating associated with any water asset, based on local knowledge about natural, cultural and socio-economic values and Catchment Action Plan settings not captured by the data/literature review. A number of additional assets and publications were also identified at the workshop.

5.5.3 Special considerations

With respect to both water quantity and habitat, vulnerability categories were assigned directly to Namoi sub-catchments using specific thresholds stated in the Namoi CAP, namely:

- Annual surface flow should be no less than 66% of pre-development surface water flow; and
- Total vegetation cover should be maintained above 70% and 30% thresholds.

For water holes, water falls and caves, a standard vulnerability class of ‘high’ was assigned, based on recognition that each of these names features represented a notable recreational and/or cultural asset.

All assets that were located within gazetted reserves (i.e. National Parks, nature Reserves etc) were assigned a ‘high’ vulnerability with respect to the habitat effect.

5.5.4 Mining Potential

Once all data were compiled, a final review was conducted in which vulnerabilities were revised downwards if the entire asset occurred outside the mapped extent of the potential coal or CSG gas resource, as depicted in Table 6. A map of coal resource potential in the Namoi catchment is provided at Figure 6.

Table 6. Revised vulnerability scores based on coal potential (relevant to CSG and coal mining activities only).

Location of Asset	Change to Vulnerability Status
Part or all within OCM/LWM areas	No change
All outside OCM/LWM areas	Medium → Low; High → Low
All or part within areas of high and/or moderate CSG potential	No change
None within areas of high or moderate CSG potential, but all or part within area of low CSG potential	Medium → Low; High → Medium
All within areas no CSG potential	Medium → Low; High → Low

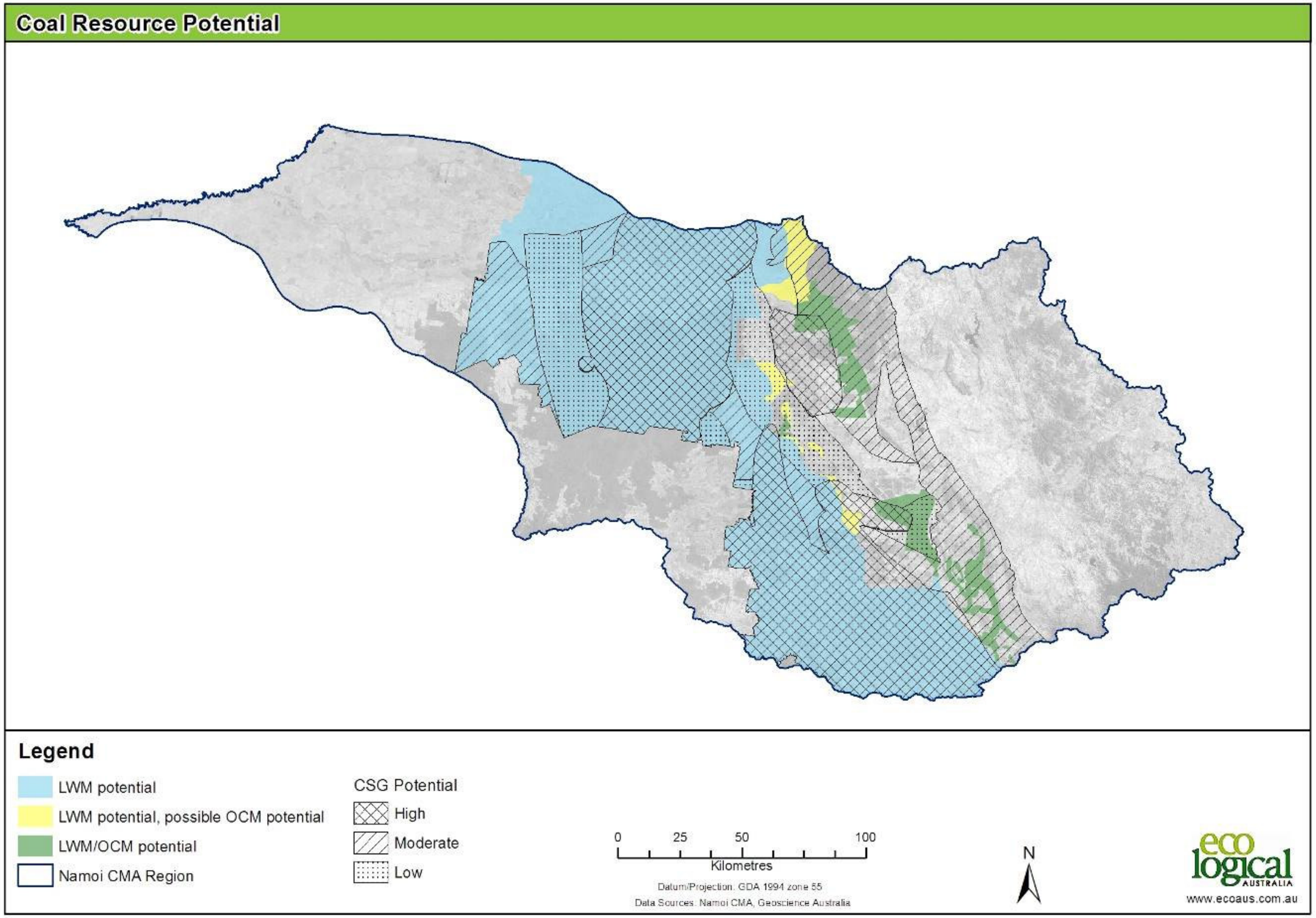

Figure 6. Coal resource potential in the Namoi catchment.

6 WAIT Database

6.1 CONTEXT

The WAIT database was developed by DSEWPaC for Phase 1 of the Bioregional Assessments. It is designed to store various data about a catchment's water assets. It includes a module that allows a broad rating of vulnerability (high, moderate or low) to be entered in relation to the potential impact of major land use activities on flow pattern, habitat, water quality and water quantity. For this project, vulnerability associated with coal mining and CSG extraction (but not other activities) were considered.

The following fields are included in the WAIT database:

General Fields

- Asset ID
- Asset Name
- NRM Region
- Description
- WaterBody_Type
- Coordinates
- Nearest_Town
- Mapsheet_100k_name
- Environmental Value
- National Water Quality Management Strategy (NWQMS) values
- Economic Value
- Social Cultural Value
- Hydrology
- Geology_geomorphology
- Other_Relevant_Details
- ManagementAuthority
- Current_landuse
- Tenure
- Condition
- Is_map_available
- Is_GISdata_available
- Is_metadata_available
- File Identifier_in_ANZMetlitetool
- Dataset_resource_title_in_ANZMetlite tool
- References
- Known_knowledge_gaps
- Primary_contact_for_asset
- Legal_protection
- Notes

Vulnerability fields

- Activity
- Impact
- Existing/potential hazard
- Mitigation in place
- Effect
- Description

6.2 METHODS AND ISSUES

Given the number of natural assets identified in the Namoi CMA and the limited time available, manually entering the information directly into the WAIT database for each asset was not feasible. An alternative method, which involved intersecting the composite natural asset layer with other spatial layers and uploading the results directly into the WAIT database was developed. The method was applied to populate several fields including: Coordinates, Nearest_Town, Mapsheet_100k_name, Geology_geomorphology, Current_landuse, Tenure, Is_GISdata_available and Impact. Information from non-spatial datasets was collated in MS excel and loaded into the WAIT database using the identity field as the unique identifying link.

In many cases duplicate asset names occurred. Care was taken to identify these assets as individual features within both WAIT and the geodatabase. For example, there are 15 Sandy Creeks within Namoi CMA, each with a unique identity number.

Note that the length of the reference field in the WAIT database was not of sufficient length to fit multiple references. Hence an abbreviated reference within the WAIT database was used, with a full list of references provided in a table created in the WAIT database, entitled 'ELA_Ref'.

6.3 RESULTS

A summary of the data uploaded into the WAIT database is provided in Table 7 as the number of records populated for each field in the database. Time and resource limitations prevented completion of all fields in the database, however the large majority of natural assets have been identified and assessed using the vulnerability criteria.

Table 7. WAIT fields populated at project completion

Database_field	#fields populated
ID	2298
AssetName	2298
NRM Region	2298
AssetID	2298
Description	1112
WaterBody_Type	1423
Coordinates_lat_long	2275
NWQMS_Values	796
coordinates_define	2140
Nearest_Town	2197

Database_field	#fields populated
Mapsheet_100k_name	2255
EnvironmentalValue	1948
EconomicValue	31
SocialCulturalValue	12
Hydrology	819
Geology_geomorphology	2259
Other_Relevant_Details	2236
ManagementAuthority	109
Current_landuse	2220
Tenure	1335
Condition	368
Is_map_available	0
Is_GISdata_available	2295
Is_metadata_available	1112
FileIdentifier_in_ANZMetlitetool	0
Dataset_resource_title_in_ANZMetlitetool	0
References	2128
Known_knowledge_gaps	0
Primary_contact_for_asset	0
Legal_protection	389
Notes	2295
Activity	4474
Impact	4474
Existing/potential hazard	0
Mitigation in place	0
Effect	4474
Description	0

Asset-specific information can be obtained by querying the WAIT database. Spatial maps of different vulnerability classes can also be produced by linking vulnerability classes to mapped assets via the geodatabase.

7 Recommendations

7.1 RECOMMENDATION 1: INCLUSION OF BIODIVERSITY ASSETS

The Namoi catchment supports a number of significant non-water related biodiversity assets that were not systematically included in Phase 1. Many of these assets are coincident with the coal resource potential of the Namoi catchment, and are likely to be impacted by mining (and other) activities. Workshop participants noted that consideration of biodiversity is important in any strategic landscape-scale assessment.

It is thus recommended that subsequent Phases of the Bioregional Assessment consider DSWEPAC Matters of National Environmental Significance (i.e. Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 threatened ecological communities, flora and fauna species and migratory species), and vegetation intactness and connectivity. Biodiversity data for these assets are generally complete and available for inclusion, and resilience thresholds are available (e.g. IUCN levels, listed critical habitat).

7.2 RECOMMENDATION 2: COLLECTION OF CONDITION STATUS

The condition of some assets in the catchment is not well known, particularly that of wetlands and GDEs. It is important that the condition of such assets, particularly those coincident with CSG and coal potential, is well understood so that an improved level of sensitivity can be assigned.

A process of remote sensing assessment, augmented with targeted survey and benchmarking would provide the relevant level of detail about condition of key assets.

7.3 RECOMMENDATION 3: REFINE RESOURCE POTENTIAL MAPS

The resource potential maps used in the vulnerability analyses are based on broad geology types, and lack detail. More refined maps of the location of likely coal deposits and potential gas exploration areas exist, but these are typically held by private interests, and are thus not freely available.

It is recommended that geological modelling and industry consultation be employed to improve resource extraction likelihood maps, and to refine vulnerability analyses.

7.4 RECOMMENDATION 4: CONDUCT A CUMULATIVE RISK ASSESSMENT

The assessment conducted in this study considered the vulnerability of water assets to coal mining and CSG extraction activities only. It did not include any of the current site, regional and landscape pressures on water assets, although it is noted that WAIT accommodates upload of such information under different activities. Vulnerability was assigned on an asset by asset basis without the capacity to give consideration to potential cumulative impacts (e.g. would a ‘low’ vulnerability stream have an elevated status if other similar streams in the areas were impacted by mining).

It is important that the vulnerability of an asset is re-assessed with respect to the ‘cumulative’ impact to other assets, and that the framework takes into account the impacts from coal mining and CSG extraction as well as those from other industries.

7.5 RECOMMENDATION 5: COAL INDUSTRY CONSULTATION

Coal industry representatives were not consulted during the study. It is recommended future efforts to determine the location, scale and type of impacts from coal mining and CSG extraction on assets in the Namoi catchment involve input from coal industry representatives. This will add to the rigour of the assessment, especially in terms of the likely location of future coal industry activities, and the type and magnitude of likely environmental impacts.

7.6 RECOMMENDATION 6: ONGOING DATA MANAGEMENT INVESTMENT

This project represents the first, important step in collating data on natural water assets across the catchment for the purposes of informing landscape level vulnerability to CSG/coal extraction. Due to data and time constraints many values for Environmental, Cultural, Economic and Hydrological characteristics of named assets were not completed. Therefore, it is recommended that an ongoing investment is allocated to build this data and knowledge to improve subsequent phases of Bioregional Assessment.

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Appendix A: Rules used to assign levels of 'sensitivity' and 'resilience' to each asset.

Outline

This Appendix outlines the rules used to assign a sensitivity and resilience level, and thus a vulnerability rating (high, medium or low) to each asset for each effect.

Algorithms

Land Use Index = [0 * intensive (ha) + 0.5 * semi-intensive (ha) + 1.0 x non-intensive (ha)] ,

Where

intensive (ha) = area of intensive agriculture, including cropping, vineyards, horticulture, industrial/urban etc

semi-intensive (ha) = area of semi intensive agriculture, mainly grazing on modified (improved)land; and

non-intensive = area of non-intensive agriculture, including grazing native pastures and woodlands, native forestry etc

EEC index = [(1 X EEC1) + (0.75 * EEC2) + (0.5* EEC3) + (0.25*EEC4) + (0 * EEC5)]/catchment area

Where

EEC1 = vegetation types that have >75% EEC candidacy

EEC2 = vegetation types that have 50 – 75% EEC candidacy

EEC3 = vegetation types that have 25 – 50% EEC candidacy

EEC4 = vegetation types that have 5 – 25% EEC candidacy

EEC5 = vegetation types that have < 5% EEC candidacy

TS index = [(1 X TS1) + (0.75 * TS2) + (0.5* TS3) + (0.25*TS4) + (0 * TS5)]/catchment area

Where

TS1 = very high overlap of threatened species

TS2 = high overlap of threatened species

TS3 = moderate overlap of threatened species

TS4 = low overlap of threatened species

TS5 = very low overlap of threatened species

(threatened species modelling process outlined in ELA 2012)

Asset class = Groundwater Aquifer

Effect = flow pattern

Sensitivity

Sensitivity = high if majority of aquifer is connected

Sensitivity = medium if majority of aquifer is transitional

Sensitivity = low if majority of aquifer is disconnected

(Information from Badenhop *et al*. 2012 and SWS 2012)

Resilience

Resilience = high if < 1% of aquifer identified as 'stressed'

Resilience = medium if 1 - 10% identified as 'stressed'

Resilience = low if > 10% identified as 'stressed'

(Information from Badenhop *et al*. 2012)

Effect = habitat

Sensitivity

Sensitivity = high if stygofauna potential is identified as high

Sensitivity = medium if stygofauna potential is identified as moderate

Sensitivity = low if stygofauna potential is identified as low

Resilience

Sensitivity = high if aquifer area ≥ 100,000 ha

Sensitivity = medium if aquifer area = 10,000 - 100,000 ha

Sensitivity = low if aquifer area < 10,000 ha

Effect = water quantity

Sensitivity

Sensitivity = high if majority of aquifer is disconnected, or if > 10% of aquifer as a identified recharge zone

Sensitivity = medium if majority of aquifer is in transition, or 1 – 10% of aquifer is identified recharge zone

Sensitivity = low if majority of aquifer is connected, or if no other information is provided

(Information from Badenhop *et al*. 2012 and SWS 2012)

Resilience

Resilience = high if < 1% of aquifer identified as 'stressed' and majority identified as 'recovering' and aquifer is large (> 1 million ha)

Resilience = medium if at least 30% identified as 'stable', < 10.0% identified as 'stressed', and aquifer is at least 10,000 ha in extent

Resilience = low if > 10.0% identified as 'stressed' or if aquifer is small (< 10,000 ha)

(Information from Badenhop *et al*. 2012 and SWS 2012)

Effect = water quality

Sensitivity

Sensitivity = high if aquifer is alluvial and/or if the total density of agricultural bores exceeds 1 per km^2

Sensitivity = low if aquifer is non-alluvial or if the total density of agricultural bores is < 0.5 per km^2

Sensitivity = medium for other combinations of aquifer type and bore density

Resilience

Resilience = high if aquifer is connected

Resilience = medium if aquifer is transitional

Resilience = low if aquifer is disconnected

(Information from Badenhop *et al*. 2012)

Asset class = Groundwater Dependent Ecosystems (GDEs)

Effect = flow pattern

Sensitivity

Sensitivity = high if supporting aquifer is poorly connected, or if aquifer connectivity is transitional and water table depth is < 10m

Sensitivity = medium if supporting aquifer is connected and water table depth is < 10m, or if aquifer connectivity is transitional and water table depth is > 10m

Sensitivity = low if supporting aquifer is connected and water table depth is > 10m, or if aquifer connectivity is transitional and water table depth is > 20m

Resilience

Resilience = high if floodplain is not regulated

Resilience = low if floodplain is regulated

Effect = habitat

Sensitivity

Polygon data only

Sensitivity = high where > 10% GDE = EEC and/or where 0 – 50% of the pre-European area of the dominant community remains in the catchment

Sensitivity = low where 0- 1% GDE = EEC and where >70% of the pre-European area of the dominant community remains in the catchment

Sensitivity = medium for all other combinations

Resilience

Polygon data only

Resilience = high where depth to water table < 10 m

Resilience = medium where depth to water table 15-25 m (or where no depth data are available)

Resilience = low where depth to water table > 25 m

Effect = water quantity

Sensitivity

Sensitivity = high if GDE linked to a poorly connected aquifer

Sensitivity = medium if GDE linked to a transitionally connected aquifer

Sensitivity = low if GDE linked to a connected aquifer

Resilience

Resilience = high if depth to water table ≤ 10 m and GDE size > 100 ha

Resilience = low if depth to water table > 20 m or GDE size < 10 ha (including springs)

Resilience= medium for all other combinations of water table depth and GDE area

Effect = water quality

Sensitivity

Sensitivity = high if surrounding land use (for springs) or *in situ* land use for more extensive GDEs is non-intensive (land use index ≥ 0.700)

Sensitivity = medium if surrounding land use (for springs) or *in situ* land use for more extensive GDEs is semi-intensive (land use index 0.300 – 0.700)

Sensitivity = low if surrounding land use (for springs) or *in situ* land use for more extensive GDEs is intensive (land use index < 0.300)

Resilience

Resilience = high if GDE size > 100 ha

Resilience= medium if GDE size 10 - 100 ha

Resilience = low if GDE size < 10 ha (including springs)

Asset class = Local catchments

Effect = flow pattern

Sensitivity

Sensitivity = high if stream density ≥ 4.0 km per 100 ha (1 km^2) of catchment

Sensitivity = medium if stream density 2.0 – 4.0 km per 100 ha (1 km^2) of catchment

Sensitivity = low if stream density < 2.0 km per 100 ha (1 km^2) of catchment

Resilience

Resilience = high if < 10% of natural medium flow is under entitlement upstream

Resilience = medium if 10 - 30% of natural medium flow is under entitlement upstream

Resilience = low if > 30% of natural medium flow is under entitlement upstream

Effect = habitat

Sensitivity

Sensitivity = high where EEC index ≥ 0.500 or TS index ≥ 0.750 or no. vegetation types ≥ 10

Sensitivity = low where EEC index = < 0.250 and TS index < 0.500 and no. vegetation types < 7

Otherwise sensitivity = medium

Resilience

Resilience measured based on historical level of clearing in catchment, and proximity to the 30%, 70% and 100% clearing thresholds (specified in Namoi CAP).

Resilience = high where % vegetation cleared = 0 – 10%, 30 – 50%, 70 – 80% (at least 20% from any threshold)

Resilience = medium where % vegetation cleared = 10 – 20%, 50 – 60%, 80 – 90% (at least 10% from any threshold)

Resilience = low where % vegetation cleared = 20 – 30%, 60 – 70%, 90 – 100% (within 10% of a threshold)

Effect = water quantity

Sensitivity

Sensitivity = high if > 30% of natural medium flow is under entitlement upstream, or if at least 1% of catchment comprises water storage

Sensitivity = low if < 10% of natural medium flow is under entitlement upstream and < 0.1% of catchment comprises water storage

Sensitivity = medium for all other combinations of entitlement level and % area occupied by storages

Resilience

Resilience = high if RCI hydrological stress index > 0.800

Resilience = medium if RCI hydrological stress index = 0.500 – 0.800

Resilience = low if RCI hydrological stress index < 0.500

Effect = water quality

Sensitivity

Sensitivity = high if majority of land use is high intensity (land use index ≤ 0.300)

Sensitivity = medium if majority of land use is semi-intensive (land use index = 0.300 – 0.700)

Sensitivity = low if majority of land use is low intensity (land use index > 0.700)

Resilience

Resilience = high if median annual flow (adjusted for entitlements) ≥ 1,000 ML/km^2/year, and ≥ 70% of catchment comprises native vegetation

Resilience = low if median annual flow (adjusted for entitlements) < 100 ML/km^2/year, or < 30% of catchment comprised native vegetation

Resilience – medium for other combinations of median annual flow and proportion of native vegetation

Asset class = Watercourse

Effect = flow pattern

Sensitivity

Sensitivity = high if % vegetation cover ≥ 70% or RCI geomorphic condition ≥ 0.700

Sensitivity = low if % vegetation cover < 30% and RCI geomorphic condition < 0.300

Sensitivity = medium for all other combinations of vegetation cover and geomorphic condition

Resilience

Resilience = high if stream order ≥ 5 and land use index ≥ 0.7

Resilience = low if stream order < 3 or land use index < 0.3

Resilience = medium for all other combinations

Effect = habitat

Sensitivity

Sensitivity = high if RCI fish/ macroinvertebrates is high (index > 0.65) and/or RCI riparian vegetation condition is high (index > 0.65), and/or total reach riparian vegetation cover > 70%

Sensitivity = low if RCI fish/macroinvertebrates and RCI riparian vegetation condition are all low (index < 0.5), and total reach riparian vegetation cover < 30%

Sensitivity = medium for all other combinations condition and cover

Resilience

Resilience = high if overall risk to instream value is low (RCI risk < 0.2) and land use index > 0.7

Resilience = low if overall risk to instream value is high (RCI risk > 0.5) or land use index < 0.3

Resilience = medium for all other combinations.

Effect = water quantity

Sensitivity

Sensitivity = high if watercourse is regulated, or if land use index < 0.300

Sensitivity = low if watercourse is unregulated and land use index ≥ 0.700

Sensitivity = medium for all other combinations

Resilience

Resilience = high if stream order ≥ 5 and committed water entitlements are < 10% of annual median flow

Resilience = low if stream order < 3 or committed water entitlements is >30% of annual median flow

Resilience = medium for all other combinations of stream order and entitlements

Effect = water quality

Sensitivity

Sensitivity = high if RCI fish/ macroinvertebrates is high (index > 0.65) and/or RCI riparian vegetation condition is high (index > 0.65), and/or total reach riparian vegetation cover > 70%

Sensitivity = low if RCI fish/macroinvertebrates and RCI riparian vegetation condition are all low (index < 0.5), and total reach riparian vegetation cover < 30%

Sensitivity = medium for all other combinations of condition and vegetation cover

Resilience

Resilience is influenced by location of major storages as well as adjacent land use and stream size (stream order).

The following table shows levels of resilience for combinations of the above.

	Stream above major storage		Stream below major storage	
% low-intensity agriculture within 200m distance	Small stream (1^{st} – 2^{nd} order)	Large stream (> 2^{nd} order)	Small stream (1^{st} – 2^{nd} order)	Large stream (> 2^{nd} order)
≥ 70	high	high	high	medium
30 - 70	high	medium	medium	low
< 30	medium	low	low	low

Asset class = Floodplains

Effect = flow pattern

Sensitivity

Sensitivity = high if floodplain regulated

Sensitivity = medium if floodplain partly regulated

Sensitivity = low if floodplain unregulated

Resilience

Resilience = high if land use index ≥ 0.700 and % native vegetation cover ≥30%

Resilience = low if land use index < 0.300 or % native vegetation cover <10%

Resilience = medium for all other combinations of land use index and % native vegetation cover

Effect = habitat

Sensitivity

Sensitivity = high where EEC index ≥ 0.333 or TS index ≥ 0.50 or no. vegetation types > 15

Sensitivity = low where EEC index = < 0.200 and TS index < 0.250 and no. vegetation types < 12

Sensitivity = medium for all other combinations of EEC index, TS index and number of vegetation types

Resilience

Resilience measured based on historical level of clearing in catchment, and proximity to the 30% and 70% clearing thresholds (specified in Namoi CAP), as well as the 100% clearing threshold

Resilience = high where % vegetation cleared = 0 – 10%, 30 – 50%, 70 – 80% (at least 20% from any threshold)

Resilience = medium where % vegetation cleared = 10 – 20%, 50 – 60%, 80 – 90% (at least 10% from any threshold)

Resilience = low where % vegetation cleared = 20 – 30%, 60 – 70%, 90 – 100% (within 10% of a threshold)

Effect = water quantity

Sensitivity

Sensitivity = high if land use index < 0.300 or number of major farm storages > 50

Sensitivity = low if land use index ≥ 0.700 and number of major farm storages < 10

Sensitivity = medium for all other combinations of land use index and major farm storages

Resilience

Resilience = high if floodplain unregulated

Resilience = medium if floodplain partly regulated

Resilience = low if floodplain regulated

Effect = water quality

Sensitivity

Sensitivity = high if land use index < 0.300

Sensitivity = medium if land use index = 0.300 – 0.700

Sensitivity = low if land use index ≥ 0.700

Resilience

Resilience = high if % of floodplain retaining true native vegetation cover is ≥ 30% or floodplain size ≥ 100,000 ha

Resilience = low if % of floodplain retaining true native vegetation cover is < 10% or floodplain size < 10,000 ha

Resilience = medium for all other combinations of native vegetation cover and floodplain size.

Asset class = Wetlands

Effect = flow pattern

Sensitivity

Sensitivity = high where majority of surrounding vegetation (in 200 m buffer) is true native

Sensitivity = medium where majority of surrounding vegetation (in 200 m buffer) is derived native

Sensitivity = low where majority of surrounding vegetation (in 200 m buffer) is exotic

(no condition data for wetlands, so surrounding vegetation used as a surrogate)

Resilience

Resilience = high if feeding floodplain/watercourse is unregulated, and wetland area ≥ 100 ha

Resilience = low if feeding floodplain/watercourse is regulated, and wetland area < 10 ha

Resilience = medium for all other combinations of regulation status and wetland area

Effect = habitat

Sensitivity

Sensitivity = high if the extent of the dominant wetland type has been historically reduced by more than 50%, or the wetland retains more than 100 ha of uncleared native vegetation, or more than 70% of the wetland buffer (200 m) supports true native vegetation

Sensitivity = low if the extent of the dominant wetland type has been historically reduced by less than 20%, if the area of native vegetation is less than 10 ha, and less than 30% of the wetland buffer (200 m) supports true native vegetation

Sensitivity = medium for all other combinations

Resilience

Resilience = high if area > 100 ha and if land use index ≥ 0.700

Resilience = low if area < 10 ha or land use index < 0.300

Resilience = medium for all other combinations of wetland area and surrounding land use

Effect = water quantity

Sensitivity

Sensitivity = high if wetland is regulated

Sensitivity = medium if wetland is semi-regulated (i.e. part of the contributing catchment is regulated)

Sensitivity = low if wetland is unregulated

Resilience

Resilience = high for wetlands with a total area > 100 ha

Resilience = medium for wetlands with a total area 10 - 100 ha

Resilience = low for wetlands with a total area < 100 ha

Effect = water quality

Sensitivity

Sensitivity = high if surrounding vegetation is predominately native vegetation types, of distance from the nearest watercourse is in excess of 1 km

Sensitivity = low if surrounding vegetation is predominately exotic and distance from the nearest watercourse is less than 200 m.

Sensitivity = medium for all other combinations of vegetation and distance

Resilience

Resilience = high if adjacent land use is predominately non-intensive and area of asset is greater than 100 ha.

Resilience = low if adjacent land use predominately intensive or area of asset is less than 10 ha

Resilience = medium for all other combinations of land use and size

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Appendix C: Stygofauna likelihood in aquifers of the Namoi Catchment

Background - Factors influencing biological distribution in aquifers

Stygofauna are the animals that live in groundwater. Recent estimates suggest there could be as many as 2680 species in the western half of the Australian continent, although approximately 12 % of these have been described (Guzik et al 2011). It is difficult to estimate the diversity of eastern Australian aquifers, but they may be just as diverse as western aquifers.

As with all fauna, groundwater invertebrates require favourable conditions to inhabit an aquifer, but with this many species, there is a broad range of variability in ecological requirements. Not all aquifers are suitable for stygofauna, and those that are suitable may become unsuitable as a result of human activities or natural changes. Biological distribution in groundwater is influenced by historical, geological, hydrological, physio-chemical, and biological properties (Strayer 1994, Hancock et al 2005). There is still a lot being learned about stygofauna ecology, particularly in the eastern states where there have been relatively few surveys compared to Western Australia. Nevertheless, it is possible to briefly summarise what is already known about aquifer conditions likely to influence distribution.

Aquifer type

Stygofauna have been collected from many aquifer types, including fractured basalt, fractured sandstone aquifers, and pesolithic aquifers, but are most common in karstic and alluvial aquifers. Critical aquifer characteristics are the hydraulic conductivity, depth to water table, and porosity.

Generally, stygofauna occur more frequently in alluvial aquifers and karst than in other geological formations (Hancock et al 2005, Humphreys 2008). Alluvial aquifers occur beneath floodplains, which often provide the following conditions favourable to stygofauna:

- Water table is shallow, so there is recharge of infiltrating rainwater and organic matter, and the water table is accessible to floodplain tree roots
- There is often some degree of hydrological connectivity with surface rivers. This is particularly influential in regulated rivers where artificial flow releases may provide aquifer recharge of organic matter and oxygen in periods where natural surface flow would be absent
- Compared to deeper aquifers, water in alluvial aquifers is young and has a rapid flux.

Hydraulic conductivity

Hydraulic conductivity indicates how rapidly water flows through an aquifer. This is important to stygofauna communities because the flux of water through an aquifer often influences how rapidly organic matter and oxygen concentrations can be replenished.

Depth of water table

Depth to water table influences the amount of organic matter and oxygen that are available to aquifer foodwebs. With increasing depth below the land surface, the concentration of organic matter dissolved in infiltrating rainwater diminishes as it is absorbed in transit by soil bacteria and plant roots. Shallow water tables of less than 15 m have been found to favour high diversity in alluvial aquifers in eastern Australia (Hancock and Boulton 2008).

Another source of organic matter to aquifer invertebrates is the presence of phreatophytic roots (Jasinska et al. 1996). Root density is likely to be higher in shallower aquifers, and the resultant availability of organic matter provides food to diverse stygofauna communities (Hancock and Boulton 2008).

Connectivity to recharge areas

A large proportion of the organic matter that fuels aquifer food webs has its origin at the surface and enters groundwater in particulate or dissolved forms. Therefore, sections of aquifers that are nearer to recharge areas are likely to have higher diversity and abundance than those that are further away since the transfer of organic matter and oxygen is greater at these sites (Datry et al 2004).

A space for living

Stygofauna can only live in aquifers with enough space for them to move around in. Space is present in the solute cavities in karst, between pesolithic sediments in calcrete, and fractures in sandstone and basalt. In sedimentary aquifers, the size of porespace between particles often correlates to the size of the animals present, with larger species occurring in aquifers of coarser material (Strayer 1994).

Also important when considering the space available for living is the connectivity between pores, cavities, and fractures. These act as migration pathways to allow fauna to move around in the aquifer and are likely to be important in recolonising following disturbance.

Evolutionary history

Most stygofauna evolved from ancestors that once lived in surface freshwater or marine environments. As a result, it is possible that they have retained some of the traits and environmental tolerances of their ancestry. As an example, in coastal areas where ancestral stygofauna species may have come from a marine origin, contemporary taxa may be tolerant of high salinity (Humphreys 2008, Hancock and Steward 2004). Conversely, taxa with a freshwater ancestry may prefer lower salinities (Hancock and Boulton 2008).

Food availability

Stygofauna have adapted to the resource-starved conditions in aquifers and can tolerate low concentrations of organic matter (Hahn 2006, Strayer 1994). Food is available to stygofauna as particulate organic matter, groundwater bacteria, or as roots of phreatic trees. In its dissolved or fine particulate form, organic matter enters aquifers with recharging water. Dissolved organic matter is taken up by groundwater bacteria, which are then imbibed by smaller stygofauna. Most stygofauna are opportunistic omnivores.

Water regime

Local or regional climate and river-flow regimes can influence aquifer recharge, and so effect the organic matter flux in the aquifer. Periods of high, steady rainfall can increase hydrological connectivity between the land surface and the aquifer and can reduce depth to water table. Exchange between rivers, the hyporheic zone, and aquifers can be an important source of nutrients to stygofauna communities (Dole-Olivier et al 1994), so flow fluctuations that enhance hyporheic exchange can subsequently enrich stygofauna communities in deeper parts of the aquifer.

Salinity

Stygofauna in inland aquifers are generally restricted to fresh or partly brackish water. Hancock and Boulton (2008) suggest that most taxa collected from alluvial aquifers in NSW and Qld prefer EC less than 5,000 µS/cm. In surveys of coastal areas and near salt lakes in Western Australia, stygofauna were collected from aquifers with salinities at or exceeding sea water (Watts and Humphreys 2004). EPA Guidance Statement 54a, recommends 60 000 mg/L as the salinity above which stygofauna are unlikely (EPA 2007).

Dissolved oxygen

Stygofauna are able to tolerate very low concentrations of dissolved oxygen. Hahn (2006) observed a strong decrease in concentrations below 1.0 mg/L, but found some fauna in concentrations down to 0.5 mg/L. Some taxa are able to survive virtually no oxygen for temporary periods for up to 6 months (Malard and Hervant 1999, Henry and Danielopol 1999). Aquifers can be heterogeneous environments, so may contain patches of water with sufficient oxygen concentration to be suitable for stygofauna. As dissolved oxygen is measured from water pumped from bores, it can be difficult to identify where these patches occur.

Likelihood of Aquifer to having stygofauna

This section assesses the likelihood of aquifer occurring in an aquifer. Aquifers where stygofauna are known to occur, or where conditions are suitable for stygofauna, are rated as having a **High sensitivity**. Where most of the conditions are suited to stygofauna, but there has been no sampling or there are other factors that may reduce suitability, the aquifer is rated as having a **Medium sensitivity**. For aquifers that are unsuited for stygofauna, a **Low sensitivity** rating has been assigned.

As an overview, the larger alluvial aquifers in the region are extremely likely to have stygofauna, and some species are known from the Namoi, Peel, and Gwydir alluvium. Smaller tributary alluvial aquifers are also likely to have stygofauna, even in relatively impacted sites provided there hasn't been excessive decline in water tables.

The fractured rock aquifers are unlikely to have stygofauna in their deeper sections, but could allow refuge to alluvial fauna at the alluvium/rock boundary if there is sufficient fracturing and good water quality.

No stygofauna are known from the Great Artesian Basin, and given the pressure and age of the water, there is unlikely to be sufficient organic matter to support stygofauna communities. However, unconfined alluvial aquifers overlying the Great Artesian Basin may contain stygofauna.

Aquifers of the Namoi Catchment

Peel River alluvial aquifer

Stygofauna surveys were conducted in the Peel River alluvial aquifer from 2003 to 2008 as part of Peter Hancock's post-doctoral research (Watt et al. 2008, Hancock and Boulton 2008, Camaho and Hancock 2010) and subsequently Moya Tomlinson's PhD (Tomlinson 2008). Stygofauna are known from the Peel Alluvium from Woolomin downstream to Attunga and are likely to occur throughout the aquifer downstream to the confluence with the Namoi. Many tributary alluvial aquifers will also have stygofauna

Likelihood: High sensitivity

Peel Valley Fractured Rock

The fractured rock aquifer of the Peel Valley is unlikely to have stygofauna, apart from in shallow sections of the aquifer adjacent to alluvium. As stygofauna are known from the alluvial aquifers of the Peel Valley, it is possible that stygofauna migrate into the adjacent rock aquifer when fracturing allows. The extent and depth of colonisation below the basement of the alluvium will be determined by both the degree of connectedness between rock fractures, and the water quality.

Likelihood: Moderate sensitivity

New England Fold Belt

No stygofauna are known from the aquifers of the New England Fold Belt. It is unlikely that there will be any stygofauna occurring in this aquifer below the shallow weathered zone adjacent to the alluvial aquifers.

Likelihood: Low sensitivity

Miscellaneous Alluvium of the Barwon Region

Smaller alluvial aquifers of the Manilla and tributaries of the upper Namoi are likely to have stygofauna. As these aquifers are connected to the Upper Namoi alluvium the stygofauna communities in the smaller aquifers will have similar species.

Likelihood: High sensitivity

Gunnedah Basin

The Gunnedah Basin consists of deep sedimentary rocks. It is unlikely that stygofauna inhabit this aquifer.

Likelihood: Low sensitivity

Oxley Basin

Like the Gunnedah Basin, the Oxley Basin consists of deep sedimentary rock and is unlikely to have any stygofauna.

Likelihood: Low sensitivity

Liverpool Ranges Basalt

The Liverpool Ranges Basalt is unlikely to have stygofauna in the deeper sections, but may have some communities in the fractured sections adjacent to the Namoi alluvium.

Likelihood: Moderate sensitivity

Upper Namoi Alluvium

Alluvial aquifers of the upper Namoi are known stygofauna habitat (Peter Serov *pers comm.*). Stygofauna have been collected from the Maules Ck alluvium.

Likelihood: High sensitivity

Lower Namoi Alluvium

The Lower Namoi Alluvium is likely to have stygofauna in areas where the aquifer water quality is suitable, and the water table is less than 20 m. The fauna here is expected to be similar to the fauna in the Upper Alluvium.

Likelihood: High sensitivity

Great Artesian Basin

No stygofauna are known from the Great Artesian Basin, and given the pressure and age of the water, there is unlikely to be sufficient organic matter to support stygofauna communities.

Likelihood: Low sensitivity

Great Artesian Basin Alluvium

Alluvial aquifers overlying the Great Artesian Basin may be suitable habitat for stygofauna if they are of sufficient porosity.

Likelihood: Moderate sensitivity

Galarganbone Tertiary Basalt

The Galarganbone Tertiary Basalt aquifer is unlikely to be suitable for stygofauna, except in areas where it is shallow and adjacent to alluvium.

Likelihood: Low sensitivity

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