Appendix G1

Managed release study (Bohena Creek)

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Managed Release Study: Bohena Creek

Narrabri Gas Project

Prepared for
Santos NSW (Eastern) Pty Ltd

September 2016

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Abbreviations

Abbreviation	Description
ANZECC	Australian and New Zealand Environment Conservation Council
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BSAL	Biophysical Strategic Agricultural Land
CAP	Catchment Action Plan
CMA	Catchment Management Authority
CSG	Coal Seam Gas
DPI Water	Department of Primary Industries – Office of Water, formerly NSW Office of Water
DTA	Direct Toxicity Assessment
DTIRE	Department of Trade Investment Resources and Energy
EPBC	Environment Protection and Biodiversity Conservation Act
EPA	Environment Protection Act
EP&A	Environment Planning and Assessment Act
ERA	Ecological Risk Assessment
EPL	Environment Protection Licence
FM Act	Fisheries Management Act
GDE	Groundwater Dependent Ecosystem
GIA	Groundwater Impact Assessment
GL	Giga Litres

Abbreviation	Description
LGA	Local Government Area
MAR	Managed Aquifer Recharge
MDB	Murray Darling Basin
ML	Mega Litres
MNES	Matters of National Environmental Significance
MRS	Managed Release Study
NEPM	National Environment Protection Measures
NSW	New South Wales
OEH	Office of Environment and Heritage
PAL	Petroleum Assessment Lease
PEL	Petroleum Exploration Licence
POEO Act	Protection of Environment Operations Act
PO Act	Petroleum (Onshore) Act
PWMP	Produced Water Management Plan
PWMS	Produced Water Management Strategy
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SEPP	State Environment Protection Policy
SSD	State Significant Development
SSI	State Significant Infrastructure
SWD	Surface Water Discharge
TDS	Total Dissolved Solids
TJ	Terra Joules
TSC Act	Threatened Species Conservation Act
TSS	Total Suspended Solids
WSP	Water Sharing Plan
WMF	Water Management Facility
WMP	Water Management Plan

Executive summary

The Project

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

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

To enable gas extraction, the depressurisation of coal seams is required. The project would thus involve the extraction of produced water from coal seams that would be treated at the Leewood Water Management Facility (WMF). As part of the Project EIS, treated water would be beneficially used for drilling, dust suppression, and irrigation, with releases to Bohena Creek occurring infrequently.

Managed release which is the focus of this report is required from time-to-time to maintain water management system operational reliability. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water, typically during prolonged periods of wet weather when Bohena Creek is flowing (natural flows ≥ 100 ML/day). This Managed Release Study (MRS) is based on a proposed 25 year assessment period.

The MRS (this report) identifies and evaluates the potential impacts on the receiving environment related to the managed release of treated water to Bohena Creek. The report documents how Santos would avoid, manage and/or mitigate unacceptable impacts.

The Receiving Environment

Bohena Creek is located in the Namoi Catchment of the Murray Darling Basin. The unregulated Bohena Creek drains in a north westerly direction, joining the Regulated Namoi River just downstream of the Narrabri Township. Bohena Creek is reported to be intermittent. An intermittent stream is defined as flowing at least 15 % of the time. Tributaries to Bohena Creek are considered to be highly ephemeral, only flowing during periods of heavy rain. Ecological survey of Bohena Creek undertaken to support this study has indicated the existing environment is classed as significant or severe to moderate impairment.

Groundwater level in the Bohena Creek Alluvium is understood to vary according to antecedent rainfall conditions. Following heavy rainfall and subsequent saturation of the surficial alluvial deposits, surface flow may occur. During dominant dry periods, groundwater levels can drop to an estimated 2 m below the surface of the creek. It is considered likely that groundwater in the Bohena Creek Alluvium is perched on the finer grained sedimentary deposits of the Orallo Formation.

Managed Release Water Management

Water produced by the Narrabri Gas Project would be transmitted from wellhead via water pipes to the centralised water treatment and distribution facility known as the Leewood WMF.

Initially at the Leewood WMF, produced water would be temporarily stored in a pond allowing warmer produced water temperatures to dissipate heat to the atmosphere and equilibrate (thermal buffering), prior to undergoing treatment. This is an important step as, at the point of release, treated water temperatures must be as close to stream temperatures as possible.

At the Leewood WMF water would be treated via a number of processes including reverse osmosis (RO). Following treatment, treated water would be conveyed to an offsite treated water storage pond on the proposed irrigation site (refer GHD, 2016a; Beneterra, 2015). The produced water ponds would provide hydraulic buffering capacity to accommodate varying demand for beneficial use options. Treated water will be used for beneficial purposes including drilling, dust suppression, irrigation and release to Bohena Creek.

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25 year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the managed release activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

Water identified as requiring release would be transported via a pipeline to the proposed outlet location in Bohena Creek from where it would be released in accordance with the managed release scheme protocols.

Managed Release Simulations

Simulations of natural flows (N1) and episodic release to a flowing creek (37GLI01-W, when natural flows are equal to or greater than 100 ML/day) have been performed to quantify and understand potential impacts related to episodic release. Although in some years the creek does not flow at all, the stage-discharge curve for the DPI Water Newell Highway gauge indicates that Bohena Creek flows at greater than or equal to 100 ML/day for approximately 12 % of the time, equating to a long-term average of 44 days per year.

Beneficial use water balance modelling indicates that upstream storage capacity is required when beneficial uses and managed release are unavailable (when natural flows are < 100 ML/day). Whilst calculated to be a rare occurrence, this is most likely to occur between June and October in any given year. Implementation of an operational driver to undertake early release of treated water before ponds reach capacity when the creek is flowing at more than 100 ML/day would reduce the requirement for upstream storage capacity by approximately 20% in terms of likelihood of the storage being engaged, however there would be an increase in the total number of release events to a stream flowing ≥100 ML/day, with each event involving a much smaller release volume. With the implementation of a managed release protocol to Bohena Creek (when natural flows exceed 100 ML/day), then in peak production years 0 to 4, modelling indicates that approximately 7.2 % of all treated water would be directed to the creek. In years 5 onward, it is likely that the need to release will diminish as produced water volumes decline.

Infiltration modelling indicates that any release to a flowing creek (≥ 100 ML/day) is unlikely to cause significant change in surface water or groundwater quantity, observed as surface water ponding.

The rainfall-runoff (hydrology) model indicates the onset of flow in Bohena Creek with an accuracy of ± 1 days. Data developed as part of the hydrology model were suitable for input into the water balance model which were used to predict whether releases would be required to the creek flowing at a rate of ≥100 ML/day.

The surface water release (hydraulic) model indicates that the release of 12.0 ML/day does not result in any significant differences in water level, flow or velocity over the 5 and 100 years Average Recurrence Interval (ARI) events.

Each of the potential impacts described above is used as the basis for describing potential impacts in the impact assessment.

Ecological Risk Assessment

An Ecological Risk Assessment (ERA) was undertaken to assess the potential for chemical contaminants in treated water released to Bohena Creek to adversely affect aquatic and riparian ecosystems including water and soil processes, flora, and fauna (invertebrates and vertebrates). Key studies undertaken as part of the ERA include a Direct Toxicology Assessment (DTA) which further investigates boron and fluoride to generate data to contribute to the development of site specific trigger values for the potential release location at Bohena Creek; and an Aquatic Ecology and Stygofauna Assessment which investigates the current ecological conditions, identifies any freshwater and riparian flora and fauna species or ecological communities of local, regional or national significance and provides an assessment of the potential impacts to these associated with the project.

Risks to the proposed managed release were determined using a Decision Tree framework similar to that presented in the ANZECC/ARMCANZ (2000) to incorporate several lines of evidence.

On the basis of the analysis undertaken to date, ecological risks from the low levels of physicochemical and chemical stressors and toxicants that may be present in treated water are considered low when released to a flowing stream where flows are in excess of 100 ML/day.

It is proposed that dissolved oxygen levels will be increased via a diffuser at the release location, and release temperature will reflect ambient temperature. Numerical mixing zone analysis indicates that rapid mixing can be achieved and effective dilution will eliminate possible toxicity risks related to SAR and ion imbalance in flowing conditions (≥ 100 ML/day).

Managed Release Protocol

A managed release protocol was developed based on Goldsim™ model simulation results to guide when releases to Bohena Creek could be undertaken. The protocol was adopted for the Impact Assessment and Risk Assessment.

Table E1 Managed Release Protocol

Narrabri Gas Project – Managed Release Protocol
Monitor flow in Bohena Creek at Newell Highway gauge • Measured flow in Bohena Creek (measured at the Newell Highway gauge) is equal to or greater than 100 ML/day.
Monitor un-amended treated water in Leewood WMF • Water quality is within design specification and the range approved for release.
Provide prior notice of the intended commencement of managed release • Notification of intended commencement of managed release given to downstream users.
Release treated water directly from the Leewood WMF • Undertake release of up to 12 ML/day of un-amended treated water to Bohena Creek with a natural flow of at least 100 ML/day.

Impact Assessment

Impacts related to the release of treated water are presented and discussed. Information used to describe potential impacts is drawn from information contained in the MRS and supporting studies which are appendices to the MRS (Ecological Risk Assessment, Direct Toxicity Assessment, Aquatic Ecology and Stygofauna Assessment, and Fluvial Geomorphology Engineering Impact Assessment).

The impact assessment assumes that Santos may wish to implement early release criteria when Bohena Creek is flowing above a minimum threshold natural flow (≥ 100 ML/day at the Newell Highway gauge).

Where appropriate, impact assessments have been undertaken using the Matters of National Environmental Significance (MNES): Significant Impact Guidelines - version 1.1 (Commonwealth of Australia, 2009). Whilst these guidelines are specifically appropriate for MNES, they have been used to determine impacts in Bohena Creek as they provide a standardised approach to consideration of receptor sensitivity and magnitude (intensity, timing, duration and frequency).

With adequate dilution by, and comprehensive mixing with, natural flows in Bohena Creek, the risks presented by releases of treated water to the creek are assessed as low.

A summary of potential impacts and significance level is presented in Table E2. Overall potential impacts from the MRS range from a significance level of "insignificant" to "low". All potential impacts can be mitigated and risks reduced by incorporating appropriate mitigation measures (summarised overleaf).

Table E2 Summary of potential impacts and significance level

Objective	Potential impact		Significance
[O1]	A change in the quantity, quality or availability of surface or groundwater	Water quantity	Insignificant
		Water quality	Low
[O2]	Alteration to groundwater pressure and/or water table levels		Insignificant
[O3]	Alteration to the ecological nature of a wetland or watercourse		Insignificant
[O4]	Alteration to drainage patterns		Insignificant
[O5]	Reduced biological diversity or change species composition		Insignificant
[O6]	Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected		Low
[O7]	Reduce the availability of water for human consumption.		Insignificant

Risk Assessment

All risks are manageable and can be reduced by incorporating the following mitigation measures:

Design

- Ensure that the water management system has sufficient hydraulic residence time to allow for temperature equilibration with the Bohena Creek, or to dissipate during pipeline transfer.
- Install data loggers, at the release point, and upstream and downstream of the managed release point (in-stream) to monitor electrical conductivity and temperature.
- Raise DO levels to be within acceptable levels through provision of an aeration system.
- Modify turbidity to be close to that of the stream.
- Design the outlet system such that where managed release occurs to a braided channel, release at one or more locations is possible. This would help to disperse flow and reduce the potential for local groundwater mounding. Alternatively, select an unbraided stretch of creek.
- Install suitable bed and bank protection around the managed release structure (where required), with consideration given to:
- installation of the structure in a straight section of channel;
- installation of the structure low in the channel;
- installation of a stilling pool to dissipate energy; and
- locating the outlet structure such that migration of sand bars within the channel does not impact outfall performance.

Monitoring

- Undertake regular inspections of creek condition to monitor for morphological change (erosion and sedimentation) upstream and downstream of the outlet structure. Check if low flow channels are static or have moved.
- Undertake regular condition inspections of the managed release outlet structure to ensure that it is operable and clear of debris.
- When the Leewood WMF becomes operational, sample in Bohena Creek before and at periods following episodic releases to indicate whether there are changes to the aquatic

ecology. Sites should be routinely monitored in autumn and spring to determine whether release is altering aquatic ecosystems.

- Improve Bohena Creek streamflow data quality (data quality and updated rating curve) at the Bohena Creek Newell Highway gauge, or alternatively install a new gauging station at the release location or between the release location and Newell Highway.
- Continue ecological and water quality sampling (upstream, at release location, downstream of mixing zone and at Newell Highway). Sites should be routinely monitored in autumn and spring to determine whether release is altering aquatic ecosystems.
- Conduct toxicological assessment during commissioning and routinely for first five years or operation.

Management

- All results should be reported to operations staff.
- Develop environmental triggers as part of threshold action response plans and/or similar documents.
- Apply adaptive management techniques. For example if monitoring detects an impact or potential for impact (by analysing trends), or vice-versa (no impact – when simulations suggested impacts may occur), then managed release may be adjusted accordingly (decreased or increased). Similarly, once additional data have been collected, future monitoring could be reduced.
- If low flow channels are observed to have moved (due to stream change), consider relocating outfall structure.

1 Introduction

1.1 Project overview

Santos NSW (Eastern) Pty Ltd (Santos) is proposing to develop natural gas from coal seams in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri (refer Figure 1-1).

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

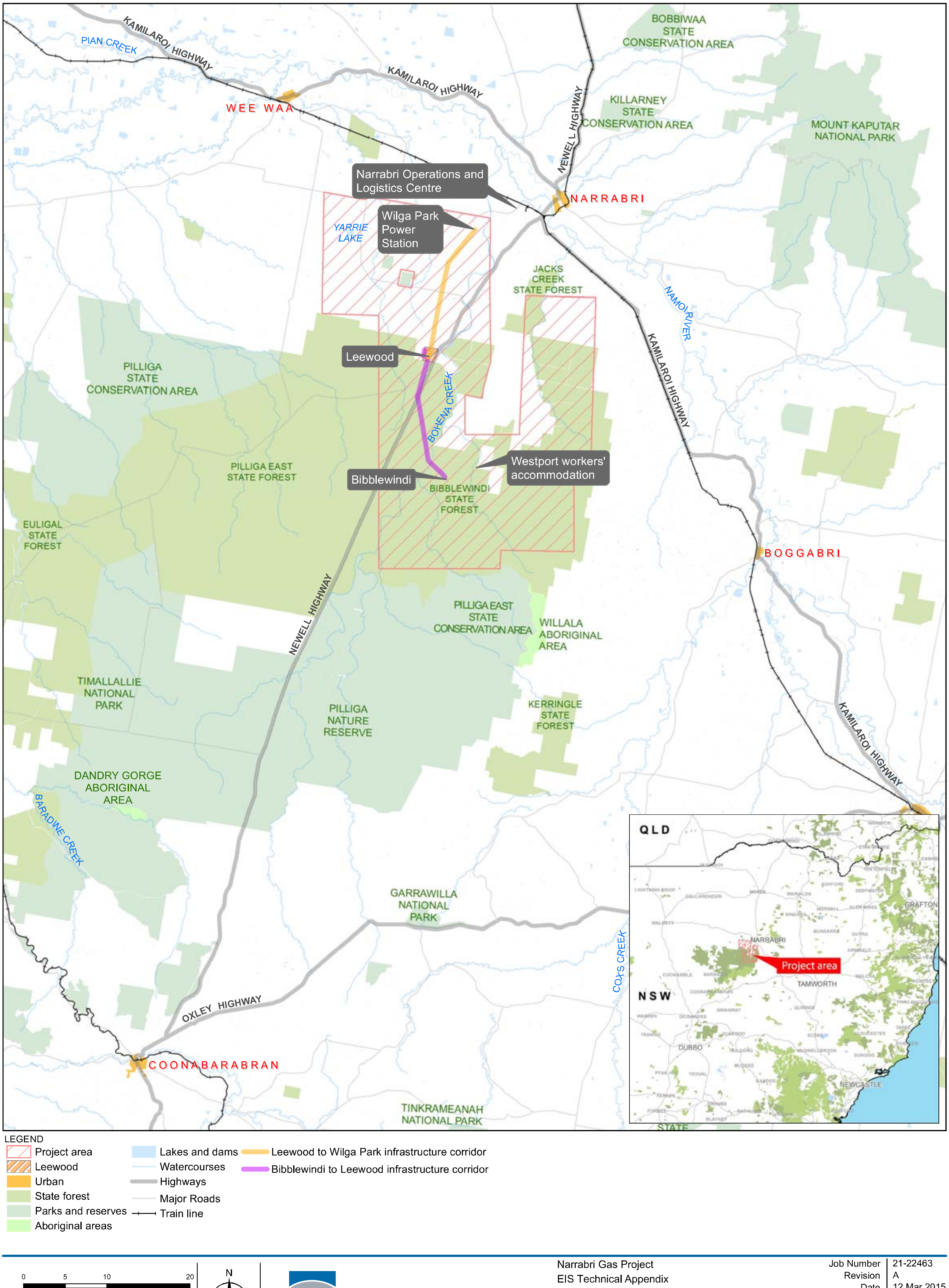
The primary objective of the project is to commercialise natural gas from coal seams for the East Australian gas market and to support the energy security needs of NSW. Production of natural gas from coal seams under the project would deliver material economic, environmental and social benefits to the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

- Development of a new source of gas supply into NSW would lead to an improvement in energy security and independence to the State. This would give NSW gas markets greater choice when entering into gas purchase arrangements. Potential would also exist for improved competition on price. Improved competition on price would have flow on benefits for NSW's economic efficiency, productivity and prosperity.
- The provision of a reduced greenhouse gas emission fuel source for power generation in NSW as compared to coal-fired power generation.
- Increased local production and regional economic development through employment and provision of services and infrastructure to the project.
- The establishment of a regional community benefit fund equivalent to five per cent of the royalty payment made to the NSW Government within the future production licence area. If matched by the NSW Government, the fund could reach $120 million over the next two decades.

1.2 Description of the Project

1.2.1 The project

The project would involve the construction and operation of a range of exploration and production activities and infrastructure. The key components of the project are presented in Table 1-1 and are illustrated in Figure 1-1.



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

Narrabri Gas Project
EIS Technical Appendix

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context and location of key infrastructure

Figure 1-1

C:\Users\AFoddy\Desktop\21_22463_KBM29.mxd [KBM: 221]

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

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

Table 1-1 Project infrastructure components

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

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

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

The project is expected to generate approximately 1,300 jobs during the construction phase and sustain around 200 jobs during the operational phase; the latter excluding an ongoing drilling workforce comprising approximately 100 jobs.

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

1.2.2 Managed release Infrastructure

This report considers the potential for managed release of treated water to Bohena Creek. Bohena Creek is an intermittent watercourse which flows in a northerly direction from the southern Pilliga Forest towards its confluence with the Namoi River close to the township of Narrabri. The proposed managed release site is located within 2 km of the proposed Leewood Water Management Facility (WMF). Only treated water would be released as part of the proposed scheme.

Proposed release infrastructure is likely to comprise the following:

- A treated water release pipeline that connects the Leewood WMF and offsite irrigation storage pond (located in the vicinity of the future irrigation area) to the proposed managed release point in Bohena Creek;
- Scour protection and engineered energy dissipation at the managed release outlet location to prevent localised erosion;
- Additional aeration (if required) at the outlet or upstream of the pipeline to increase dissolved oxygen (DO) levels; and
- Designated monitoring locations (groundwater, surface water and aquatic ecology) for compliance and operational purposes.

The infrastructure listed above (with the exception of the Leewood WMF and offsite storage) is likely to be located within the potential release location reach in Bohena Creek as shown on Figure 1-1

It is also likely that various environmental data sensors would be installed to assist project operators understand when managed releases should be initiated. Information collected in real-time is likely to include: rainfall, evaporation, creek flow, groundwater level gauges, pond levels, pipeline flows, and online treated water quality. Operation plans describing how information is collected and interpreted would be completed following approval of the proposed managed release scheme described in this study.

1.3 Project Location

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

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

The majority of the project area is located within a region known as 'the Pilliga', which is an agglomeration of forested area covering more than 500,000 hectares in north-western NSW around

Coonabarabran, Baradine and Narrabri. Nearly half of the Pilliga is allocated to conservation, managed under the *NSW National Parks and Wildlife Act 1974*. The Pilliga has spiritual meaning and cultural significance for the Aboriginal people of the region.

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

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

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

Within the Pilliga, the project would be developed in State forests identified as suitable for ‘forestry, recreation and mineral extraction’ under the Brigalow and Nandewar Community Conservation Area Act 2005.

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

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

Figure 1-2: Bohena Creek - Potential release location and reach

1.4 Planning framework and structure of this report

1.4.1 Planning framework

The project is permissible with development consent under the *State Environmental Planning Policy (Mining, Petroleum and Extractive Industries) 2007*, and is identified as 'State significant development' under section 89C (2) of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* and the *State Environmental Planning Policy (State and Regional Development) 2011*.

The project is subject to the assessment and approval provisions of Division 4.1 of Part 4 of the EP&A Act. The Minister for Planning is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Secretary of the Department of Planning and Environment or to any other public authority.

The project is also a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The project was declared to be a controlled action on 5 December 2014, to be assessed under the bilateral agreement between the Commonwealth and NSW Governments, and triggering the following controlling provisions:

- listed threatened species and ecological communities
- a water resource, in relation to coal seam gas development and large coal mining development
- Commonwealth land.

This *Managed Release Study* (this report) identifies the potential environmental issues associated with construction and operation of the managed release scheme and addresses the Secretary's environmental assessment requirements for the project (refer to GHD, 2016a for full list of requirements). The assessment will be used to support the EIS for the project. The requirements addressed in this report are listed in Table 1-2.

Table 1-2: Agency requirements addressed in this report

Agency	Description of agency requirement	Reference
Department of Planning and Infrastructure Secretary's Environmental Assessment Requirements	<u>General:</u>	
	A water management strategy, including produced water management strategy, having regard to the EPA's and NSW Trade and Investment's requirements.	Section 5
	An assessment of the likely impacts of the development on the environment, focusing on the specific issues identified below, including:	Section 8
	a description of the existing environment likely to be affected by the development, using sufficient baseline data; and	Section 4
	an assessment of the likely impacts of all stages of the development, including any cumulative impacts, taking into consideration any relevant laws, environmental planning instruments, guidelines, policies, plans and industry codes of practice.	Section 8
	A description of the measures that would be implemented to mitigate and/or offset the likely impacts of the development:	
	an assessment of whether these measures are consistent with industry best practice, and represent the full range of reasonable and feasible mitigation measures that could be implemented;	Section 9
	the likely effectiveness of these measures; and	
	Whether contingency plans would be necessary to manage any residual risks.	Section 9

Agency	Description of agency requirement	Reference
	Water: An assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources, having regard to the EPA's and NSW Trade and Investment's requirements. An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users. An assessment of the likely flooding impacts of the development.	Section 9 Section 9 Section 8 Section 8 Section 6
Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS)	Water A detailed description of the produced water resulting from the project, including outlining the management, treatment, and disposal methods to be implemented, and the final disposal pathway. Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts. Proposed surface and groundwater monitoring for the project. Detailed surface water and groundwater modelling to assess impacts of the project undertaken in accordance with standards outlined in relevant National and State Guidelines. The EIS should also describe the plan for ongoing validation calibration and development of the model. Consideration of relevant Federal and State policies and guidelines. Watercourse and riparian land A detailed description of potential impacts on the watercourses/riparian land. A description of the design features and measures to be incorporated to mitigate potential impacts. Geomorphologic and hydrological assessment of watercourses including details of stream order (Strahler System), river style and energy regimes in both channel and on adjacent floodplains. Fish habitats The EIS should specifically address impacts on the aquatic ecology of waterways (e.g. Bohena, Bibblewindi, Cowallah, Yellow Spring & Jack Creeks).	Section 5 Section 8 Section 9 Section 9 Section 8 Section 3 Section 8 Section 9 Appendix D Section 4 Appendix C
New South Wales Office of Water (NOW)	General: A detailed description of the produced water resulting from the project, including outlining the management, treatment and disposal methods to be implemented, and the final disposal pathway. Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts. Proposed surface water and groundwater monitoring for the project. Detailed surface water and groundwater modelling to assess impacts of the project, undertaken in accordance with standards outlined in relevant National and State Guidelines. The EIS should also describe plan for ongoing validation calibration and development of the model. Consideration of relevant Federal and State policies and guidelines.	Section 5 Section 6 Section 8 Section 9 Section 9 Section 9 Section 3

1.4.2 Structure of this report

The structure of this report is as follows:

Section 1 Introduction – introduces the Narrabri Gas Project and the proposed managed release scheme;

Section 2 Methodology – outlines the study objectives and scope of work;

Section 3 Legislative context –provides a summary of the legislation applicable to a managed release scheme and the associated requirements;

Section 4 Existing environment – provides a summary of the existing hydrological and ecological environment within Bohena Creek and its catchment;

Section 5 Project water management – describes the proposed water treatment process at the Leewood WMF and provides a summary of the expected treated water quality and quantity to be released to Bohena Creek;

Section 6 Managed release simulations – describes the managed release scenarios which were simulated, summarises the modelling undertaken and presents the associated results;

Section 7 Managed release protocol – describes the protocol under which treated water would be released to Bohena Creek;

Section 8 Impact assessment – identifies the potential impacts on surface water, groundwater and ecology from a managed release to Bohena Creek;

Section 9 Risk assessment – describes the Santos risk assessment process and provides the results of the risk assessment based on the potential impacts identified in Section 8; and

Section 10 Conclusions – describes the project conclusions.

2 Methodology

2.1 Managed Release Study Overview

This Managed Release Study (MRS) identifies and evaluates the potential impacts on the receiving environment associated with managed release of treated water to Bohena Creek and documents how Santos would avoid, manage and/or mitigate and unacceptable impacts. This MRS synthesises information contained in a number of supporting studies including the:

- Ecological Risk Assessment (Eco Logical Australia, 2016a) (Appendix A);
- Direct Toxicity Assessment (Acqua Della Vita, 2016) (Appendix B);
- Aquatic Ecology and Stygofauna Assessment (Eco Logical Australia, 2016b) (Appendix C);
- Fluvial Geomorphology Engineering Impact Assessment (Eco Logical Australia, 2016c) (Appendix D);
- Mixing Zone Study (Eco Logical Australia, 2016d) (Appendix E).

2.2 Study objectives

The key objectives of the MRS are to:

- Identify and assess the potential impacts from managed release on the receiving environment; and
- Determine how impacts can be effectively avoided, managed and/or mitigated.

In order to meet the MRS objectives, the study has focused on the potential of the scheme to cause: [1]

[O1] A change in the quantity, quality or availability of surface or groundwater;

[O2] Alteration to groundwater pressure and/or water table levels;

[O3] Alteration to the ecological nature of a wetland or watercourse;

[O4] Alteration to drainage patterns;

[O5] Reduced biological diversity or change species composition;

[O6] Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected; and

[O7] Reduced availability of water for human consumption.

[1] Specific objectives for this report have been established based on Independent Expert Scientific Committee (IESC) Guideline (Australian Government, 2013a); Draft Significant Impact Guidelines: Coal seam gas and large coal mining development – impacts on water resources (Australian Government, 2013b) and the Significant Impact Guidelines (Commonwealth of Australia, 2013).

2.3 Study scope

The scope of the MRS is summarised as follows:

- Identify a suitable site for managed release to the Bohena Creek proximal to the proposed Leewood WMF;
- Identify and describe protocols for managed release of treated water to Bohena Creek;
- Conduct site-specific field monitoring and establish a preliminary environmental baseline covering hydrology, water quality, ecological, geomorphological, flooding and other relevant data;
- Complete a series of site-specific assessments (support studies), including:
    - Ecological Risk Assessment;
    - Direct Toxicity Assessment;
    - Aquatic Ecology and Stygofauna Assessments;
    - Geomorphological Investigation;
    - Mixing zone study.
    - Identify potential impacts on the receiving environment from the proposed managed release scheme.
- Conduct risk assessments to:
    - Identify measures required to mitigate or manage potential risks and associated impacts on the receiving environment;
    - Consider the proposed measures to avoid or reduce impacts on the receiving environment and identify if these measures can be considered adequate to reduce the level of potential impact below that which may be deemed significant during formal environmental assessment[2]; and
    - Consider the likelihood of significance of potential impacts to water resources after the application of mitigation and management measures.
- Identify practical monitoring and management measures that may be incorporated into the proposed release scheme that would improve operational reliability.

2.4 Supporting studies

The scope of the supporting studies underpinning the MRS Summary Report and their interface to the impact assessment objectives identified in Section 2.2 are provided in Table 2-1.

[2] A 'significant impact' is described as an impact which is important, notable, or of consequence, having regard to its context or intensity.

Table 2-1: Supporting Studies

Study Title	Link to Impact Assessment Objectives	Scope Overview	Reference
Ecological Risk Assessment (ERA)	[O1][O3] [O5][O6]	The ERA determines whether chemical concentrations of discharged treated water could have detrimental effects on down gradient ecological receptors.	Appendix A
Direct Toxicity Assessment (DTA)	[O6]	The DTA assessed contaminants of interest Boron: for which the maximum concentration in the treated water is expected to exceed the ANZECC/ARMCANZ (2000) default trigger value of 0.37 mg/L; and Fluoride for which there is no ANZECC/ARMCANZ (2000) trigger value but fluoride concentrations are expected to exceed the Canadian guideline of 0.12 mg/L (CCME 2009) and therefore this has been assessed in detail.	Appendix B
Aquatic Ecology & Stygofauna Impact Assessments (AEA)	[O3][O5]	The AEA documents threatened freshwater and riparian species, endangered populations and ecological communities as listed under various acts and their habitats, which are known or considered likely to occur in the study area. The report also considers managed release aquatic ecology impacts.	Appendix C
Fluvial Geomorphology Engineering Impact Assessment	[O4]	This assessment investigates the potential impacts from: Proposed discharge on the geomorphology of the Bohena Creek; and River geomorphology on the design and function of the proposed outfall structure. Additionally, concept design advice is given in relation to minimum engineering requirements for the pipeline outfall in relation to design considerations to minimise erosion risk and scour potential; and maximise temperature and dissolved oxygen equilibration.	Appendix D
Mixing zone study	[O1]	The mixing zone study considers the conceptual diffuser design, and calculates a blending/dilution ratio to apply to mixing zone calculations.	Appendix E

2.5 Fieldwork

Fieldwork specifically to inform elements of this study was undertaken from 11th to 15th March 2013 and 3rd – 5th December 2013. Eco Logical Australia and CH2M Hill undertook the collection of water and sediment samples as well as undertaking aquatic ecology and geomorphic field surveys. The aquatic surveys included Australian River Assessment System Assessments (AusRivAS) (Parsons et al., 2002) of site condition and macroinvertebrate community assemblages, aquatic habitat assessment, riparian condition and floristic surveys, water quality assessments, and fish community sampling.

Four sites were sampled along the Bohena Creek study area, and comparison sites selected in the Namoi River. Sites were selected upstream and downstream of the proposed managed release point at

Bohena Creek and revisited again on several occasions. A Sampling and Analysis Quality Plan (SAQP) was developed prior to conducting field work.

These data are supplemented by data collected during fieldwork for other studies including baseline data collection in the vicinity of the discharge site, such as surface water quality monitoring data for Bohena Creek.

2.6 Limitations and assumptions

Surface water, groundwater, ecological and other environmental data presented in and discussed in this report and any reports undertaken as part of project investigations are likely to vary spatially and to fluctuate with time. Interpretations have been made based on incomplete data largely acquired during 2013 and 2014 but with additional historical published data and partial knowledge of the surface and subsurface and of the surface and groundwater conditions therein. The interpretations made in this report are based on the data supplied and alternative interpretations may be applicable following the realisation of new or additional data.

Produced water and final treated water chemistry has been provided by the Client. Water chemistry would be subject to final water treatment plant design and would be confirmed with the regulator as soon as available. Water chemistry used is a best estimate based on current projection software and operating experience.

It is assumed that treated water temperatures at the point of release would be as close to ambient Bohena Creek water temperatures as possible.

3 Legislative context

A review of Commonwealth Legislation, State Legislation and relevant guidelines has been undertaken in relation to the proposed managed release scheme. This provides the regulatory framework within which the MRS fits.

Table 3-1 Key Legislation and Guidelines

Legislation	Summary	Relevance to the Managed Release Scheme
Commonwealth Legislative Framework		
Environment Protection and Biodiversity Conservation Act 1999	The *EPBC Act 1999* requires the assessment of an 'action' as a whole. As such, where an action referred to the department includes both extraction activities which have a significant impact on a water resource (with relation to coal seam gas or mining projects) and other activities (such as associated infrastructure) then the significance of the whole of the referred action on water resources is considered (SEWPAC 2013a).	Matters of National Environmental Significance (MNES) identified under the EPBC Act, and including Water Resources, specifically for coal seam gas projects, have been assessed for the proposed action through the NGP EIA process.
Water Act 2007	The *Water Act 2007* regulates the management of the water resources of the Murray Darling Basin (MDB) and established the requirement of the MDB Plan. The definition of a water resource in this Act has links to other legislation. *"being surface water or groundwater, or a watercourse, lake, wetland (whether or not it currently has water in it) or aquifer and including all aspects of the water resource including water, organisms and other components and ecosystems that contribute to the physical state and environmental value of the water resource"*	The project and proposed manage release site is located within the MDB.
State Legislative Framework		
Water Management Act 2000.	This Act controls the extraction of water, how water can be used, the construction of works such as dams and weirs and the carrying out of activities on or near water sources. This Act also establishes rules for managing the State's water resources via Water Sharing Plans (WSPs). In areas where there is no WSP, the Water Act 1912 applies.	The construction of an in-stream outfall structure and associated piping is considered an activity on or near a water stream.
The Protection of the Environment Operations Act 1997	The Protection of the Environment Operations Act 1997 (the POEO Act) aims to protect, re-establish and enhance the environment in the state of NSW through the regulation of pollution of all water, including groundwater, in NSW. Any premises that have the capacity to produce more than five petajoules of gas per annum must hold a licence. These licences are administered by the NSW Environment Protection Authority (EPA). The licence may include conditions relating to waste management and water quality. The Environment Protection Licence (EPL) may require a variation to incorporate alterations to the site water management system.	An EPL would be required for the project which would include the managed release to Bohena Creek. Information developed in this study would be used in support of obtaining a licence.

Legislation	Summary	Relevance to the Managed Release Scheme
The Petroleum (Onshore) Act 1991	This Act regulates the exploration for and production of petroleum in NSW, including CSG. Under the *Petroleum Onshore Act 1991* (the PO Act), the project gas fields would require a petroleum prospecting title and a petroleum production title.	As part of PEL 238, Santos is required to prepare a Produced Water Management Plan which guides beneficial reuse options including managed release, investigated as part of this report.
The Catchment Management Authorities Act 2003	The *Catchment Management Act 2003* (the CMA Act) provides for the implementation of Catchment Action Plans (CAP). A CAP has been prepared by the Namoi Catchment Management Authority, is applicable and has been considered as part of this project.	The Namoi CAP sets targets for groundwater and surface water quality however it does not impose any requirement for approvals, licences or other regulatory instruments for development within the CAP. Where practicable the targets and objectives of the Namoi CAP would be met.
The Fisheries Management Act 1994	This report will inform the design of the proposed WMF at 'Leewood', however it is important to note that it is an offence to harm fish declared as threatened species under the Fisheries Management Act 1994 (the FM Act) or to harm endangered ecological communities or critical habitat declared as such under the FM Act without a permit/licence.	FM Act permits are not required for SSD or SSI (State Significant Infrastructure) projects.
The Local Government Act 1993	The *Local Government Act 1993* regulates stormwater drainage work.	The *Local Government Act 1993* may have some applicability to the proposed managed release scheme.
Aquifer Interference Policy (AIP)	The NSW Aquifer Interference Policy defines the regime for protecting and managing the impacts of aquifer interference activities on NSW's water resources. There are three key parts to the Policy: All water taken must be properly accounted for. The activity must address minimal impact considerations for impacts on water table, water pressure and water quality. Planning for measures in the event that the actual impacts are greater than predicted, including making sure that there is sufficient monitoring in place.	Appropriately designed, built and operated the proposed managed release scheme would minimise impact on water table, water pressure and water quality. Mitigation measures are proposed to reduce impacts and monitoring proposed where residual impacts are possible.
Guidelines		
ANZECC/ ARMCANZ (2000)	The main objective of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (the Water Quality Guidelines) is: "to provide an authoritative guide for setting water quality objectives required to sustain current, or likely future, environmental values [uses] for natural and semi-natural water resources in Australia and New Zealand".	This Managed Release Study is primarily concerned with indicator types such as water quality, biological assessment, sediment quality and environmental flows which are a feature of aquatic ecosystem guidelines.

Legislation	Summary	Relevance to the Managed Release Scheme
Water Quality and River Flow Objectives	Objectives consist of three parts: environmental values, their indicators and their guideline levels. The objectives comprise community-based environmental values and their associated national criteria drawn from the ANZECC/ARMCANZ (2000) framework. Objectives consist of three parts: environmental values, their indicators and their guideline levels. The objectives comprise community-based environmental values and their associated national criteria drawn from the ANZECC/ARMCANZ (2000) framework. Water Quality and river flow objectives of Bohena Creek and the Namoi River are identified and are consistent with NSW Government Department of Environment, Climate Change (DECCW) and Water definitions.	Bohena Creek exists within a mainly forested area, typified by relatively natural flows and water quality representative of the Pilliga state forest in the upper area of the Bohena Creek catchment. The river flow and water quality objectives for the unregulated streams of the catchment, such as Bohena Creek, needs to be accounted for in the design and operation of the scheme.
Independent Expert Scientific Committee	The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development (the Committee) provides scientific advice to decision makers on the impact that coal seam gas and large coal mining development may have on Australia's water resources. The Committee was established as a statutory committee in 2012 by the Australian Government under the Environment Protection and Biodiversity Conservation Act 1999 (Cth) in response to community concerns about coal seam gas and coal mining (Australian Government, 2013a).	As defined in the MRS objectives, this report specifically investigates items [O1], [O2], [O3], [O4], [O5] and [O7] with which the IESC is concerned.

4 Existing environment

4.1 Namoi Catchment Overview

The Bohena Creek catchment is part of the greater Namoi Catchment. The Namoi catchment drains in a westerly direction from the western flank of the Great Dividing Range, for some 400 km, to discharge into the Barwon River at Walgett. The main surface water system is the Namoi River with flow contributed by major tributaries including Macdonald River, Manilla River, Peel River, Mooki River, Cox's Creek, Maules Creek, Bohena Creek, Bundock Creek and Baradine Creek. The catchment is bounded to the north by the Nandewar Ranges and the New England Plateau and to the south and west by the Liverpool Plains and Warrumbungle Range.

4.1.1 Sub-catchments

There are five major sub-catchments in the Namoi catchment:

- Macdonald/ Manilla sub-catchment;
- Peel sub-catchment;
- Mooki sub-catchment;
- Middle Namoi sub-catchment; and
- Lower Namoi sub-catchment.

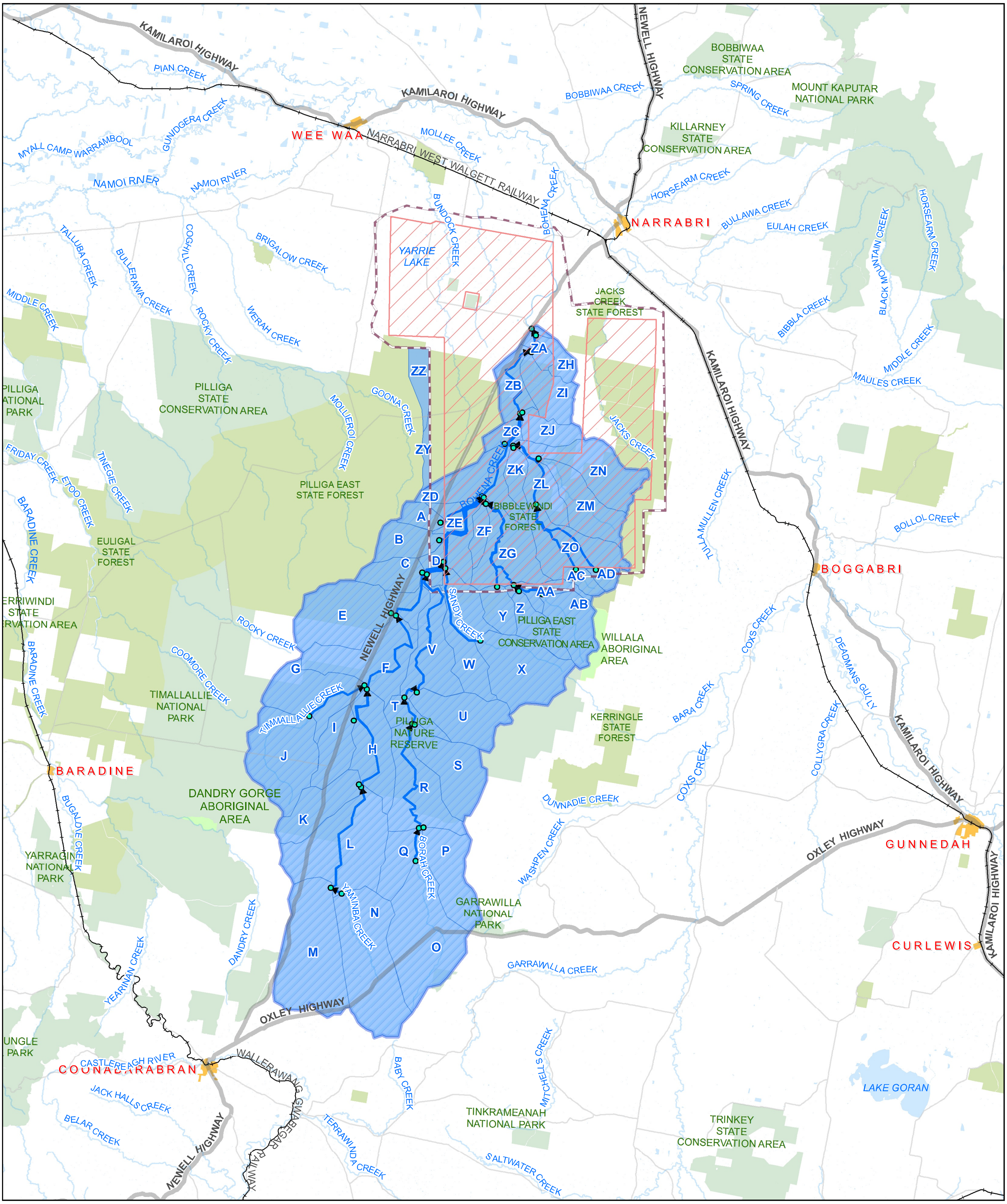
Bohena Creek is located within the lower Namoi sub-catchment.

Generally, all tributaries in the Bohena Creek sub-catchment drain in a north-westerly direction towards the Namoi River floodplain as shown in Figure 4-1. The headwaters of the tributaries are generally located in forested conservation areas (e.g. Pilliga Forest) while the un-forested areas of the sub-catchments are utilised predominately for sheep and cattle grazing as well as dryland cropping. A full Bohena Creek sub-catchment breakdown is included in GHD (2016b).

4.1.2 Regulated flow structures

Flows within the Bohena Creek sub-catchment are unregulated. There are a number (approximately 10) of small ponds located on private properties in the Bohena Creek catchment, operated by landholders with the main purpose of stock watering. These ponds have a negligible regulating impact as their storage volume is always below approximately 2 ML. These structures do not intersect Bohena creek or its main tributaries; the closest of them being Garlands Dam located some 250 m away from Bohena Creek.

Flows just downstream of the Bohena Creek confluence with Namoi River are regulated by Mollee Weir (located downstream of Narrabri) and backs up water into a Weir pool several kilometres long along both Narrabri Creek and the Namoi River. It was installed in the 1970s to regulate and control flows for provision of water for irrigation and livestock use.



LEGEND

- Project area
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Hydrological catchment
- Sub-catchment Outlets
- Model streams
- TUFLOW Model Extent
- Model sub-catchments

0 5 10 20
Kilometers

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

N

GHD

Narrabri Gas Project
EIS Technical Appendix Managed Release Study

Job Number	21-22463
Revision	A
Date	28 Jul 2016

Sub-catchment map

Figure 4-1

N:\AU\Sydney\Projects\21\22463\GIS\Maps\21_22463_KBM29_.mxd [KBM: 260]

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

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

4.2 Bohena Creek

4.2.1 Catchment description

Bohena Creek flows in a generally northern direction through the project area and eastern Pilliga Forest to its confluence with the Namoi River approximately 12 km downstream of the Narrabri Township on the Namoi River as shown in Figure 4-1.

Bohena Creek is reported to be an intermittent creek, defined as flowing at least 15% of the time. It is classified as a lowland chain of symmetrical, discontinuous ponds, separated by poorly defined channel depressions, swampy fills and/or sand deposits (Lampert and Short, 2004). The creek has a naturally low nutrient status similar to many of Australia's freshwater systems because of the sand dominated substrate lacking in organic matter and the lack of perennial flow.

There are number of tributaries that drain into Bohena Creek, the largest of these include:

- Spring Creek: an undisturbed second order water course;
- Yellow Spring Creek;
- Bibblewindi Creek;
- Mt Pleasant Creek: an ephemeral creek which runs east to west to Cowallah Creek; and
- Cowallah Creek: an ephemeral creek which runs east to west to join Bohena Creek.

All tributaries draining to Bohena Creek are considered to be highly ephemeral and only flow during periods of sustained heavy rainfall. The steep slopes and shallow regolith/soils combine to give high runoff rates and highly variable, peaky discharges (Lampert and Short, 2004).

Bohena Creek itself is a sixth order stream (as classified using the Strahler Stream Order classification system (Strahler, 1957) – refer Figure 4-2 and Figure 4-3).

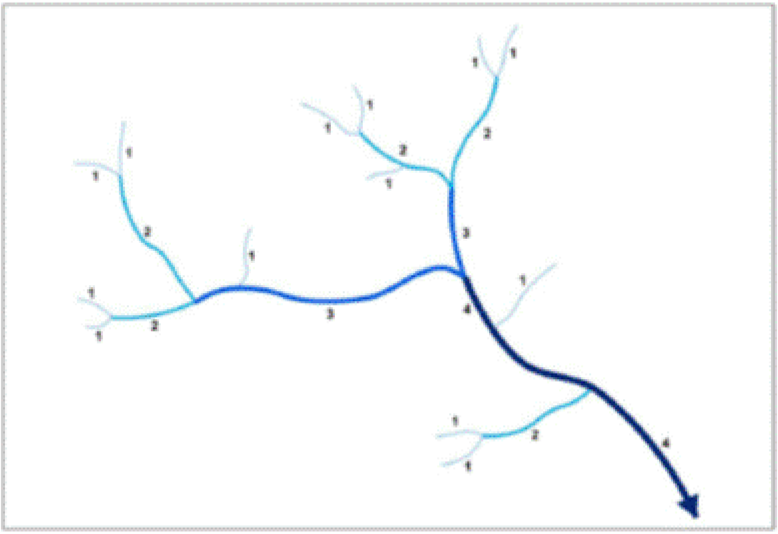


Figure 4-2: Strahler Stream Order Methodology

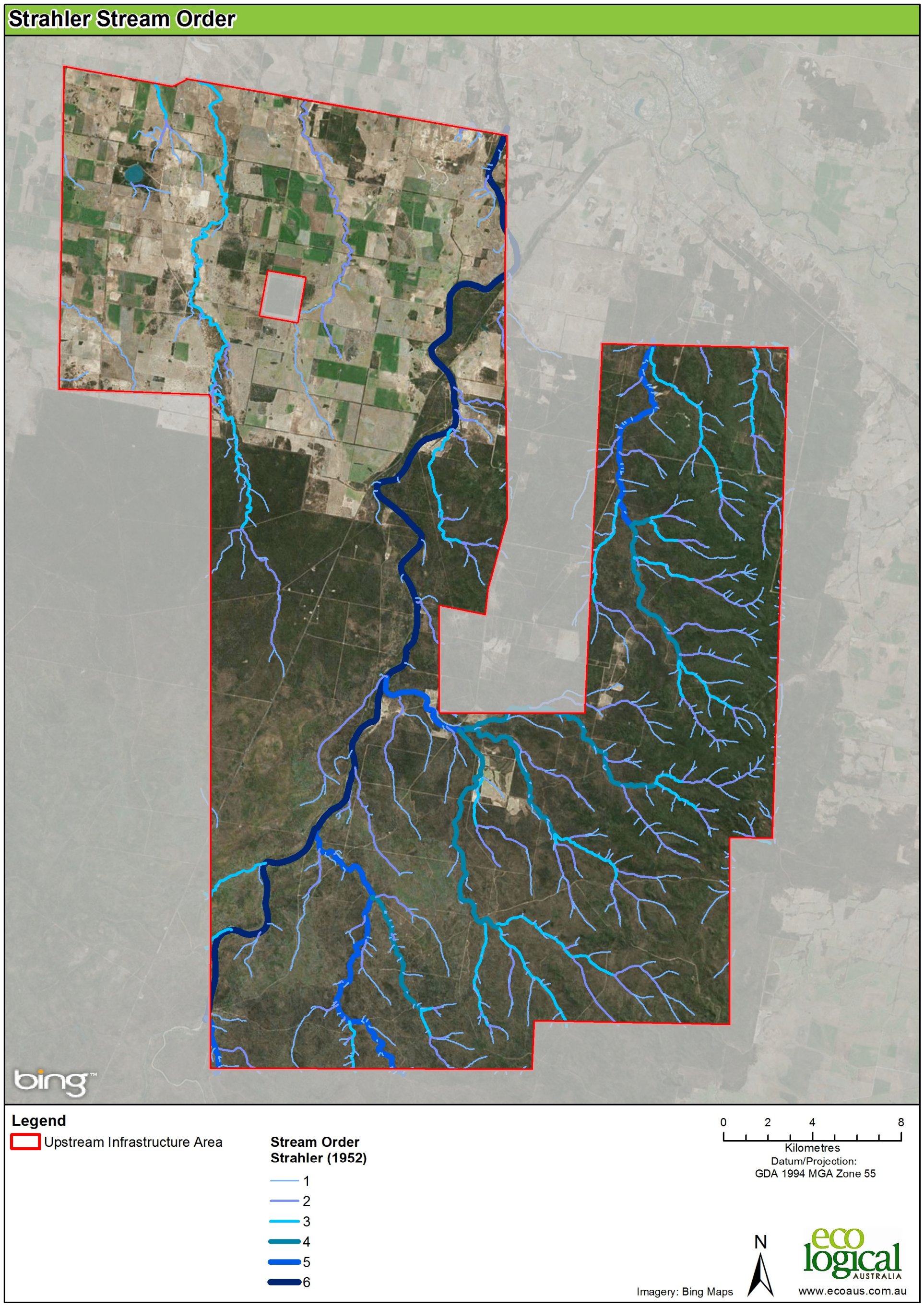


Figure 4-3: Strahler Stream Order

Strahler numbering begins at the top of a catchment with headwater ('new') flow paths being assigned the number 1 (Strahler, 1957). Where two flow paths of order 1 join, the section downstream of the junction is referred to as a second order stream. Where two second order streams join, the waterway downstream of the junction is referred to as a third order stream, and so on. Where a lower order stream (e.g. first order) joins a higher order stream (e.g. third order), the area downstream of the junction will retain the higher number (i.e. it will remain a third order stream).

4.2.2 Rainfall and Evaporation

Daily rainfall data are available at Rosewood Farm (Bureau of Meteorology station number 53103) located near the Newell Highway crossing on Bohena Creek, approximately 6 km northeast of Leewood. Monthly rainfall statistics are given in Table 4-1 and mean monthly rainfall is plotted in Figure 4-4. The monthly rainfall pattern is bimodal with the main rainfall season occurring during summer. Mean annual rainfall since 1979 is 677 mm/yr.

Mean annual potential evaporation in the project area is 1300-1400 mm/yr.[3]

Table 4-1 Rosewood Farm monthly rainfall statistics

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Low	0	24.6	0	0	0	0	0	0	0	0	0	5.2	386.5
10th%ile	8.8	28.6	3.2	1	0.1	17.5	5.8	2.7	0	8.6	10.7	16.7	444.1
Mean	88.2	72.1	41	24.5	49.6	48.2	52.4	25.7	43.2	49.2	78.6	94.5	676.7
90th%ile	167	132.9	83	56.8	124.8	92.2	102.2	52.3	87.5	86.2	165.5	196.5	945.1
High	329.2	199.3	191.8	90.4	175.8	232.2	201.6	109	110.9	95.4	230	406.9	992.8

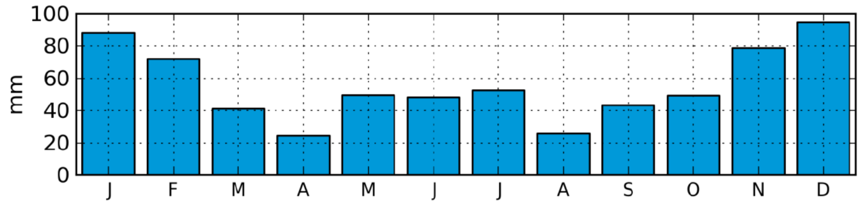


Figure 4-4: Rosewood Farm mean monthly rainfall (1979-present)

4.2.3 Streamflow

Table 4-2 summarises the available recorded hydrological information for the Namoi River at Mollee weir and Bohena Creek at the Newell Highway. This table is based on the dataset from 1962 to 2009 following the construction of Keepit Dam[4] and clearly shows the difference between the regulated Namoi River and the uncontrolled, intermittent behaviour of the Bohena Creek.

Table 4-2: Flow statistics for the Namoi River and Bohena Creek (ML/day)

Location	Station Number	Flows (ML/day)					Catchment Area (km²)
		Median	Flood (0-5%)	Freshes (5-25%)	Moderate (25-65%)	Low (65-100%)	
Bohena Creek @ Newell highway	419905	0	More than 611.0	0 – 611.0	0	0	2,000
Namoi River @ Mollee	419039	567	More than 5722.0	1497.7 – 5722.0	291.8 – 1497.7	Less than 291.8	28,200

[3] Bureau of Meteorology, http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/

[4] Data source: Pineena database v9.3, NSW Office of Water

The Namoi Catchment Water Study (NCWS) (Schlumberger, 2011) indicates that watercourses downstream of Narrabri make little contribution to flow in the Namoi River except in wet periods. Although CSIRO (2007) indicates significant flows may be expected during heavy rainfall events from the Pilliga Region of the Namoi Valley.

A single Department of Primary Industries – Office of Water (DPI Water) gauging station, located at the Newell Highway crossing (station number 419905), measures daily streamflow in Bohena Creek. The available dataset at the time of preparing this report was 16 years from 1 September 1995 to 4 February 2012, although there is a step change in data obtained from the gauge after June 2005. Consequently, the stage-discharge rating curve used to convert river stage to flow is calibrated differently after June 2005, resulting in far fewer incidences of flow. Hence the data have been sampled, with all data after June 2005 being rejected, limiting the sample period from September 1995 to June 2005. Further discussion and analysis is provided in Section 6.4.2.2, whilst Figure 6-17 illustrates the plotted river stage and flow data and Figure 6-18 elaborates the difference in stage-discharge relationships pre- and post-2005. On average, monthly flows between January and June are lower than from July to December as shown in Figure 4-5. The histogram in Figure 4-5 presents data in years, hence the sampled record commences in silo 1995-1996 and is curtailed in silo 2005-2006 although the sample data extend from September 1995 to June 2005.

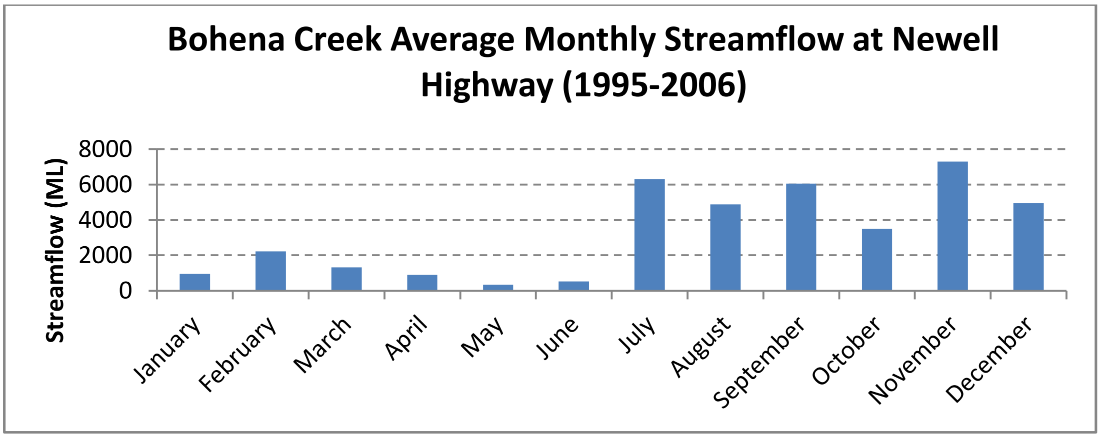


Figure 4-5: Bohena Creek Average Monthly Streamflow at Newell Highway (1995-2006)

Figure 4-6 presents daily streamflow data which have been transformed into flow data by means of a rating curve. From

Figure 4-6 the flow nature of the Bohena Creek at the Newell Highway crossing is noticeably intermittent, with flows being recorded only during 15% of the sample period between September 1995 and June 2005[5] equivalent to a long-term average of 55 days per year.

Figure 4-6 also demonstrates that flows at or greater than 100 ML/d are indicated to occur during approximately 12% of the sample period. This equates to an average frequency of flows exceeding 100 ML/day in Bohena Creek of approximately 44 days per year on the basis of the flow duration curve.

[5] It is noted that a large number of data values in the Pineena database are unchecked or flagged as low quality.

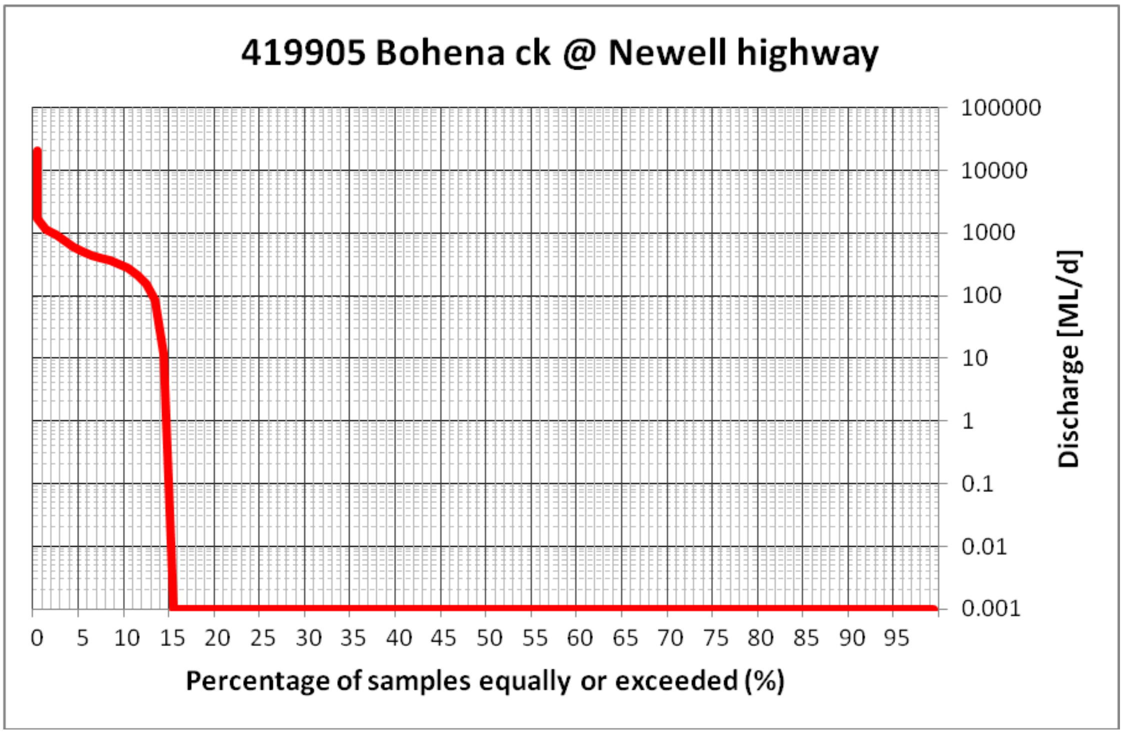


Figure 4-6: Flow duration curve at the Bohena Creek at Newell Highway

Analysis was undertaken of the conversion of rainfall to runoff to provide an indication of data reliability and antecedent streamflow conditions. Figure 4-7 plots stream discharge volumes and rainfall.

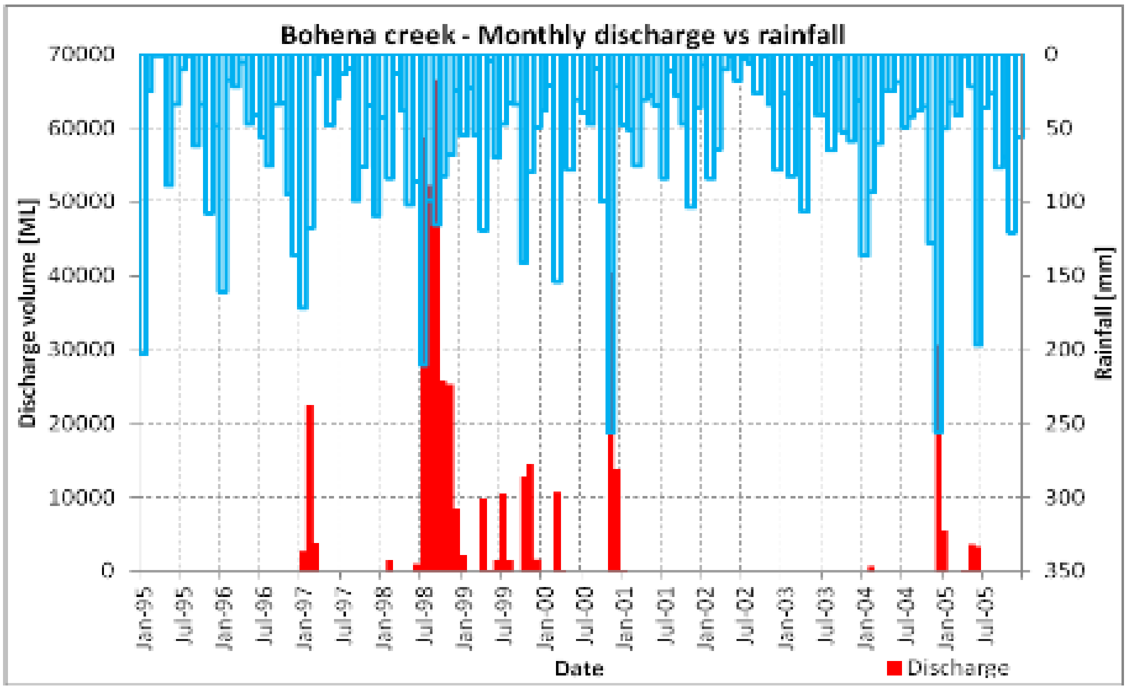


Figure 4-7: Rainfall vs streamflow at Newell Highway Crossing

Data Reliability

From Figure 4-7 a number of gaps are observed (circa Jan-1995 to Jan-1997; Jan-01 to Jan-04). The following observations are made:

- there are missing or incomplete streamflow records for 9 of the 16 years (approximately 56%) including the period 2005 to 2012, inclusive;
- zero streamflow was recorded in 2001, 2002 and 2003; this could be due to the small annual rainfall in 2002 and 2003, an inability to record small flow depths at the stream gauge, or incorrect measurement or operation of the stream gauge, and
- a large annual streamflow volume of 240 GL was recorded in 1998 in association with above average rainfall of 993 mm; however, zero streamflow was recorded in 2004 when there was above average rainfall of 1004 mm.

Antecedent streamflow conditions

Analysis of rainfall and streamflow data suggests that approximately 100 to 110 mm of rainfall in a given month would lead to streamflow in Bohena Creek at the Newell Highway crossing (as shown in Figure 4-7).

Ivkovic (2006) carried out base flow separation analysis of a number of creeks and rivers within the Namoi catchment, although Bohena Creek was not assessed as part of this study. Ivkovic did however classify rivers by flow duration (or persistence). Rivers were classified as gaining if they had flow recorded over 90% of the time. Should Bohena Creek have been included in this study, the absence of flow in Bohena Creek (≈15% of the time) would likely result in Bohena Creek being classified as a losing stream.

Note that CSIRO (2007) and Ivkovic (2006) both classify the Namoi downstream of Narrabri as a losing stretch, disconnected from the water table (unsaturated aquifer beneath the river bed).

4.2.4 Channel, floodplain and alluvium characteristics

The Bohena Creek channel can be characterised within the low sinuosity, sand river category. The creek bed consists of a planar, mobile sand sheet with scattered gravel, while the floodplain is broad, continuous and gently undulating, with paleo-channels and frequent terraces as valley margins. In the lower reaches beyond the State forest, permanent pools of water exist as documented by AGE (2006) and Eco Logical Australia (2016b).

During streamflow events, the disconnected pools (disconnected at the surface), link-up and surface flows are observed.

4.2.5 Geology and Hydrostratigraphy

The surface geology of the project area is shown in Figure 4-8.

The modern course of the Bohena Creek lies within the Bohena Creek alluvium and is bounded laterally by unnamed alluvium and colluvium units of Cenozoic age. The surficial alluvial deposits overlie the upper sediments of the Orallo Formation (Cretaceous age) which outcrop in the southeast of the project area where the alluvial cover is absent.

The Keelindi Beds are considered to be the lateral equivalent of the Blythesdale Group within the Gunnedah Basin, consisting of the Orallo Formation, Mooga Sandstone and lowermost Bungil Formation. Underneath the Keelindi Beds is the Pilliga Sandstone, which in turn is underlain by the Purlawaugh Formation.

The hydrostratigraphic sequence from the ground surface to the base of the Purlawaugh Formation is summarised in Table 4-3.

Table 4-3: Hydrostratigraphic units

Name	Age	Lithology Description	Source
Bohena Creek Alluvium	Cenozoic	Gravel and sand with clay lenses	Geoscience Australia [1]
Unnamed alluvium	Cenozoic	Piedmont plain: texture contrast soils with sand predominating at surface Alluvial terrace: interpreted clay, silt, sand, gravel	Santos
Unnamed colluvium	Cenozoic	Sheet wash: clayey alluvium often gilgaid (shrink and swell)	Santos
Keelindi Beds [2]	Early Cretaceous to Late Jurassic	Off-white, fine to coarse grained, poorly to well sorted, quartzose sandstone, pebbly sandstone and conglomerate interbedded with minor shale, siltstone and coal. Cross-bedded, kaolinitic and iron stained.	Geoscience Australia [1]
Pilliga Sandstone	Late to Middle Jurassic	Medium to very coarse grained, well sorted, angular to subangular quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained Sandstone and coal. Common carbonaceous fragments and iron staining.	Geoscience Australia [1]
Purlawaugh Formation	Middle to Early Jurassic	Fine to medium grained lithic to labile sandstone thinly interbedded with siltstone, mudstone and thin coal seams. Abundant carbonaceous fragments, thin beds of flint clay.	Geoscience Australia [1]

Notes:

1. *Australian Stratigraphic Units Database (http://www.ga.gov.au/products-services/data-applications/referencedatabases/stratigraphic-units.html)*
2. *Considered to be the lateral equivalent of the Orallo Formation, Mooga Sandstone and lowermost Bungil Formation which are members of the Blythesdale Group.*

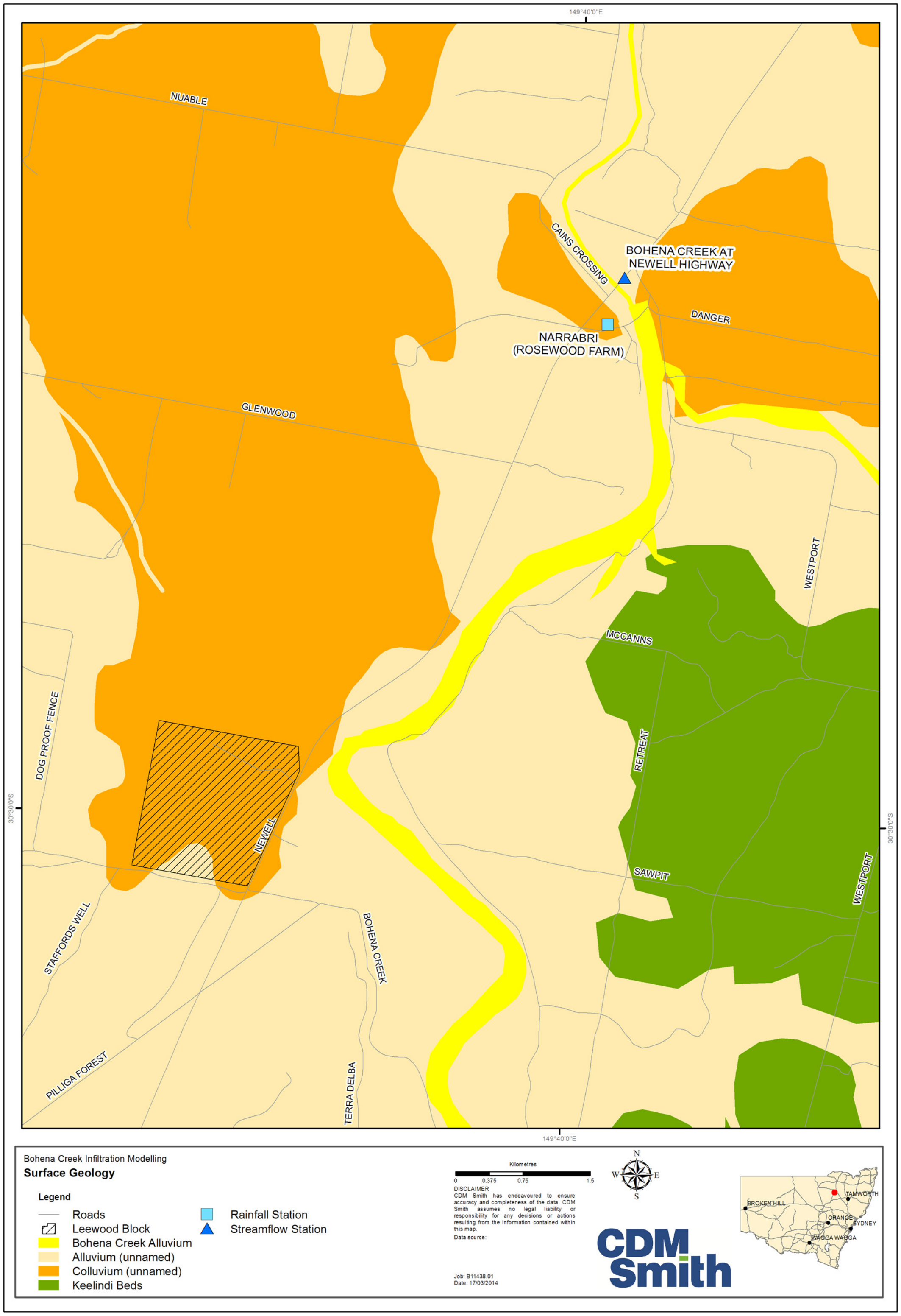


Figure 4-8: Surface Geology

4.2.6 Surface water-groundwater interaction and infiltration into alluvium

The groundwater level in the alluvium of Bohena Creek is understood to vary according to antecedent rainfall conditions. Following heavy rainfall and subsequent saturation of the surficial alluvial deposits, surface flow may occur, which is understood to do so at least 15 % of the time. AGE (2006) indicate that during dominant dry periods, groundwater levels can drop to an estimated 2 m below the surface of the creek. It is considered likely that groundwater in the Bohena Creek Alluvium is perched on the finer grained sedimentary deposits of the Orallo Formation because the piezometric head in the Pilliga Sandstone aquifer is 20 – 30 m below the ground level of the area (AGE, 2006).

It is considered likely that the alluvium, forming a contiguous part of the wider sheet alluvial/colluvial deposits, follows a pattern of muted topography which is not controlled by the current channel. Recharge of the alluvium occurs generally from infiltration of surface water when there is flow in the creek, but also from direct infiltration of rainfall on the sand deposits (AGE, 2006).

As there are limited available data to observe and interpret streamflow behaviour in Bohena Creek, these limited data have been interpreted to improve Santos' understanding of the impact of managed releases to the creek during flowing conditions.

4.2.7 Baseline Water Quality

Surface water samples have been collected specifically for the Bohena Creek MRS at several locations in the Namoi River Catchment. Further to this, Santos has undertaken baseline surface water quality sampling across the project area. Samples have been analysed for nutrients, physio-chemical indicators (e.g., dissolved oxygen and suspended solids), major anions/cations, total and filtered (dissolved) metals, monocyclic aromatic hydrocarbons (benzene, toluene, ethylbenzene and xylenes [BTEX]), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), pesticides and volatile organic compounds (VOCs).

Data collected in Bohena Creek were typically collected after rainfall events or from isolated pools within the stream bed, due to its intermittent flow. Data collected by Santos for the wider catchment were collected over eighteen months to capture seasonal variation. A preliminary summary of the results is provided in Table 4-4. Note that analytes with zero detections have been excluded from this summary table (full details are provided in **Appendix A**).

Table 4-4: Summary of Surface Water Analytical Results

Analyte	Units	No. Samples taken	Results detected above LOD	Mean	Minimum	Maximum
pH (Lab)	-	18	18	7.00	5.59	8.03
Electrical conductivity *(lab)	µS/cm	17	17	176	76	512
Total Dissolved Solids @180°C	mg/L	3	3	105	86	116
TDS (sum of ions)	mg/L	13	13	142	86	220
TSS	mg/L	17	15	25	<5	130
Turbidity	ntu	16	16	41.0	2.5	165.0
Boron	mg/L	17	0	ND	<0.05	<0.05
Sodium (Filtered)	mg/L	17	17	16	7	37
Magnesium (Filtered)	mg/L	17	17	7	2	23
Aluminium	mg/L	17	17	1.30	0.07	7.46
Silica	µg/L	15	15	15160	11400	25700
Potassium (Filtered)	mg/L	17	17	2	1	5
Calcium (Filtered)	mg/L	17	17	5.8	2	21
Vanadium	mg/L	17	1	ID	<0.01	0.02
Chromium (III+VI)	mg/L	17	6	0.0024	<0.001	0.011
Manganese	mg/L	17	17	0.28	0.064	2.04
Iron	mg/L	17	17	5.3	1.22	16.3
Cobalt	mg/L	17	13	0.0033	<0.001	0.02
Nickel	mg/L	17	17	0.0042	0.001	0.012
Copper	mg/L	17	3	0.0011	<0.001	0.005
Zinc	mg/L	17	3	0.0035	<0.005	0.011
Arsenic	mg/L	17	2	ID	<0.001	0.002
Selenium	mg/L	17	0	ND	<0.01	<0.01
Strontium	mg/L	17	17	0.092	0.031	0.32
Molybdenum	mg/L	17	1	ID	<0.001	0.002
Cadmium	mg/L	17	0	ND	<0.0001	<0.0001
Barium (Filtered)	mg/L	17	17	0.033	0.022	0.066
Mercury (Filtered)	mg/L	17	0	ND	<0.0001	<0.0001
Lead	mg/L	17	1	ID	<0.001	0.005
Uranium	µg/L	17	0	ND	<1	<1
Alkalinity (Bicarbonate as CaCO3)	mg/L	16	16	41	17	81
Alkalinity (Carbonate as CaCO3)	mg/L	17	1	ID	<1	54
Alkalinity (total) as CaCO3	mg/L	17	17	42	17	81
Ammonia as N	µg/L	21	9	15	<10	70
Kjeldahl Nitrogen Total	mg/L	21	21	0.64	0.4	1.3
Nitrate (as N)	mg/L	16	9	0.04	<0.01	0.23
Nitrogen (Total Oxidised)	mg/L	20	12	0.033	<0.01	0.14
Nitrogen (Total)	µg/L	21	21	671	400	1300
Sulphate	mg/L	6	0	ND	<1	<1
Chloride	mg/L	17	17	28	8	102
Fluoride	mg/L	17	0	ND	<0.1	<0.1
Phosphorus	mg/L	19	18	0.06	<0.01	0.2

Table notes:

1. Only values with detections greater than laboratory limits of detection (LOD) presented in summary.
2. Mean calculated assuming LOD as positive value for non-detects
3. Full suite of analysis and laboratory certificates of analysis included in Appendix A.

Source: Data collected as part of this report; CDM Smith, 2016b.

The key outcomes from the sampling are noted below:

- The results provide a breakdown of water quality composition for nutrients, physio-chemical indicators, major anions/cations, and total and filtered metals.
- BTEX, PAHs, PCBs, TPH, and VOCs were not detected.
- Among pesticides, only two fungicides, chlorothanlonil and benomyl were detected.
- The pH in surface water ranged from slightly acidic (pH of 5.89) to very slightly alkaline (pH of 7.72).
- Low EC concentrations (< 500 µS/cm) measured in Bohena Creek are considered to be indicative of freshwater recharge.
- Levels of major anions/cations displayed little variability among the sample locations.
- Common metals (aluminium, barium, cobalt, iron, manganese, nickel, and strontium) were generally observed at low concentrations and at relatively consistent levels. Copper, cadmium, lithium, molybdenum, and zinc were infrequently detected. Several metals (arsenic, beryllium, boron, mercury, selenium, silver, tin, and uranium) were not detected in total or filtered samples.

Santos has conducted a water baseline report (CDM Smith, 2016b) as part of the project EIS (GHD, 2016a) to characterise the hydrological baseline and allow for the preparation of site-specific Water Quality Objectives.

4.2.8 Aquatic habitat

An ecological desk-top study and subsequent aquatic ecological field surveys were undertaken to ascertain the potential for impact to sensitive ecological receptors as a result of the managed release scheme. Fifteen ecological plant communities and twenty two threatened plant species are potentially present in the project area. No aquatic plant species of conversation significance, including *Cyperus conicus*, were found in the project area despite field searches at each survey site. Fringing vegetation of *Phragmites australis* was the main habitat features at the four survey sites along Bohena Creek.

Nine threatened fauna species were identified during desk based characterisation as having the potential to occur within the project area. Of these, three species were considered likely to be present in the study area, though in the Namoi River rather than Bohena Creek:

- *Bidyanus bidyanus* (Silver Perch);
- *Maccullochella peelii peelii* (Murray Cod); and
- *Tandanus tandanus* (Freshwater Catfish).

Records of threatened aquatic species in Bohena Creek are limited by the intermittent nature of the creek network which limits the opportunity to survey for freshwater dependent fauna, and therefore, it was concluded that there remains a possibility that Bohena Creek still offers a suitable habitat for threatened aquatic species. Four fish species were identified at the Bohena Creek sites, though only two, *Leiopotherapon unicolor* (Spangled Perch) and *Hypseleotris* sp., are native.

Macroinvertebrate surveys identified the highest diversity in Bohena Creek upstream of the proposed managed release site. The Stream Invertebrate Grade Number – average level (SIGNAL) scores (Chessman, 2003) were above 3.7 for all sites. The highest scoring site (at 4.2) was the proposed managed release site, although the presence of *Leptoceridae* and *Acarina* are indicative of severe to moderate impairment. The main stress at this site is that it was in a drying phase at the time of sampling and was then a small pool of less than 10 m length.

All sites returned AusRivAS results in Band B or Band C. These bands indicate that the sites are of a significant or severely impaired quality compared to modelled reference sites, with fewer of the expected taxa of and lower quality. However, these results need to be kept in the context that few modelled reference sites are available for ephemeral streams in the north-western slopes of NSW, which is why the AusRivAS results are considered only as part of the ecological assessment that also included fish communities, water chemistry, and other ecological indicators.

4.2.9 Water users

There are no registered bores in the Bohena Creek alluvium. It is possible that there may remain in use a small number of unregistered bores. It is likely that such bores are limited to stock watering use only.

There are no licensed surface water extractions from the Bohena Creek. It is further understood that from time to time the creek may be used for the unlicensed extraction of surface water, principally for stock use or fire-fighting.

A more detailed assessment and appraisal of water users within the wider project area has been conducted as part of the Groundwater Impact Assessment (CDM Smith 2016a) and this should be consulted in conjunction with this document.

4.2.10 Groundwater dependent ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined by the Department of Land and Water Conservation (2008) as 'ecosystems which have their species composition and natural ecological processes wholly or partially determined by groundwater'. A High Priority GDE is defined as having high ecological value (HEV) and is, therefore, considered a high priority for management action. The NSW Department of Primary Industry - Water (DPI Water) has documented two GDEs (Hardys and Eather Springs) as being of a high priority. Both springs are classified as recharge springs and are located at the outcropping junction of the Pilliga Sandstone and Purlawaugh Formation.

4.2.11 Preliminary Water Quality Objectives

In 2006 the NSW Government released the Namoi River Water Quality and River Flow Objectives to guide plans and actions that aim to ensure the long-term health of NSW waterways as well as satisfying the NSW Government requirement to meet its inter-governmental obligations to improve river health, such as in the Murray-Darling Basin. The guideline is split into water quality objectives (WQOs) and river flow objectives (RFOs). The objectives are divided into categories depending on the type of stream.

The Namoi River downstream of Keepit Dam is classed as a "major controlled river", the Mooki River and all other streams near to the Narrabri projects are mainly "uncontrolled streams". The exception to this is Bohena and Baradine Creeks where headwaters are located in "mainly forested area".

The WQOs for Bohena Creek are listed below:

- Aquatic ecosystems
- Visual amenity
- Primary and Secondary contact recreation
- Drinking water
- The RFOs for Bohena Creek are listed below:
- Protect pools in dry times;
- Protect natural low flows;
- Manage groundwater for ecosystems; and
- Minimise effects of weirs and other structures;

Although Bohena Creek is relatively undisturbed, particularly in the area immediately downstream of the Pilliga State Forest, it also receives runoff from land disturbed to varying degrees by grazing or pastoralism (as noted in Section 3.2.5, pesticides have been detected in surface water samples collected from Bohena Creek) and exotic species are common. Under these circumstances and in accordance with ANZECC/ARMCANZ (2000) Guidelines, the default level of protection for 'slightly to moderately disturbed systems' is considered appropriate to meet the management goal of maintenance or improvement of ecological conditions.

The Water quality objectives also note that 'The ANZECC 2000 Guidelines define upland streams as those above 150m altitude. However it is noted in the objectives that recent information suggests that for the NSW Murray-Darling Basin, within which Bohena Creek sits, 250 m may be a scientifically more appropriate altitudinal trigger to distinguish between lowland and upland rivers.' This corresponds with the description of a lowland catchment in Lampert and Short (2004) and the findings of ecological survey in Bohena Creek.

At the point of proposed discharge, the altitude of Bohena Creek is approximately 249 m above height datum (AHD). From here, the river descends in altitude towards Narrabri Township where the altitude is approximately 194 m AHD. Therefore, the area of assessment is sited below the 250 m altitude. The lowland river classification is adopted for this study.

5 Project water management

To enable gas extraction, coal seam depressurisation is required. The project involves extraction of produced water from coal seams and treatment of this at the Leewood WMF.

5.1 Overview of Leewood WMF storage and treatment

Water produced by the Narrabri Gas Project would be transmitted from wellhead via water pipes to the centralised water treatment and distribution facility known as the Leewood WMF.

Initially at the Leewood WMF, produced water would be temporarily stored in a pond for approximately 12 days (based on the proposed produced water storage pond volume and the maximum predicted inflow of produced water). This would allow warmer produced water to dissipate heat to the atmosphere and equilibrate, prior to undergoing treatment. This is an important step because released water temperatures must be as close to the ambient temperature of Bohena Creek as possible.

The next step is water treatment. At the Leewood WMF, produced water would be treated via a number of processes including reverse osmosis (RO) which would create a treated water stream and a brine stream. Brine from the RO plant may undergo further treatment (concentration) to minimise the resultant brine volume, and when operating, the thermal distillate from the brine concentrator would be combined with the RO treated water stream augmenting this treated water stream. A process flow diagram is presented as Figure 5-1.

Following treatment, treated water would be temporarily stored in a treated water pond either at the Leewood WMF or offsite near the proposed irrigation area (GHD, 2016a; Beneterra, 2015). The treated water ponds and the produced water pond would provide hydraulic buffering capacity to accommodate varying demand for beneficial use options. Treated water may either be used for beneficial purposes such as drilling, dust suppression, irrigation or for release to Bohena Creek.

Water required for release would be transported via an approximately 2 km pipeline to the proposed outlet location in Bohena Creek from where it would be released according to the managed release protocol. The proposed outlet structure would also be designed to minimise the potential for localised erosion, improve turbidity (an increase to be within the range of natural stream turbidity) and also to increase dissolved oxygen levels.

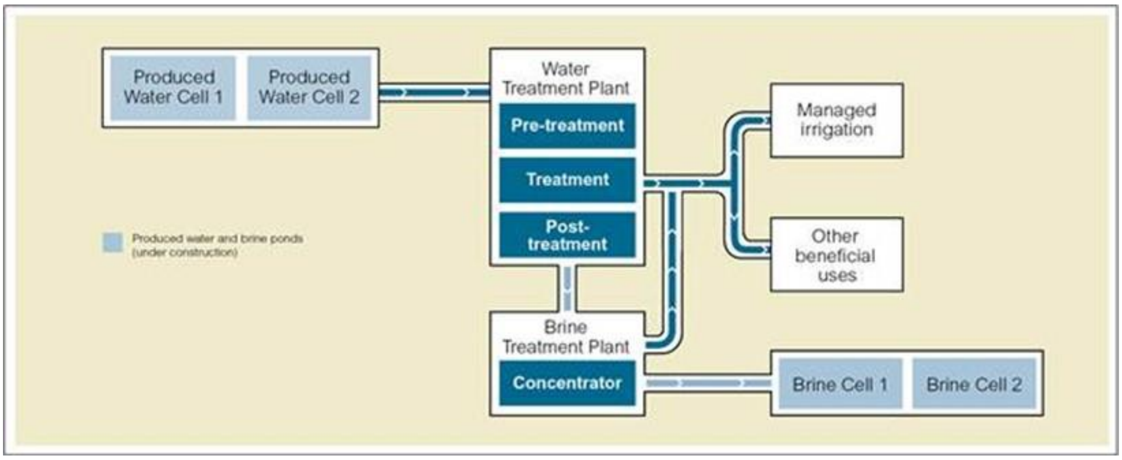


Figure 5-1: Process flow diagram steps

5.2 Treated water quantity

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25 year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the managed release activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

Figure 5-2 presents the base case water production forecast for the 25 year assessment period. Of this total volume, approximately 95% of this water would be made available after treatment for beneficial use including managed release.

The average production rate for the project from year zero to year four is expected to be approximately 9.1 ML/day and for later years the average production would reduce to approximately 3.8 ML/day (years five to 19) and approximately 1.7 ML/day (post year 20) as shown in Figure 5-2.

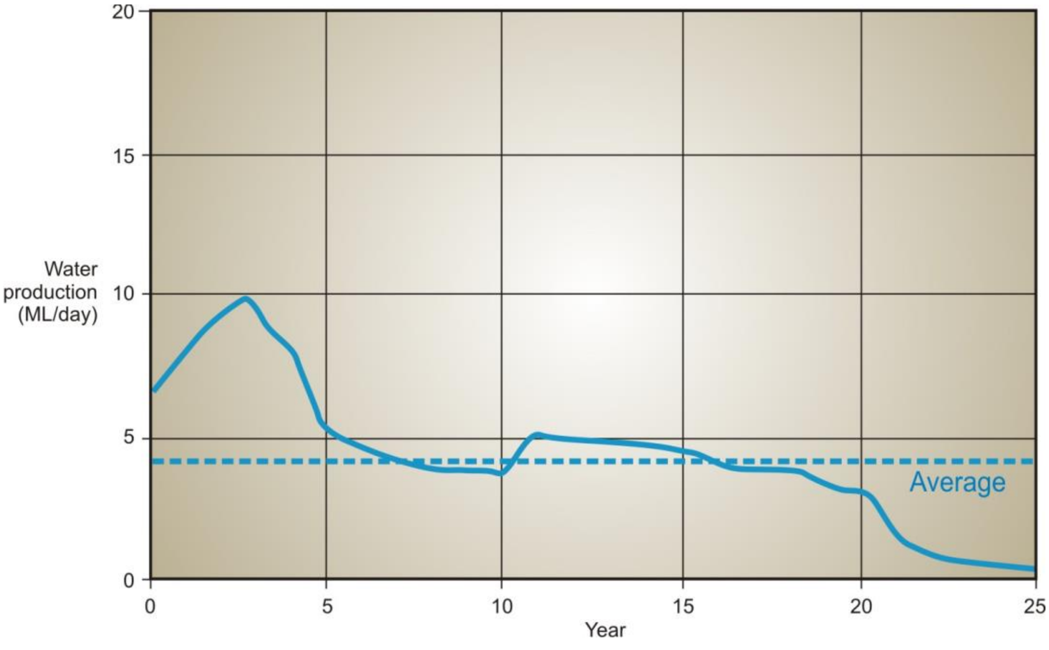


Figure 5-2: Produced Water Forecast (Production Curve)

5.3 Treated water quality

The model-predicted treated water quality provided by Santos (derived using the Hydranautics IMS Design modelling software) is presented in Table 5-1. Modelled projections do not reflect any further post-treatment water quality amendment for sodium adsorption ratio (SAR) or pH (post-treatment would be undertaken in accordance with the final intended use).

Table 5-1: Modelled treated water quality data (post chlorination)

Constituent	Units	Mean	Maximum
pH		7.1	9.2
Electrical conductivity (EC)	µS/cm	357	645
TDS (calculated)	mg/L	232	419
Turbidity	NTU	<0.5	1.0
Boron	mg/L	0.12	0.68
Sodium	mg/L	77	140
Magnesium	mg/L	0.01	0.01
Aluminium	mg/L	<0.001	0.01
Silica	µg/L SiO2	23	27
Potassium	mg/L	0.8	1.0
Calcium	mg/L	0.01	0.01
Chromium (III+VI)	mg/L	<0.001	0.001
Manganese	mg/L	<0.001	0.001
Iron	mg/L	<0.001	0.005
Cobalt	mg/L	<0.001	-
Nickel	mg/L	<0.001	0.000
Copper	mg/L	<0.001	0.002
Zinc	mg/L	<0.001	0.003
Arsenic	mg/L	<0.001	0.001
Selenium	mg/L	<0.001	0.001
Molybdenum	mg/L	<0.001	0.000
Cadmium	mg/L	<0.001	0.00056
Barium	mg/L	<0.001	0.027
Mercury	mg/L	0.0000067	0.0002
Lead	mg/L	<0.001	0.000
Uranium	µg/L	-	0.003
Alkalinity (Carbonate as CaCO3)	mg/L	139	-
Alkalinity (total) as CaCO3	mg/L	139	193
Ammonia	µg/L	15	50
Nitrate (as N)	mg/L	-	-
Nitrogen (Total Oxidised)	mg/L	-	-
Total Nitrogen	µg/L	-	-
Sulphate	mg/L	0.003	0.532
Chloride	mg/L	15	83
Fluoride	mg/L	0.08	0.16
Phosphorus	mg/L	0.01	<0.01

Notes:
[a] Final treated water chemistry will be subject to final water treatment plant design and will be confirmed with the regulator as soon as available. Water chemistry supplied is a best estimate based on current projection software and operating experience.
[b]Modelled projections do not reflect any further post treatment for SAR or pH. All treated water values are calculated from the Hydranautics IMS Design modelling software output and increased by at least 15%, based on Stage 1 and 2 values and the recovery ratios. The model was run assuming 30°C water temperature and SWC4B MAX membranes in both stages.
- Blank cells indicate values could not be calculated; < indicates concentrations are below the limit of detection (LOD)

6 Managed release simulations

A number of conceptual and numerical models have been developed to inform research, project design, impact analysis, monitoring design for the project. Information contained within the models includes water extracted (hydrogeological model; CDM Smith 2016a), beneficial use water balance, irrigation, rainfall-runoff (hydrology) and surface water release (hydraulics). Additionally investigations specific to the Leewood WMF have been completed which are described in GHD (2016a). Specifically relevant to the MRS, the beneficial use water balance model provides ranges for volumes of treated water used in the various beneficial use options implemented for the project.

6.1 Simulation development

As described in the Project EIS (GHD, 2016a), beneficially using water for drilling, dust suppression and irrigation is considered a higher priority activity than using water for managed release.

The potential to conduct managed release would be particularly important during periods of extended wet weather during which capacity to beneficially use treated water for higher priority uses may be constrained.

There are three reasons why managed release may be required:

- Release may be required during wet weather when other beneficial use options are unavailable.
- Release may be required during wet and dry weather to maintain treated water pond operating reliability[6].
- Beneficial use options other than release may not be possible *or* have some limitations, therefore, managed release must form part of the overall water project water management strategy.

Santos has developed a water management facility that will accommodate project requirements to store and treat water prior to release. Additionally Santos has evaluated a number of beneficial use options that are feasible and appropriate for the Project EIS. Santos has confirmed that the Leewood WMF will provide sufficient upstream storage capacity so that managed release is only required during wet weather.

The Project EIS proposes to beneficially use produced water whenever possible. Produced water would be treated and used (in order of priority) for drilling, dust suppression, irrigation and release to surface waters. Water available for release to surface waters is dependent on the demand for higher priority uses being satisfied first.

During the development of the MRS, it was observed that the risks associated with the proposed release scheme to Bohena Creek could be negligible, if releases only occur when the characteristically-intermittent Bohena Creek is flowing (natural flow ≥ 100 ML/day). Thus, when developing the project

[6] To maintain pond operating reliability, water levels (during normal operations) must not rise above the maximum operating limit. This is so rainfall events can be contained within the environmental containment freeboard above the pond maximum operating limit. Pond operators must return pond water levels to below the maximum operating limit following rainfall events.

water management strategy one of the goals for Santos was to reduce potential risks from managed release. It was accepted that this could be done in number of ways, with the preferred option being *episodic release to Bohena Creek* which is defined as infrequent release of treated water, typically during prolonged periods of wet weather when Bohena Creek is flowing (natural flow ≥ 100 ML/day). Section 4.2 discusses the hydrology of Bohena Creek in detail, with current data suggesting that the creek typically only flows following heavy rainfall and subsequent saturation of the surficial alluvial deposits, with flows estimated to occur at least 15 % of the time.

Consideration of drilling, dust suppression, and irrigation beneficial use limitations and uncertainties

Irrigation and dust suppression can be constrained during and following wet weather or when maintenance is required. Additionally, irrigation can only be operated when there is sufficient demand based on factors such as season, crop life-cycle stage, soil moisture deficit and a range of other factors. Further information on these limitations and uncertainties can be found in the Irrigation Study (Beneterra, 2015).

Consideration of infrastructure requirements

A finite volume of water can be stored in ponds associated with the project. Santos must carefully manage ponds so they do not spill. Pond water levels must be maintained below respective maximum operating levels. A number of factors must be proactively managed to ensure this occurs. Factors such as weather (rainfall and evaporation), beneficial use demand and managed release must be considered as they each play an important part in managing pond water levels on a day-to-day basis. Furthermore, as treatment infrastructure is constrained by a limited treatment capacity, Santos may sometimes require to move water between ponds and release treated water to maintain reliable pond operating levels.

Consideration of managed release limitations and uncertainties

There are a number of uncertainties inherent in the numerical modelling undertaken to simulate managed release. These include uncertainty in the geological model and subsequently in the hydrological model.

Approach

Given relative limitations and uncertainties outlined above, it was considered prudent to consider a range of possible scenarios for managed release to Bohena Creek. The purpose of this was to understand potential impacts of varying types of release (for example intermittent and constant release). A number of release scenarios were initially developed independently of water balance modelling and included episodic release and constant release scenarios. The range of scenarios modelled was considered broad enough to understand and assess:

- limitations and uncertainties related to other beneficial uses which may alter operation of managed release and consequently potential impacts to Bohena Creek;
- limitations and uncertainties related to infrastructure; and
- impacts related to change of magnitude (timing, frequency, intensity).

Selected scenarios were simulated using numerical modelling software to predict the response of groundwater-surface water interactions within the Bohena Creek and alluvial aquifers.

Scenarios considered in this report

Santos has elected to proceed only with episodic release to Bohena Creek when natural flow in Bohena Creek is ≥ 100 ML/day measured at the Newell Highway gauging station. The main reason for proceeding with episodic release only is to align treated water releases with environmental flows, therefore resulting in the least environmental impact. Potential impacts related to the episodic release form the basis for undertaking the impact assessment (refer Section 8 of this report).

The scenario considered in this report, 37GLI01-W, comprises episodic release to a flowing creek (≥ 100 ML/day). Variants on this scenario have been investigated to place the proposed release protocol in context including the:

Base case - managed release to creek flowing at 100 ML/d, initiated by storage pond full condition

Case 1 - managed release to creek flowing at 100 ML/d, initiated by creek flow rate threshold; and

Case 2 - managed release to creek flowing at 50 ML/d, initiated by creek flow rate threshold.

6.2 Beneficial use water balance model

6.2.1 Model conceptualisation

The Narrabri Gas Project proposes to beneficially use CSG water where possible. CSG water would be treated as required and used (in order of priority) for drilling, dust suppression, irrigation and episodic release to surface waters. Water available for release to surface waters is dependent on the demand for higher priority uses being satisfied first.

A water balance model representing how beneficial uses would be prioritised was developed using GoldSim©, a general purpose probabilistic simulation tool used to undertake reliability and risk assessments by quantitatively addressing the uncertainty inherent in complex systems. The aim of this model was to:

- develop an integrated perspective of the system;
- understand the relative weight of the different demands;
- understand timing and volume of the potential episodic releases into Bohena creek (corresponding to storage surpluses from the 200 ML treated water storage pond and if early release could lessen potential impacts on Bohena Creek); and
- understand whether these releases occur to a flowing creek (≥ 100 ML/day).

6.2.2 Model development

Table 6-1 describes key GoldSim model features. Figure 6-1 shows a schematic diagram of the GoldSim model configuration.

Table 6-1 Beneficial Use Water Balance – Key GoldSim Model Features

Model feature	Description
Treated water curve	A 12.0 ML/d constant feed rate was used.
Direct rainfall	1963 – 2013 data from Narrabri post office rain gauge (ID 053030), as per the HowLeaky irrigation model (Beneterra, 2015).
Evaporation losses	Same gauge as for rainfall data
Beneficial use priority	The model sets up a priority for outflows, in case the demand of water exceeds the stored volumes. The priority order for the treated water demands are: 1. Drilling 2. Dust suppression 3. Irrigation 4. Managed release into Bohena creek
Drilling demand	50.0 ML/yr constant demand, corresponding to the lowest demand between project years 2 to 5
Irrigation	Irrigation demands for years 1963 to 2013 as per HowLeaky model (Beneterra, 2015) with 12.0 ML/day water production; 200 ML storage pond; 500 ha irrigable area; 30 mm soil water deficit (irrigation trigger).
Dust suppression	0.27 ML/d (3 tankers x 30 m^3 x 3 runs). If irrigation is suspended due to significant rainfall, dust suppression is also suspended.
Storage pond and tank	5 ML tank (assumed 4m deep) to feed dust suppression and drilling demands; 200 ML storage pond (assumed 5m deep) to feed irrigation demands and managed release scheme. Overflows from the 5 ML tank are diverted to the 200 ML storage pond.
Managed release	Storage surpluses from the 200 ML storage pond are directed into the Bohena Creek when Creek flows are ≥100 ML/day. [a] [b]
Bohena Creek wet and dry time series	Derived from rainfall-runoff modelling, as described in Section 6.5.

Notes:
[a] Onsite water management functionality will allow treated water from the Leewood WMF to be directed to release point, rather than water from the 200ML irrigation pond being used.
[b] If all beneficial uses and managed release are unavailable (e.g. due to wet weather or for operational reasons and Bohena Creek is not flowing at ≥100 ML/day) additional water would be stored within the water management system either at Leewood or within the proposed 200 ML offsite irrigation storage pond.

6.2.3 Model simulation

Table 6-3 lists scenarios that were analysed using the water balance model. All the scenarios use a constant treated water flow of 12.0 ML/d, a storage pond size of 200 ML and an irrigable area of 500ha. The 1963-2013 period was modelled in all cases. The managed release scenarios can release up to 12.0 ML/d into the Bohena Creek.

The scenarios listed in Table 6-2 were completed with an aim of understanding the potential benefits (in terms of reducing the risk of environmental impacts) related to managed release. Case 0 is used as the baseline for comparison, while the other two scenarios (case 1 and case 2) test different management criteria options by releasing water held in the treated water pond prior to the pond reaching capacity.

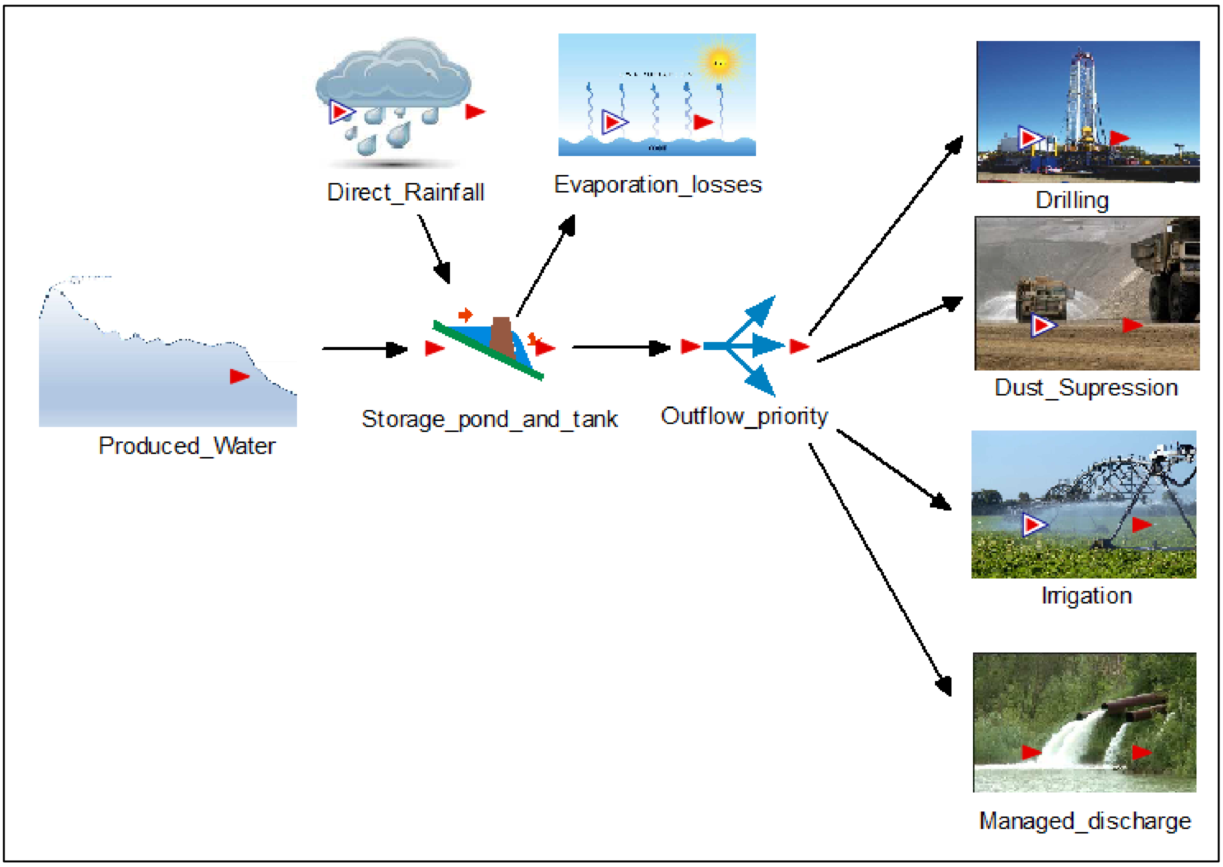


Figure 6-1: Beneficial Use Water Balance – GoldSim model schematic

Table 6-2: Beneficial Use Water Balance – Scenarios modelled

Release scenario	Release type	Scenario ID
37GLI01	Episodic	Case 0 – Release treated water only when 200 ML irrigation pond reaches maximum operating level. (Base case)
	Episodic	Case 1 – Early release of treated water when Bohena Creek flow is measured to be ≥ 100 ML/d
	Episodic	Case 2 – Early release of treated water when Bohena Creek flow is measured to be ≥ 50 ML/d

6.2.4 Model results

Model results are presented in terms of magnitude (timing, frequency & intensity) of episodic release to Bohena Creek for the three scenarios listed in Table 6-2.

It is important to note that the episodic release results presented are only for peak treated water production years 0 to 4. Given that reduced volumes of treated water will be available for beneficial uses in years 5 onward, it is likely that the requirement to initiate an episodic release from years 5 onward would be reduced compared with years 0 to 4.

6.2.4.1 Timing and frequency (years 0 to 4)

Figure 6-2, Figure 6-4 and Figure 6-6 present timing and frequency expressed as likelihood of a release day to occur in a given month of the year. It is evident that, regardless whether early release is undertaken, there is likely to be some requirement for upstream storage when beneficial uses (drilling, dust suppression and irrigation) and managed release are unavailable. This is most likely to occur between June and October in any given year. These events correspond to cessation of irrigation during periods when flow in Bohena Creek is less than 100 ML/day. In these months, there is typically a combination of low crop water demand, low evapotranspiration rate and occurrence of some rain (although not enough rain as to initiate flow in Bohena Creek).

For case 0 (base case – release occurring when ponds reach capacity), flowing creek (≥ 100 ML/day) release days are more likely to occur also within winter and spring months. For the ≥ 100 ML/d (case 1) and ≥ 50 ML/d (case 2) (early release) it is evident that the temporal pattern of flowing-creek releases changes significantly when compared to the baseline scenario, with some likelihood of flowing-creek release days occurring in every month. The main difference between the case 1 / case 2 early release scenarios versus case 0 pond-full scenario is that the likelihood of the requirement for upstream storage is reduced. This is important as it translates to reduced pond footprint on site.

6.2.4.2 Intensity (years 0 to 4)

Figure 6-3, Figure 6-5 and Figure 6-7 present intensity expressed as likelihood in any given year of a release event of a given volume to Bohena Creek, presented as flowing (≥ 100 ML/day, blue) and when there is a requirement for upstream storage capacity (i.e. when beneficial uses are offline, and managed release is unavailable because creek flow is < 100 ML/day, red). For this analysis, ‘event’ is defined as any succession of consecutive days with either (i) release into Bohena Creek or (ii) requirement for upstream storage. When the release ceases or the requirement for upstream storage ceases, so the event ceases.

For case 0 (base case – release occurring when irrigation pond reaches capacity), the likelihood of given volumes requiring management by *release to a flowing stream* and *upstream storage* is similar. The chart (Figure 6-3) shows that such consecutive-day release events would most likely release less than 200 ML in the creek; however higher volume releases are possible (releases to a flowing creek over a longer period of consecutive days).

When incorporating an early release protocol as presented in Figure 6-5 and Figure 6-7[7], a marked change in the pattern of release volumes for flowing creek (≥ 100 ML/day) events occurs, with a larger frequency of small events when the stream is flowing at ≥ 100 ML/day. Also there is a smaller frequency of larger events when there would otherwise be a requirement for upstream storage capacity. Therefore, if an operational driver *to undertake early release of treated water before ponds reach capacity when the creek is flowing (≥ 100 ML/day)* is considered, then this would result in:

- a greater number of release events when streamflow is ≥ 100 ML/day, however each event is likely to involve a much smaller release volume (and, consequently, a reduced potential environmental impact);
- a reduction in the likelihood of (and therefore the requirement for) upstream storage capacity.

Comparing case 1 (≥ 100 ML/d) and case 2 (≥ 50 ML/d) (both scenarios comprising early release before ponds reach capacity), it can also be seen that a slight reduction in the likelihood of a high volume release would be required, when compared with the case 0. There is no conceptual difference when comparing the results of case 1 and case 2.

6.2.4.3 Total proportion directed to episodic release and beneficial uses (years 0 to 4)

Figure 6-8, Figure 6-:6-9 and Figure 6-10 show how the total water volumes are allocated to each beneficial use for the simulation period. This represents the expected average water allocations during produced peak water production times[8] during years 0 to 4.

Irrigation is the dominant demand, accounting for between 87.4% and 93.2% of the total water use. The result of releasing water to Bohena Creek when the creek is flowing (≥ 100 ML/day, case 1 or ≥ 50 ML/day, case 2) approximately trebles the amount of water released into the Bohena creek. There is only a small difference between volume allocations for case 1 and case 2. The water volumes used for dust suppression, drilling and natural evaporation from the ponds remain unchanged among the three scenarios.

6.2.4.4 Summary

Comparing Figures 6-2 to 6-10 indicates that:

- the requirement for upstream storage when streamflow is < 100 ML/day is likely to occur between June and October in any given year. This corresponds to periodic cessation of irrigation, due to a combination of low crop water demands, low evapotranspiration rates

[7] Likelihood values of more than 100% in Figure 6-5 and Figure 6-7 for releases to a flowing stream (≥ 100 ML/day) indicates that there will be more than one release within the indicated volume range, in any given year.

[8] Future actual allocations may vary from these estimates according to the actual rainfall depths observed during produced peak water production

and occurrence of some rain (although not enough rain as to initiate a creek flow in Bohena Creek).

- implementation of an operational driver *to undertake early release of treated water before ponds reach capacity when the creek is flowing (≥ 100 ML/day)* would:
  - reduce the requirement for upstream storage in terms of likelihood of requirement by approximately 20%, however this also increases the volume released when streamflow in Bohena Creek is ≥ 100 ML/day; and
  - increase the total number of release events, however each event is likely to involve a much smaller release volume.

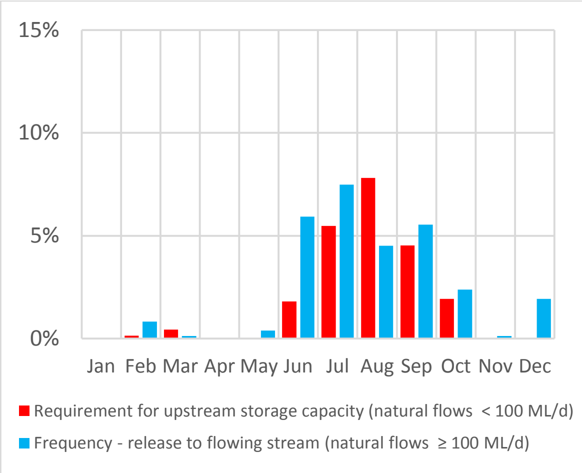


Figure 6-2: Timing & Frequency – Likelihood of release day occurring in a given calendar month (Case 0 – base case)

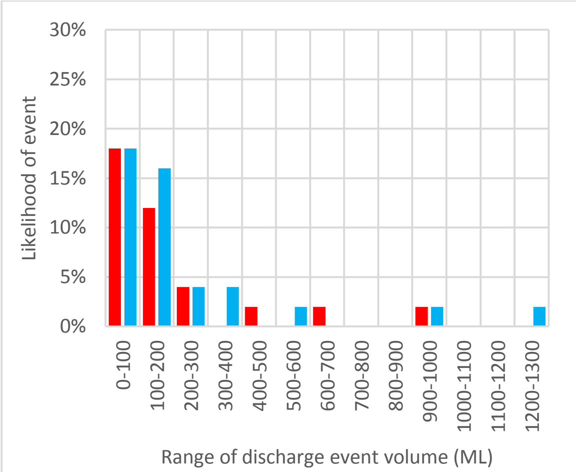


Figure 6-3: Intensity – Likelihood in any given year of release events vs. range of volume (Case 0 – base case)

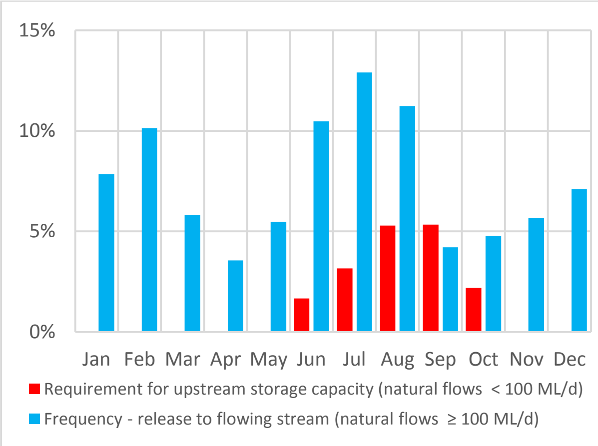


Figure 6-4: Timing & Frequency – Likelihood of release day occurring in a given calendar month (Case 1: early release ≥ 100 ML/d)

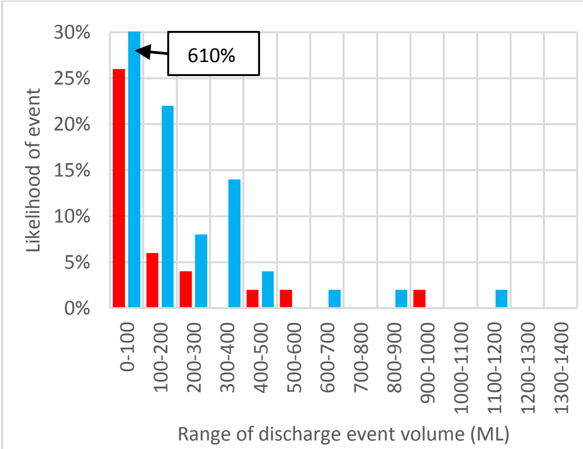


Figure 6-5: Intensity – Likelihood in any given year of release events vs. range of volume (Case 1: early release ≥ 100 ML/d)

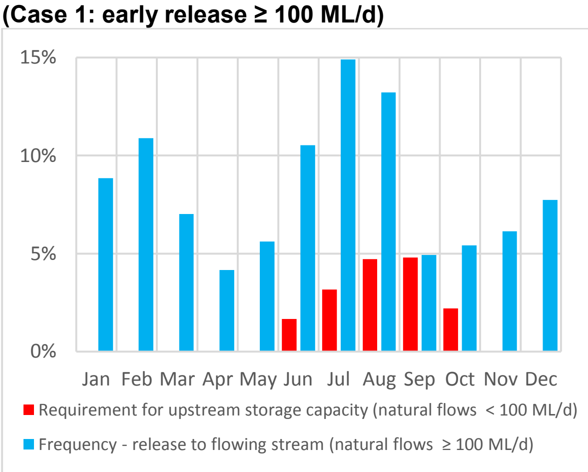


Figure 6-6: Timing & Frequency – Likelihood of release day occurring in a given calendar month (Case 2: early release ≥ 50 ML/d)

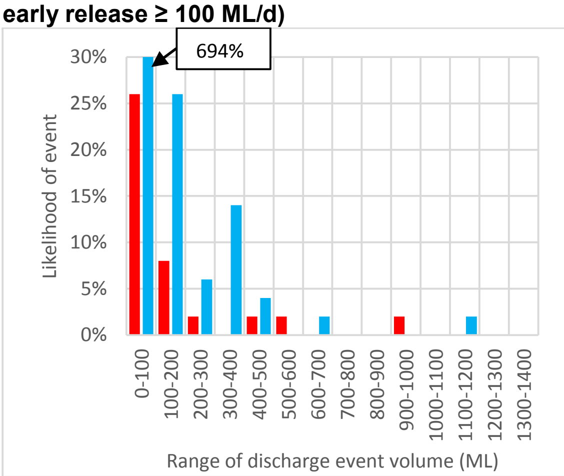


Figure 6-7: Intensity – Likelihood in any given year of release events vs. range of volume (Case 2: early release ≥ 50 ML/d)

Note: Likelihood values of more than 100% in Figure 6-5 and Figure 6-7 for releases to a flowing stream (≥ 100 ML/day) indicates that there will be more than one release within the indicated volume range, in any given year.

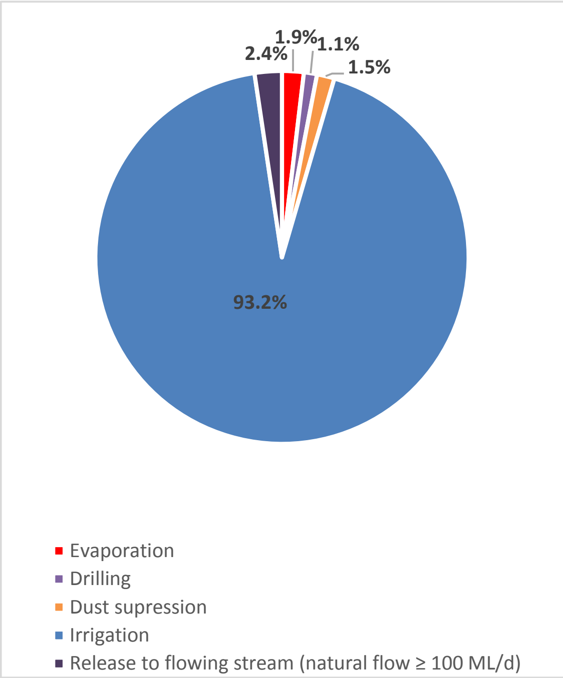


Figure 6-8: Volume allocations per beneficial use (Case 0 – base case)

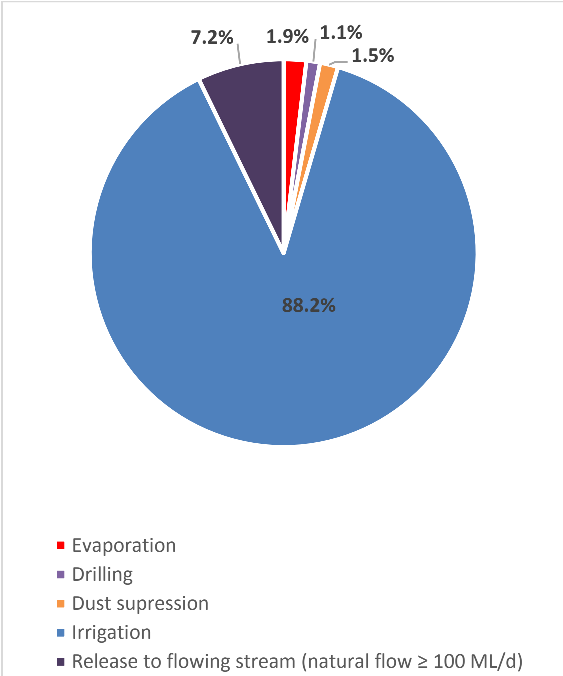


Figure 6-:6-9 Volume allocations per beneficial use (Case 1: early release ≥ 100 ML/d)

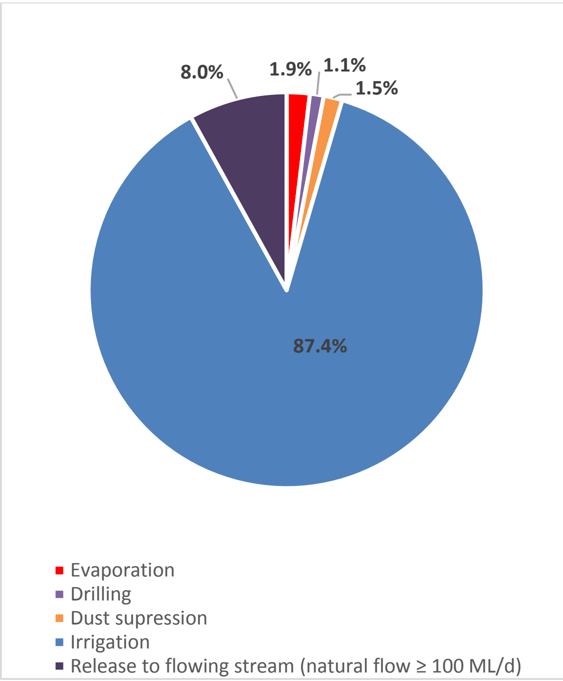


Figure 6-10: Volume allocations per beneficial use (Case 2: early release ≥ 50 ML/d)

6.3 Creek flow mechanisms and episodic release in the context of natural flows

Information presented in Section 6.3 is based on data acquired from the Newell Highway stream flow gauge and has been synthesised by Santos to inform the conceptualisation and design of the Narrabri Gas Project.

6.3.1 Creek flow conceptualisation

Conceptualisation of flow in the Bohena Creek in the MRS combines a geological and hydrostratigraphic model of the region. This provides an understanding of physical flow processes that occur in the subsurface, at the surface and in particular when there is dynamic surface water – groundwater interaction.

6.3.1.1 Geological and Hydrostratigraphic Model

In the subsurface, an important distinction is made between basin scale hydrogeological processes (flow in the Pilliga Sandstone) and local scale groundwater flow in permeable alluvial and colluvial sediments aligned with Bohena Creek.

- The former involves slow regional scale groundwater flow, as simulated in the Gunnedah Basin Regional Model. Rainfall leads to recharge which drives relatively horizontal flow in aquifers and vertical flow through aquitards between aquifers, generally westwards towards the Great Artesian Basin.
- The latter has a relatively fast response time. Groundwater flows steadily downstream in the alluvium beneath Bohena Creek, but the water table in the alluvium responds rapidly to rainfall and runoff events, and is expected to respond similarly to the release of treated water.

Based on the geological and hydrogeological information described in Section 4, the Bohena Creek Alluvium is considered to be deposited on unnamed alluvium and colluvium, which overlie the Keelindi Beds, which in turn overlie the Pilliga Sandstone.

6.3.1.2 Flow Processes

When water flows in the system naturally or is released at the surface, slightly different processes occur in three parts of the shallow system:

- Initially when a stream begins to flow, water pools at shallow depth around low points in the topography. If the stream bed is dry, then water would infiltrate into the alluvium almost immediately to the water table below. When the water reaches the water table, as “point” recharge, the water table would rise. Since the water table slopes generally downstream, in the direction of episodic streamflow, additional water added into the creek system flows more easily in that direction. A surface can be defined that separates ambient water flowing along the alluvial aquifer from the water that has infiltrated – a release zone, analogous to the capture zone of a bore.
- When surface water run-off drains to a dry stream, the water table rises beneath the point of infiltration, until it intersects the dry stream bed. When the water table reaches the surface, water would either: pond in a depression in the streambed, until the level in the pond causes that pond to overtop; or continue as surface flow downstream along the creek.
- Equally, direct rainfall to the dry creek surface will infiltrate to the water table at depth and with continued rainfall infiltration and infiltration of surface run-off, the water table will rise to ground surface, forming pools as described above and coalescing to yield streamflow.

- When the stream flows, additional reaches of the stream become wet, creating an opportunity for infiltration further along the channel.

6.3.1.3 Streamflow

As explained in Section 4, Bohena Creek flows in response to rainfall-runoff events, flowing north towards the Namoi River. Santos' proposal to release treated water to Bohena Creek when the creek is flowing at or above 100 ML/d is based on the notion that water would be produced throughout the year, and there would be a need to release treated water on occasion.

Table 6-4 presents a summary of periods of continuous streamflow recorded between 1997 and 2004 at the DPI Water Newell Highway gauge on Bohena Creek. The table records when continuous flow commenced in the creek, the duration of the continuous flow event and the total volume of flow that took place during that flow event, as calculated from the gauge.

Table 6-3: Summary of continuous streamflow events at Newell Highway between 1997 and 2004

Start Date	Duration (days)	Total discharge (ML)	Mean discharge (ML/d)	Peak discharge (ML/d)
30 Jan 1997	47	29,000	617	4,414
10 Feb 1998	5	1,400	279	540
22 Jun 1998	4	1,000	241	458
18 Jul 1998	159	237,000	1,429	20,820
1 Jan 1999	7	2,300	331	381
7 Apr 1999	27	10,000	368	1,071
9 Jun 1999	8	1,400	179	374
1 Jul 1999	33	11,000	331	500
11 Aug 1999	3	300	116	120
27 Aug 1999	4	700	187	246
6 Oct 1999	67	29,000	431	1,101
9 Mar 2000	23	11,000	468	1,564
15 Nov 2000	47	54,000	1,156	9,373
9 Dec 2004	44	36,000	821	15,325
Mean	**34**[9]	**30,000**	**497**	**4,021**

The longest events can be seen to result in substantial natural discharges of many thousands of megalitres, whilst even the shortest recorded continuous flow event during this period yielded a calculated total flow of 300 ML over three days – a mean discharge of 116 ML/d. The mean discharge rate throughout the 14 recorded continuous flow events from 1997 to 2004 is 497 ML/d. The proposed episodic release of up to 12 ML/d of treated water during a natural streamflow event would lead to only

[9] This value represents the mean duration in days of those continuous flow events recorded at the Newell Highway gauge on Bohena Creek during the period 1997 to 2004 where a continuous flow event is defined as continuous records of river stage above gauge zero persisting over a period greater than 24 hours.

a very marginal increase in streamflow even during the most minor natural flow event. Surface waters eventually drain to the Namoi River which is a regulated river.

6.4 Rainfall-runoff hydrology model

A rainfall – runoff hydrology model has been calibrated to the observed flow series at Bohena Creek at Newell Highway. The purpose of the model is to understand the wetting and drying patterns of Bohena Creek to predict when Bohena Creek would be flowing ≥ 100 ML/day. The outputs of the rainfall-runoff modelling have been used as part of beneficial water use simulations presented in Section 6.2. The rainfall-runoff model uses 51 years of recorded data (1963 - 2013) as part of simulations.

6.4.1 Model conceptualisation

Water added into the hydrological system has three fates:

- it can be added to groundwater storage in the subsurface;
- it can be added to surface water storage above ground; or
- it can be lost to the atmosphere by evapotranspiration.

Rainfall in the catchment of Bohena Creek is likely to initially infiltrate into catchment soils. Once soils become saturated, a proportion of rainfall would be converted into overland flow. Overland flows drain via the lowest topography points to watercourses. The main catchment watercourse Bohena Creek also has a sandy substrate into which overland flows initially infiltrate.

6.4.2 Model development

Data series presented in Table 6-4 have been used as part of rainfall-runoff modelling.

Table 6-4: Rainfall-runoff model - data series used

Data type	Name of series	Period and frequency available	Source
Rainfall	55263 (Mullaley (Keigho))	1966 – 2014 (Daily)	Bureau of Meteorology [a]
	55301 (Mullaley (Kirkbright))	1954 – 2014 (Daily)	
Observed water levels	Bohena Creek at Newell Highway	1995 – 2013 (Daily)	NSW Office of Water [b]
Observed flows	Bohena Creek at Newell Highway	1995 – 2013 (Daily)	NSW Office of Water [b]
Rating curve	Bohena Creek at Newell Highway	Post 16/06/2005 rating curve available	NSW Office of Water [b]

Sources:
[a] http://www.bom.gov.au/climate/data
[b] http://realtimedata.water.nsw.gov.au/water.stm

6.4.2.1 Rainfall

As shown in Table 6-4, rainfall data at gauges 55263 and 55301 (Mullaley at Keigho and at Kirkbright, respectively) have been used. These gauges were selected as they are located near the barycentre of the Bohena Creek catchment, they have good quality records for the period of study and they show a good correlation with flow records at the Bohena Creek. Gauge 55263 is used as primary gauge while gauge 55301 is used as donor to in-fill periods with missing data at gauge 55263.

Figure 6-11 shows the two original rainfall data series plus the in-filled one, used to calibrate the rainfall-runoff model. Figure 6-12 shows the spatial location of the gauges with respect to the Bohena Creek catchment and the flow gauging location at the Newell Highway.

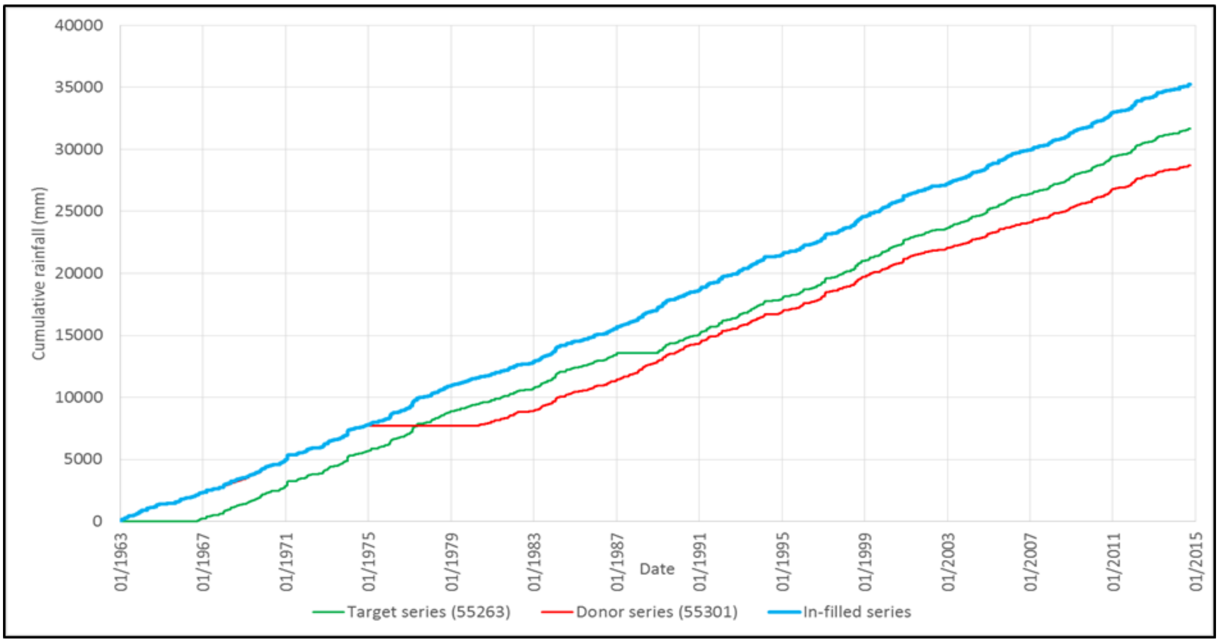


Figure 6-11: Rainfall-runoff model – Cumulative rainfall data series

The above figure indicates good correlation between rainfall series[10]. The target data series (gauge 55263, Mullaley (Keigho)) shows the following missing data:

- Whole period between 01/01/1963 and 31/08/1966;
- Whole period between 01/03/1987 and 31/12/1988;
- Scattered single days missing during the rest of the series; and
- There are also some cases in which only one values is provided to represent the accumulated rainfall over two or three days (identified by the quality flags provided by BoM).

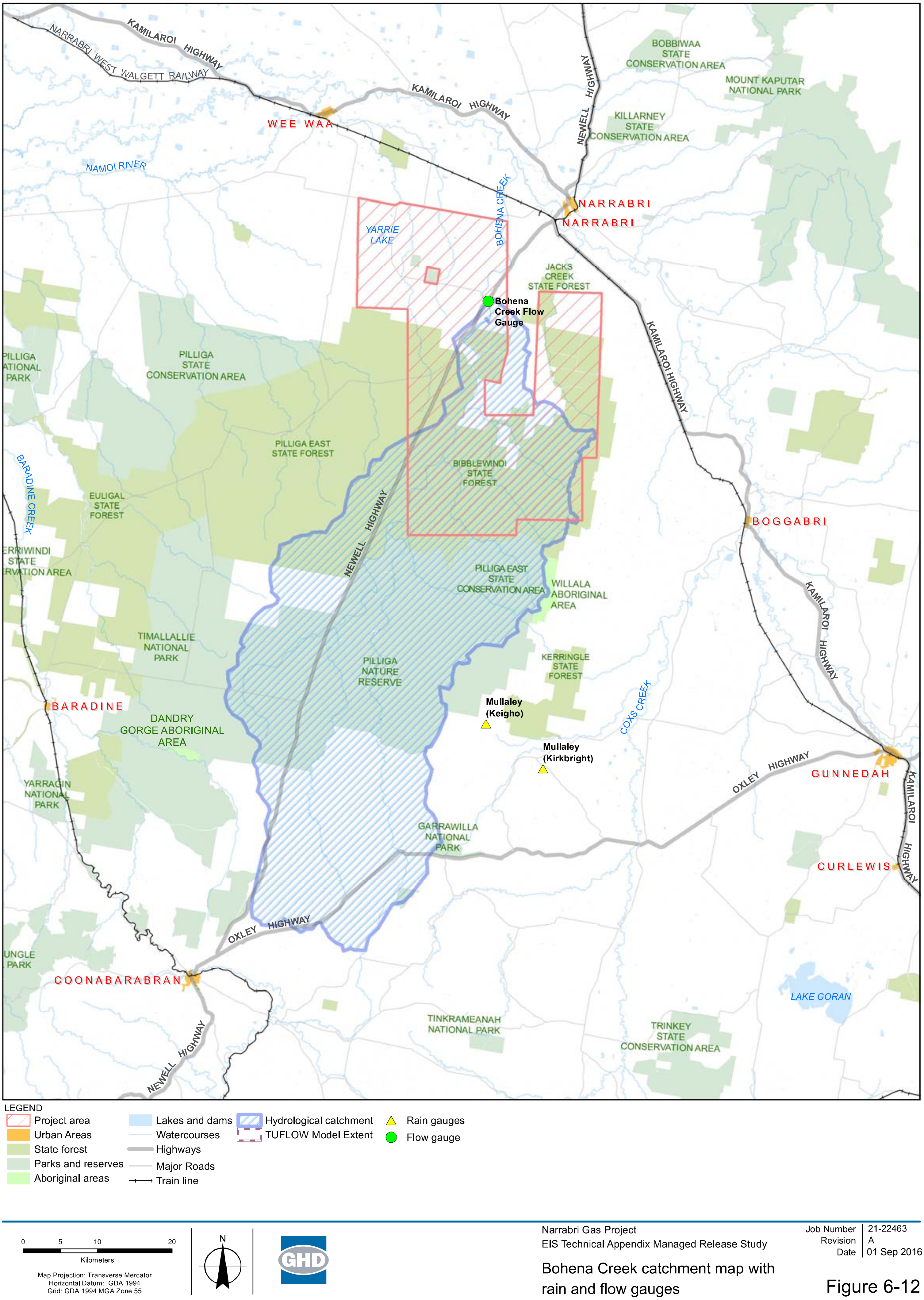
In order to have a continuous rainfall data series, the target data series was in-filled using the donor series, based on the following procedure[11]:

[10] Since 2003 gauge 55301 has been recording slightly lower rainfall than gauge 55263, however as this period is fully available in the target data series it was deemed not necessary to reconcile the differences.

[11] This simple in-filling procedure has not been further refined since this would not provide any practical differences in the application of the results of the rainfall-runoff model.

- For the continuous missing periods, as well as for the single scattered missing values, the recorded rainfall at Mullaley (Kirkbright) was used.
- For the values representing rainfall accumulated over more than one day, the accumulated rainfall was spread through the days following the same proportion of rainfall values observed at Mullaley (Kirkbright)[12].

[12] For example on 27/02/2012 gauge 55263 shows 12.6 mm corresponding to that day and the previous one (there are no data available for 26/02/2012), while gauge 55301 shows 4.5 mm on 26/02/2012 and 5 mm on 27/02/2012 (for a total of 9.5 mm over both days). The series at gauge 55263 is then corrected by allocating 5.97 mm to 26/02/2012 (12.6mm x 4.5mm / 9mm), and 6.63 mm to 27/02/2012 (12.6mm x 5mm / 9mm).



Narrabri Gas Project
EIS Technical Appendix Managed Release Study

Job Number 21-22463
Revision A
Date 01 Sep 2016

Bohena Creek catchment map with rain and flow gauges

Figure 6-12

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

6.4.2.2 *Observed water levels and flows*

Figure 6-13 shows the observed water levels at Bohena Creek at Newell Highway gauging station, and the corresponding flows calculated by means of applying the rating curves at the gauge. The following aspects can be observed:

- There are continuous water level data available for the period 02/09/1995 – 27/10/2014, with no missing values;
- The water level data series shows prolonged flat periods, corresponding to zero flow in the gauge (dry creek);
- There are several 'spiky' hydrographs, representing short duration flow events, characteristic of intermittent, sandy watercourses;
- There is a marked 'step' in the zero flow level on 06/07/2005. Before this period the zero flow level was 0.34 mALD (above local datum), after this date it is 0.69 mALD. There is no information available to justify this change; and
- The flow data series is continuous before 06/07/2005, while after this date only one event is shown (2 to 12 December 2010), corresponding to the highest water level recorded in the period.

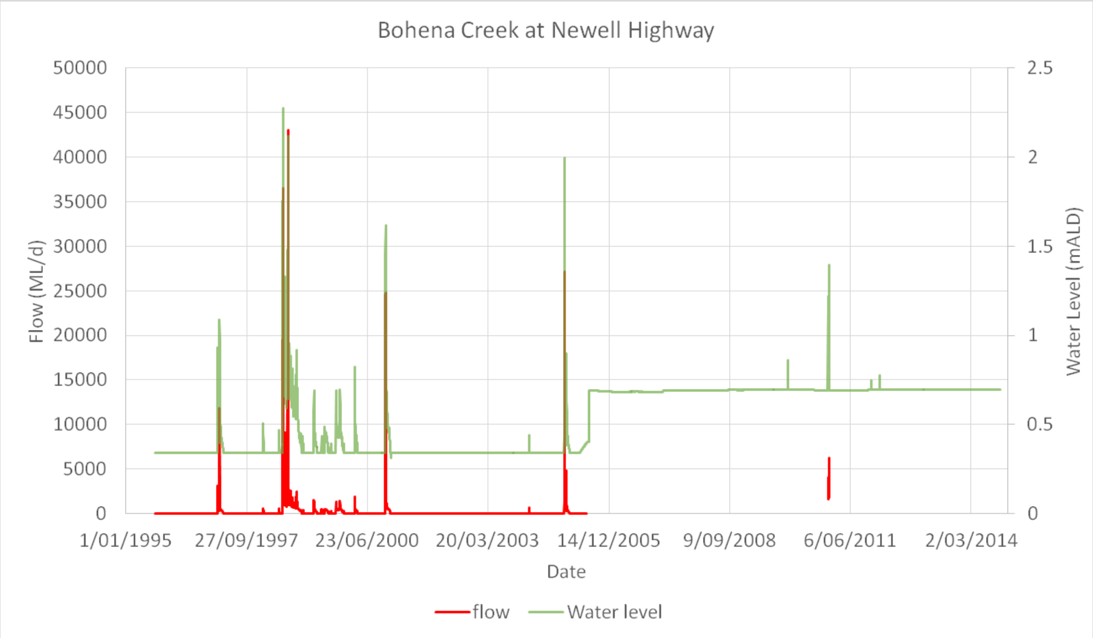


Figure 6-13: Bohena Creek observed water levels and flows at Newell Highway

The latest available rating curve at the Newell Highway gauging station (orange series, post-2005) is shown. Based on observed data, there are no rating curve data for flows below 1,100 ML/d (corresponding to water levels below 0.700 mALD). This may explain why there are a number of missing values in the recorded flow series post 2005.

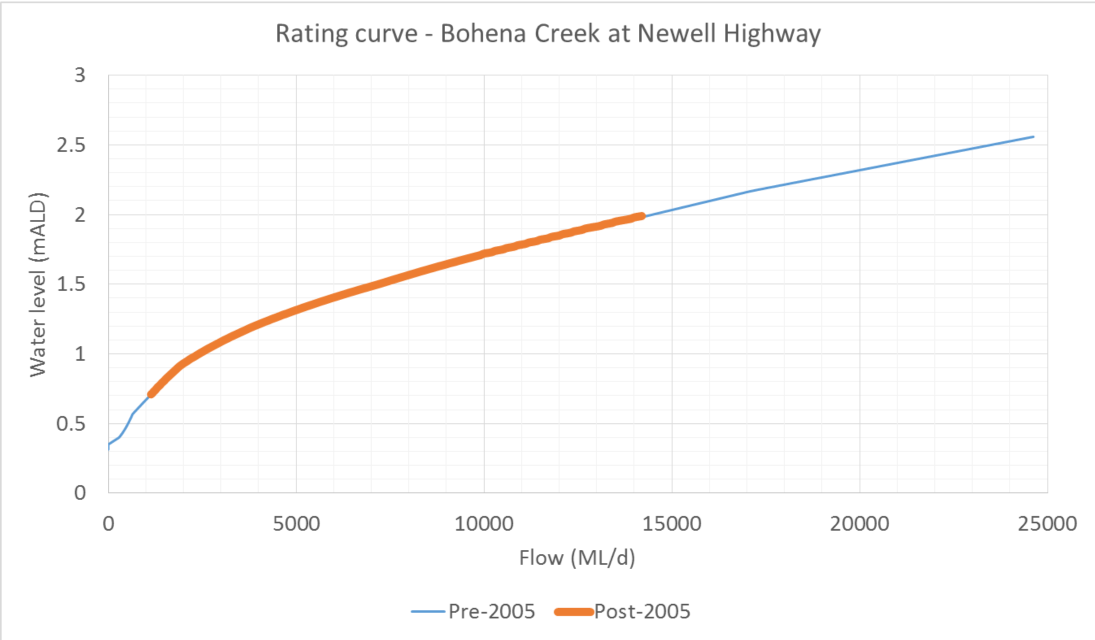


Figure 6-14: Bohena Creek Rating curves at Newell Highway gauging station

Although data was not available for the rating curve used pre-2005, missing data can be derived from the relationship of the observed flow and water level series. Figure 6-14 indicates that for flows over 1,100 ML/d the rating curve is the same as the post-2005 rating curve[13].

The flow data series as shown in Figure 6-14 have been used to calibrate the rainfall – runoff model. No modifications or adjustments were performed to this series.

Using the data described above, a rainfall-runoff model has been calibrated.

As the purpose of the rainfall-runoff model is principally to predict periods when Bohena Creek would be flowing ≥100 ML/day, a higher objective to calibrate this pattern with high accuracy was established.

A rainfall – runoff model was built using the HEC-HMS modelling platform[14], developed by the US Army Corps of Engineers. The model was constructed using the data shown presented above for a catchment area of 2,046 km^2, corresponding to the Bohena Creek at Newell Highway. For simplicity purposes, a single, lumped catchment was modelled, i.e. the hydrological model was not broken down into different sub-catchments.

The final rainfall-runoff model methods and parameters adopted in the HEC-HMS model are shown in

Table 6-5. These parameters demonstrated best-fit with recorded hydrographs and enabled the HEC-HMS model to predict periods of flow and zero flow (no-to-low-flow < 100 ML/day).

Table 6-5: HEC-HMS sub-models and parameter values adopted

13 The pre-2005 data curve starts at zero flow. This explains why there are continuous flow data available pre-2005 (including low flows), while not post-2005).

14 Available for free at http://www.hec.usace.army.mil/software/hec-hms/downloads.aspx

Sub-model	Method	Parameters
Losses	Deficit and Constant	Initial deficit = 40mm Maximum deficit = 110 mm Constant rate = 1.5 mm/hr Impervious = 0%
Transformation	Clark Unit Hydrograph	Time of concentration = 12 hr Storage coefficient = 24 hr
Baseflow	Linear Reservoir	Number of reservoirs = 1 Initial type = Release GW Initial = 0.05 m3/s GW coefficient = 250

6.4.3 Model simulation

6.4.3.1 Calibration

Calibration of the rainfall-runoff model was primarily focused on accurately determining the onset of flow in the creek (periods of flow and zero flow)[15]. Accuracy in reproducing peak flows was a secondary objective.

6.4.4 Model results

6.4.4.1 Calibration results

If a threshold of 100 ML/day is used to define Bohena Creek as flowing, then creek flows would be predicted within ± 1 days of actual occurrence.

Calibration results are presented in Table 6-6 and Figure 6-15. Table 6-6 shows the observed events in which more than 100 ML/d were observed in the creek, and the date this flow threshold was crossed (both for the rising and falling limbs of the hydrograph). As shown in Table 6-6, in the 8 cases the model predicts that creek flows would surpass 100 ML/d, 7 are predicted within ± 1 days of its actual occurrence. There are 7 cases in which the creek flows are higher than 100 ML/d that the model does not predict, however in all cases (except for the July-August 1999 event) the duration of the event is less than 10 days. The model rain-fall runoff model seems to have a tendency to overestimate the duration of the events, as the crossing down of the 100 ML/d occurs approximately 10 to 20 days later than observed.

[15] Data outputs were used as part of beneficial use water balance simulations presented in Section 6.2.

Table 6-6 Calibration results: 100 ML/d threshold crossing occurrences

Observed threshold crossing up	Observed threshold crossing down	Duration (days)	Modelled threshold crossing up	Modelled threshold crossing down	Difference onset (days)	Difference duration (days)
30-Jan-97	15-Mar-97	44	30-Jan-97	2-Apr-97	0	-18
11-Feb-98	15-Feb-98	4				
22-Jun-98	26-Jun-98	3	23-Jun-98	14-Jul-98	0	-18
18-Jul-98	24-Dec-98	159	18-Jul-98	15-Dec-98	0	9
1-Jan-99	9-Jan-99	8				
7-Apr-99	2-May-99	25	6-Apr-99	10-May-99	1	-9
9-Jun-99	16-Jun-99	6				
1-Jul-99	3-Aug-99	33				
11-Aug-99	14-Aug-99	2				
27-Aug-99	31-Aug-99	4				
6-Oct-99	12-Dec-99	67	7-Nov-99	21-Dec-99	-32	23
9-Mar-00	1-Apr-00	22	10-Mar-00	21-Apr-00	0	-20
15-Nov-00	31-Dec-00	45	16-Nov-00	17-Jan-01	0	-17
24-Feb-04	26-Feb-04	2				
9-Dec-04	19-Jan-05	41	10-Dec-04	28-Jan-05	-1	-8

Notes:

(shaded cell)	Calibration has been performed for events shown as shaded cells.

Figure 6-15 presents the events where flows were recorded and hence calibration of the rainfall – runoff model was undertaken. Results are presented for the 1995 – 2005 period. Periods with zero observed and calibrated flow within the calibrated period are not shown.

From Table 6-6 and Figure 6-15 it can be concluded that:

- The rainfall-runoff model predicts the onset of flow in the Bohena Creek with an accuracy of ± 1 days in the vast majority of cases;
- The calibration is conservative in the sense that it does not provide any false positives (i.e. the model only predicts creek flow when actual stream flows were recorded);
- The average duration event used for calibration is 51 days; and
- The model overestimates the duration of the calibrated events in the creek for approximately 15 days in average.

Although the calibrated model overestimates flow event duration, this was not considered as important as predicting the onset of flow. As demonstrated in Section 6.2, the volume of most releases will be in the order of <200 ML per event which equates to a release over 16 days or less. For events that were used for calibration, the duration of these events were on average 51 days. This suggests that whilst a best fit calibration has been achieved and there is some overestimation of predicted creek flow duration (based on the available data), then, actual required releases to Bohena Creek are likely to be for a shorter duration than periods of when creek flow is experienced. This is also important because when releases are to be managed in real-time (when creek flow is predicted to occur), then it will be important to put a check in place to determine whether Bohena Creek is truly flowing (≥ 100 ML/day) or not flowing. If releases to flowing streams cease during the period of when actual stream flow is occurring, then stream drying patterns will not be impacted.

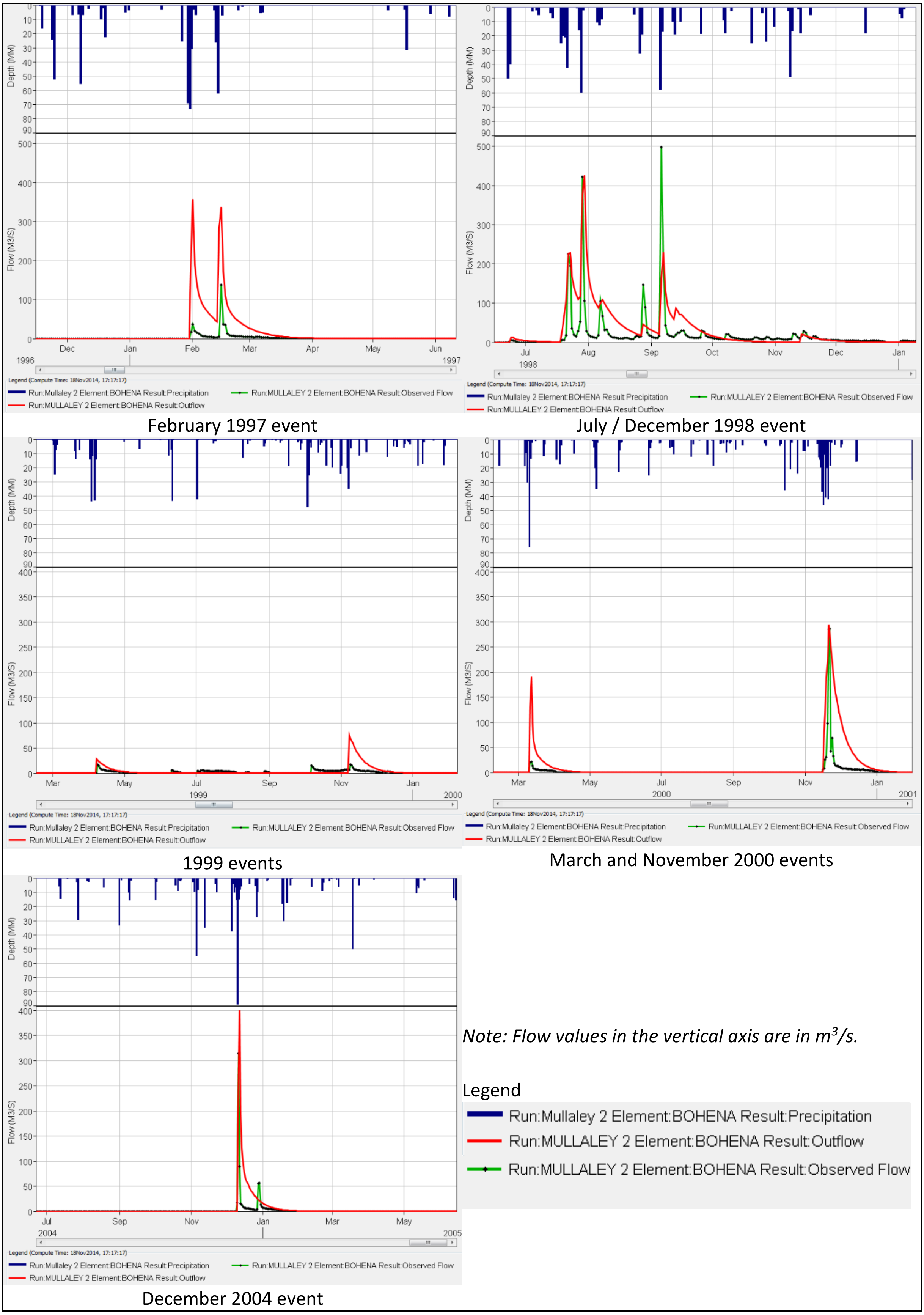


Figure 6-15: Bohena Creek Rainfall – runoff model calibration results

6.5 Surface water release hydraulic model

Narrabri Gas Project Flood Study (GHD, 2016b) presents a flood study and flood risk estimates for the Project EIS area, at a regional scale. Section 6.5 (this Report) presents detailed results undertaken from additional modelling.

An analysis of changes to water levels and velocities was undertaken as part of the MRS to quantify possible flood risk caused by the addition of the proposed treated water release to the Bohena Creek watercourse. Sensitivity analysis is also performed on the different variables involved in the calculations, to confirm appropriateness of selected model variables including tail water conditions in the flood assessment. This section thus describes:

- Hydrologic and hydraulic modelling of the receiving water course to understand flood risk; and
- Comparison of pre-development and post-development flood levels scenarios.

6.5.1 Model development

6.5.1.1 Hydrology data

A description of the flood model hydrology data used on the regional flood study undertaken as part of the EIS (GHD, 2016b) is described below.[16]

Sub-catchment boundaries were defined from the available topographic mapping information. Key sub-catchment parameters included as input to the RAFTS hydrological model developed for the study are:

- Sub-catchment area
- Slope
- Surface roughness; and
- Percentage impervious

Initially a single rainfall loss model was adopted for the proposed catchment given that the catchment is essentially fully rural and substantially pervious. The Manning's "n" was set at a constant 0.08.

The sub-catchments were broken down into areas of relatively similar sizes between 1043 and 11228 [ha] (refer GHD, 2016b for full subcatchment delineation details).

A range of value for the manning's roughness coefficient "n", rainfall losses and catchment lag parameter were investigated. The values that were adopted for the study and were found to provide the best fit to the recorded flow rate at station 419905 Bohena Creek at Newell Highway were:

- Manning's roughness coefficient "n": 0.08;
- Initial and continuous losses: 10.0 mm; 2.0 mm/hr; and
- Catchment lag link time based on a standard velocity of 4.0 m/s.

The comparison between the calibrated model and the recorded flow rate is shown in Figure 6-16. This figure shows that the timing of the modelled hydrograph is occurring 7.5 [hr] later than the recorded hydrograph for the 1998 event. Further information on calibration can be found in (GHD 2016b).

[16] It is important to note that the flooding hydrology model has a different purpose to the rainfall-runoff hydrology model. Calibration of model is to suit the particular purpose that model is used for.

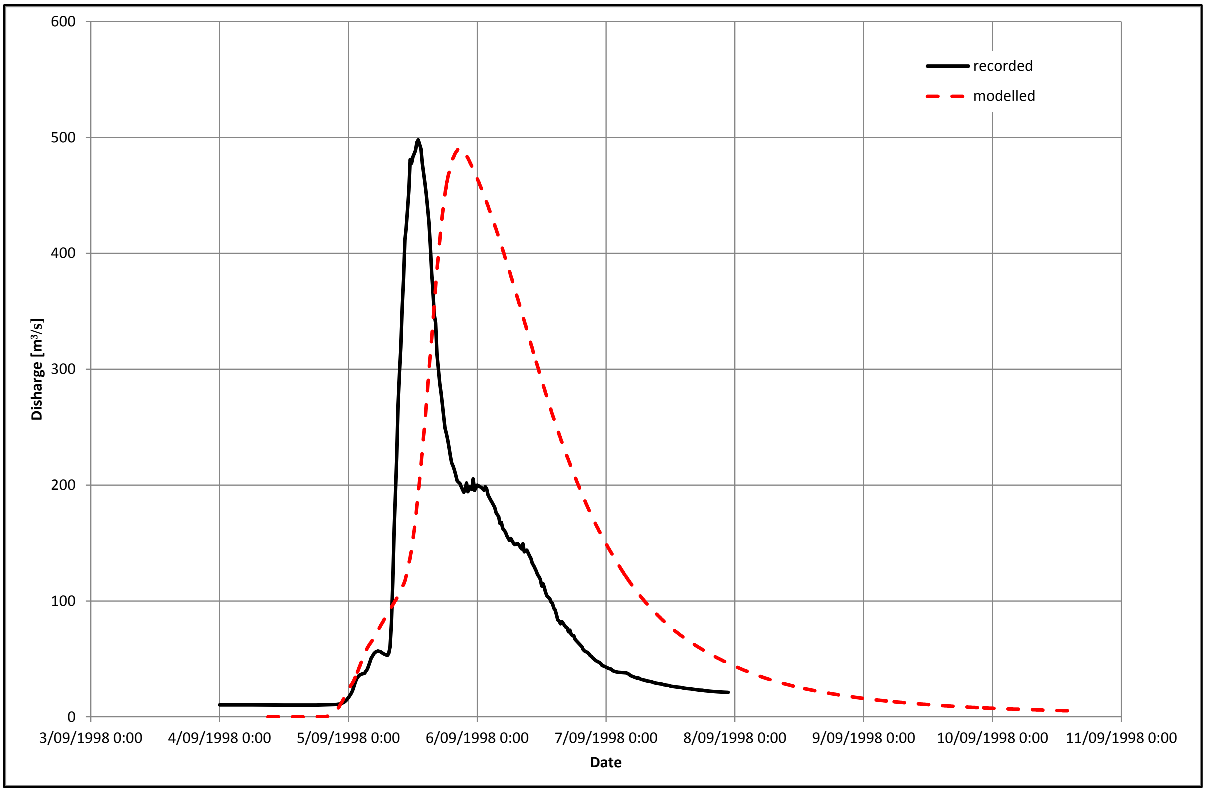


Figure 6-16: Comparison of Recorded and Modelled Flow Hydrograph at Bohena Creek
Source: GHD (2016b)

Prior to GHD (2016b) results being available, a rational method calculation was conducted. Results are presented in Table 6-7 with a comparison to results from RAFTS model (GHD, 2016b).

Table 6-7 Estimated peak flow – Bohena Creek Newell Highway Crossing

	5 year ARI (m3/s)	100 year ARI
Rational Method[17]	1,094	1,576
RAFTS (GHD, 2015b)	Not calculated	4,100

[17] Rational Method results were compared to an uncalibrated RORB model to verify peak flow estimates, The RORB model was also used to create a hydrograph shape for the design event. The parameter values used in RORB were IL=25 mm, CL=2.5 mm/hr, Kc=99.64 and m=0.80. RORB's 100 year ARI peak flow estimation for these parameter values is 1,530 m^3/s, which compare to 1,576 m^3/s predicted by the Rational Method.

6.5.1.2 Hydraulic model topography data

The yellow grid in Figure 6-17 shows the extents where detailed digital terrain model (DTM) (LiDAR) data are available. The resolution (cell size) of this data is 1 m x 1 m. Given that the data was gathered at a time when Bohena Creek was dry and the spatial resolution was high, the characteristics of the Bohena Creek watercourse when the data was flown are represented in this dataset with high accuracy.

The red rectangle in Figure 6-17 indicates availability of 10 m x 10 m DTM data. Manual checks were performed at different locations within this area and it was found that none of the watercourses were accurately represented in this dataset. Therefore, the 10 m x 10 m DTM data should be treated with caution prior to its use for modelling purposes.

Figure 6-17: Detailed (1m x 1m) LiDAR data availability

6.5.1.3 Hydraulic model selection and schematisation

The Bohena Creek hydraulic model was developed as a 1-dimensional ISIS model[18].

The modelled reach of Bohena Creek extends 14 km upstream of Newell Highway Bridge, which crosses the creek at GDA 1994 reference -30.45/149.67. The river channel and the floodplain areas are represented by a series of extended ISIS river sections (Figure 6-18). The river channel lies below floodplain level and there are no flood defences present along the riverbanks. Therefore, the method for extended cross-sections has been considered appropriate.

A river section spacing of 400 m was used, as this allowed for sufficient detail in representing channel and floodplain geometry changes and therefore changes in the conveyance along the thalweg. The channel and floodplain geometry was based on the dataset described herein.

For the initial model development a global in-back channel roughness value of n = 0.025 $m^{1/3}/s$ was used; an out-of-banks roughness value of n = 0.04 $m^{1/3}/s$ was adopted. Owing to the sandy/gravelly substrate of the main channel, the initial global roughness was considered appropriate.

Inflows into the model are schematised as two Flow-Time boundary units, located at the upstream extend of the model (node BC14000) and as a lateral inflow in the downstream reach of the model (node BCLateral1), respectively. The downstream boundary of the model is defined by a Flow-Head boundary unit (rating curve).

[18] ISIS is a full hydrodynamic simulator for modelling flows and levels in open channels and estuaries. ISIS is able to model complex looped and branched networks, and is designed to provide a comprehensive range of methods for simulating floodplain flows. It incorporates both unsteady and steady flow solvers, with options that include simple backwaters, flow routing and full unsteady simulation. The simulation engine provides a direct steady-state solver and adaptive time-stepping methods to optimise run-time and enhance model stability.

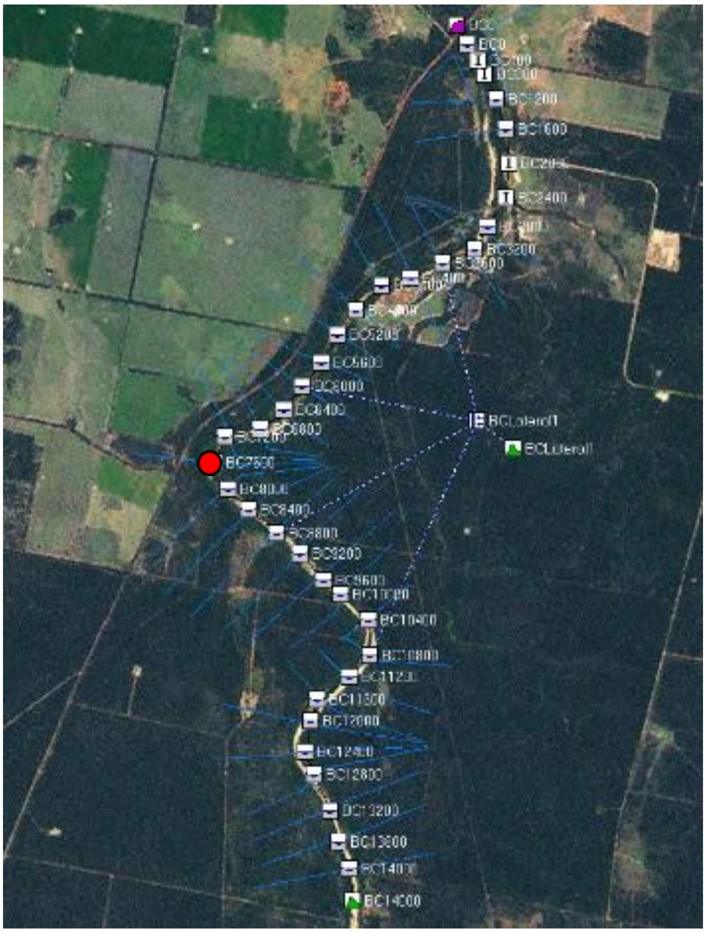


Figure 6-18: Bohena Creek hydraulic model schematic

Note: red dot indicates proposed release location for modelling purposes.

6.5.1.4 Hydraulic model design inflows

The final design hydrographs were distributed over two ISIS boundary units, with BC14000 at the upstream extent of the model contributing 95% of the total inflow and BCLateral1 contributing 5% of the total inflow

6.5.2 Model simulation

The potential impact of a proposed continuous discharge of up to 12.0 ML/d (0.139 m^3/s) to Bohena Creek was assessed. Two scenarios were run for the Bohena Creek model for different events, a base-case scenario and one impact scenario. In the base-case scenario the hydrological design flows as outlined in the previous section were modelled. For the impact scenario an additional lateral inflow to node BC7600 was modelled, representing the proposed flow discharge of 12 ML/d. Both scenarios were modelled for the ‘zero flow’, 5 year event and 100 year ARI event.

6.5.3 Model results

Table 6-8 summarises the results for these modelled scenarios. The analysis indicates that the release of 12.0 ML/day does not result in any significant differences in water level, flow or velocity over the 5 and 100 years ARI events. Differences in peak water levels are less than 1 mm, in the 5 year ARI and there is no change in the 100 year ARI event. There is no change in velocity in the 5 and 100 year ARI events.

Table 6-8 Hydraulic model results for flow, water level and velocity at proposed release point

Parameter	Change from base-case 37GLI01-W 5 yr ARI (≥ 100 ML/day) with addition of 12.0 ML/day~	Change from base-case 37GLI01-W 100 yr ARI (≥ 100 ML/day) with addition of 12.0 ML/day
Δ Flow	+0.139 m^3/s	+0.139 m^3/s
Δ Water level	+0.001 m	+0.000 m
Δ Velocity	0.0 m/s	0.0 m/s

Notes:
(ISIS node = BC7600)
~ At the time when flooding analysis was conducted for this report, a calibrated flooding hydrology model was not available. Results for the 5 yr ARI are based on rational method calculations.

6.6 Summary

Simulations of natural flows and episodic release to a flowing creek (≥ 100 ML/day) (37GLI01-W) have been performed. Simulations are based on beneficial use water balance modelling.

Beneficial use water balance modelling indicates that:

- the requirement for upstream storage when streamflow is < 100 ML/day is likely to occur between June and October in any given year. This corresponds to cessation of irrigation during periods, due to a combination of low crop water demands, low evapotranspiration rates and presence of some rain (although not enough rain as to initiate a creek flow in Bohena Creek).
- implementation of an operational driver *to undertake early release of treated water before ponds reach capacity when the creek is flowing (≥ 100 ML/day)* would:
- reduce the requirement for upstream storage in terms of likelihood of requirement creek by approximately 20%, however this also increases the volume released when streamflow in Bohena Creek is ≥ 100 ML/day; and
- increase the total number of release events, however each event is likely to involve a much smaller release volume.

Infiltration modelling indicates that:

- For scenario 37GLI01-W there is unlikely to be significant change in surface water quantity, observed as surface water ponding.
- The rainfall-runoff (hydrology) and hydraulic models indicate that:
- The onset of flow in the Bohena Creek can be predicted with an accuracy of ± 1 days in the vast majority of cases;
- Data developed as part of the hydrology model was suitable for input into the water balance model which is used to predict whether releases would be made to a flowing (≥ 100 ML/day) or whether upstream storage capacity is required; and
- The release of 12.0 ML/day does not result in any significant differences in water level, flow or velocity over the 5 and 100 years ARI events.

Each of the potential impacts described in Section 6 *Managed release simulations* is used as the basis for describing potential impacts in Section 8.

The Impact assessment adopts the managed release protocol described in Section 7.

7 Managed release protocol

This section describes the managed release protocol proposed for the project. The protocol is used to guide when releases to Bohena Creek could be undertaken. The managed release protocol has been developed based on an evaluation of the simulation results which are presented in Section 6. Section 8 (impact assessment) and section 9 (risk assessment) rely on implementation of the managed release protocol.

Table 7-1 Managed Release Protocol

Narrabri Gas Project – Proposed release protocol
Monitor flow in Bohena Creek at Newell Highway gauge Measured flow in Bohena Creek (measured at the Newell Highway gauge) is equal to or greater than 100 ML/day.
Monitor un-amended treated water in Leewood WMF Water quality is within design specification and the range approved for release.
Provide prior notice of the intended commencement of managed release Notification of intended commencement of managed release given to downstream users.
Release treated water directly from the Leewood WMF Undertake release of up to 12 ML/day of un-amended treated water to Bohena Creek with a natural flow of at least 100 ML/day.

8 Impact assessment

The impact assessment addresses the objectives identified in Section 2.2 and listed below:

- [O1] A change in the quantity, quality or availability of surface or groundwater;
- [O2] Alteration to groundwater pressure and/or water table levels;
- [O3] Alteration to the ecological nature of a wetland or watercourse;
- [O4] Alteration to drainage patterns;
- [O5] Reduced biological diversity or change species composition;
- [O6] Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected; and
- [O7] Reduce the availability of water for human consumption.

Only impacts related to the 37.5 GL episodic release scenario are presented and discussed. Information used to describe potential impacts is drawn from information contained in preceding sections of this report and information contained in the appendices (**Appendix A to Appendix E**) of this report.

The impact assessment assumes that Santos may wish to implement “early” release when Bohena Creek is flowing in excess of 100 ML/d, as this will reduce the likelihood that upstream storage will be required when beneficial uses and managed release are unavailable.

Where appropriate, impact assessments have been undertaken using the *MNES Significant Impact Guidelines - version 1.1* (Commonwealth of Australia, 2009). Whilst these guidelines are specifically appropriate for MNES, they have been used to determine impacts in Bohena Creek as they provide a standardised approach to consideration of receptor sensitivity and magnitude (intensity, timing, duration and frequency). Assessment of mitigation measures has been excluded as mitigation measures are discussed in Section 9.3.

Where the significance of an impact is described, the following definitions have been used (Commonwealth of Australia, 2009):

High Significance: Significant impact with high likelihood of impact to a rare environmental value on a regional or national scale designated as a potential water resources MNES. Impact results in irreversible or persistent high severity impact on the quantity, quality or availability of surface or ground water with little or no chance of recovery in the foreseeable future. An impact with potentially high significance will be identified within the referral to SEWPaC.

Medium Significance: The environmental value which has a medium quality and rarity on a local scale would be degraded by the impact of moderate severity with impacts persisting over time, or as a result of a short term impact that recovers immediately upon completion of the activity. The impact may extend over regional scale or across multiple aquifer units. An impact of medium significance should be referred to SEWPaC as potentially significant.

Low Significance: The environmental value, which has moderate quality and rarity on a local scale, will be affected by a low severity impact. Impacts are likely to be of short duration and to have rapid recovery when the activity is completed.

Insignificant: An insignificant impact exists to an environmental value. The impact is of low severity and restricted to the immediate area of activity. There are no medium or long term impacts and recovery is rapid.

8.1 Change in the quantity, quality or availability of surface or groundwater

8.1.1 Surface water quantity

When Bohena Creek is flowing at or greater than 100 ML/d (37GLI01-W) then change in surface water quantity, observed as surface water ponding is unlikely.

During years 0 to 4, releases may occur to a flowing creek (≥ 100 ML/day), with modelling indicating that approximately 7.2% of all treated water potentially being directed to the creek over this period[19]. Estimates have not been performed for later years of the project (for example when average production is 3.8 ML/day and 1.7 ML/day[20]), because both the frequency of release and the corresponding magnitude of potential impact will be reduced. According to the production curve (Figure 5-2) from year 5 onward, water extraction will reduce from previous years. As pond sizes and irrigation areas are designed to accommodate peak production years, it is therefore likely that the need to release will diminish or not occur at all (refer Section 6.1 which describes why managed release may be required).

In terms of change to total Bohena Creek water quantity during years 0 – 4 of the project, the median increase in total Bohena Creek flow volume is estimated to be 0.49%.[21]

As surface water quantity impacts are **insignificant** during years 0 to 4 (refer significance assessment for more information), and given that treated water directed to managed release in later years of the project will be of a reduced magnitude potentially to zero, then surface water quantity impacts in later years of the project can also be regarded as **insignificant**.

Whilst it is possible that episodic release prior to, during and following streamflow events may marginally extend the period of time the creek would take to dry, the effect is considered too small to be measureable and this potential impact would diminish as water production reduces.

8.1.2 Surface water quality

A comparison of the treated water concentrations from the Hydranautics IMS Design modelling software output and ANZECC/ARMCANZ (2000) Guideline Trigger Values is presented in Table 8-1.

The Hydranautics IMS Design modelling software output is based on the design parameters for the RO Leewood Water Management Facility (WMF). The output concentrations are mean and maximum concentrations. For several metals, treatment will reduce the concentrations to below the limit of detection (LOD), and the concentrations are therefore assumed to occur at mean levels below the LOD.

[19] An estimate of 7.2% is based on a peak irrigation demand of 12.0 ML/day (correlating with a hypothetical produced water peak of 12.6 ML/day), and a streamflow trigger of >100 ML/day is adopted (refer Section 6).

[20] Beneficial use water balance estimates have been undertaken using a hypothetical peak production rate of 12.6 ML/day. During this time up to 12.0 ML/day would be used for irrigation which is likely to be conducted over a fixed land area during this years. For later years in the project, estimates have not been performed as irrigation areas may be reduced. The extent of irrigation area reduction is dependent on crop type and a number of other factors. Refer Beneterra (2015) and GHD (2016a) for further information.

[21] This estimate is based on the rolling 4-year sum of release and streamflow during the assessment period 1995 to 2005 when streamflow data were recorded.

Several parameters do not have associated ANZECC/ARMCANZ (2000) trigger values and could not be evaluated against these guidelines (TDS, alkalinity, calcium, chloride, magnesium, sodium, potassium, fluoride, sulphate, silica, barium, cobalt, iron, and molybdenum). For these parameters, comparison to background concentrations was undertaken as presented in Table 8-1.

All other monitored parameters, where the number of data points warranted, were also calculated to provide an interim 80th percentile. The aim of this is to provide additional context to the impact assessment. In Table 8-1, only pH, turbidity, copper and mercury have treated water levels that both exceed trigger values and interim 80th percentile background levels in Bohena Creek. Electrical conductivity, TDS, alkalinity and chloride, cadmium also exceed trigger values or background levels. This is discussed further in the Ecological Risk Assessment in **Appendix A**.

Baseline concentrations were also compared to trigger values (where available) to ascertain whether the watercourse may already be experiencing chemical stresses irrespective of the quality of the proposed treated water release. Comparison of background concentrations to trigger values suggests that Bohena Creek may already be under stress from levels of turbidity, aluminium, chromium, and phosphorus from sources unrelated to the project. During commissioning stage monitoring and continued baseline monitoring, Santos will notify the EPA if anthropogenic sources of chemicals from other sources are encountered that are deemed to impact water quality.

Specific toxicity testing was conducted for Boron and Fluoride which are chemicals in treated water that (on occasion) may have elevated levels above ANZECC/ARMCANZ (2000) and other guidelines. Site-specific trigger derivation for these chemicals was undertaken (refer **Appendix B**; Acqua Della Vita (2015)). No toxicity due to Bohena Creek test water alone was observed (Acqua Della Vita, 2015). For boron, the most sensitive test result based on the EC10 result for boron was the chronic test with the macrophyte *Lemna dispersum* and the least sensitive test was the *Paratya australiensis* acute test. *Lemna dispersum* is a small floating plant that commonly occurs in inland rivers and was used to represent macrophytes in this system. *Paratya australiensis* is a small ubiquitous shrimp species that occurs in freshwater streams and rivers in Australia. For fluoride, the most sensitive acute test based on the EC10 result was that for the freshwater shrimp *Paratya australiensis* acute test and the most sensitive chronic test were the growth test for the microalgae *Selanastrum capricornutum.* These results suggest that site specific trigger values should be higher than the present guidelines. Additional details of the Direct Toxicology Assessment (DTA) testing results are presented in **Appendix B**.

On the basis of analysis undertaken taken to date, ecological risks from the physicochemical and chemical stressors and toxicants that may be present in amended treated water are considered **low** (refer Table 7-3). The following should be noted:

- Adjustment of pH will occur prior to release.
- Dissolved oxygen will be increased to ambient levels via a diffuser at the release location.
- Mixing zone analysis indicates that risks related to SAR and ion imbalance are eliminated once treated water mixes with flowing creek conditions.
- It has been assumed that release temperature will be as close to ambient temperature as possible (measured in pools in the receiving environment). If water outside these ranges is expected, then water temperatures can be successfully mitigated through effective project design (upstream residence time, pipe heat transfer losses, and other mechanical approaches to achieve a match with ambient receiving water temperatures).

Table 8-1 Trigger Values Comparison Summary

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems'*	Bohena Creek background (interim 80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is interim 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed default trigger?
pH		6.5-8.0	7.43	7.10	5.8-9.2	MAX	MAX			
EC	uS/cm	125-2,200	197	357	645		MEAN/MAX		224	No
TDS	mg/L		184 115 [d]	232 [c]	419 [c]		MEAN/MAX		170	
Turbidity	NTU	6.0-50.0	59.2	<0.5	<1.0	MEAN/MAX	MEAN/MAX	YES		
Boron	mg/L	1.8 [a]	-	0.12	0.68				0.09	No
Sodium	mg/L		18 [f]	77	140				28.7	
Magnesium	mg/L		7 [f]	0.01	0.01				5.928	No
Aluminium	mg/L	0.055	1.95	<0.001	0.01			YES		
Silica	µg/L SiO2		16220	23.3	27.3					
Potassium	mg/L		2.8 [f]	0.8	1.0					
Calcium	mg/L		6.8 [f]	0.01	0.01					
Chromium (III+VI)	mg/L	0.001	0.004	<0.001	0.001			YES		
Manganese	mg/L	1.9	0.248	<0.001	0.001					
Iron	mg/L		7.742	<0.001	0.005					
Cobalt	mg/L		0.004	<0.001	-					
Nickel	mg/L	0.011	0.006	<0.001	0.000					
Copper	mg/L	0.0014	0.001	<0.001	0.002	MEAN/MAX	MAX		0.0012	No
Zinc	mg/L	0.008	0.003	<0.001	0.003					
Arsenic	mg/L	0.013	-	<0.001	0.001					
Selenium	mg/L	0.005	-	<0.001	0.001					
Molybdenum	mg/L		-	<0.001	0.000					
Cadmium	mg/L	0.0002	-	<0.001	0.00056	MEAN/MAX			0.00010	No
Barium	mg/L		0.055 [f]	<0.001	0.027					
Mercury	mg/L	0.00006	-	0.0000067	0.0002	MEAN/MAX	MEAN/MAX		0.000065	Yes [g]
Lead	mg/L	0.0034	-	<0.001	0.000					
Uranium	µg/L		-	-	0.003					
Alkalinity (Carbonate as CaCO3)	mg/L		-	139	-		MEAN			
Alkalinity (total) as CaCO3	mg/L		52	139	193		MEAN/MAX			
Ammonia as N	µg/L	900	20	15	50					
Nitrate (as N)	mg/L		0.03	-	-					
Nitrogen (Total Oxidised)	mg/L	0.04	0.04	-	-					
Nitrogen (Total)	µg/L	500	800	-	-			YES		
Sulphate	mg/L		-	0.003	0.532					
Chloride	mg/L		29	15	83		MAX		33.6	
Fluoride	mg/L	0.46 [a]	-	0.08	0.16				0.061	No
Phosphorus	mg/L	0.05	0.094	0.010	<0.01			YES		

Table footnote:

1. Blank cells and cells with '-' indicate value is not available or could not be calculated because it was not detected. 2.80th percentile calculations use 0.5 x LOD; 3; Max = Maximum

[a] Site-specific Boron and Fluoride Protective Concentrations developed in the DTA were used in place of ANZECC/ARMCANZ (2000) Guideline Trigger Values; [b] With 10:1 background dilution (surface water: treated water). Calculation uses mean background concentrations.

[c] Calculated; [d] Measured at @180°C; [e] Based on post chlorination treated water quality projections; [f] Based on filtered measurements;

[g] Projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately 4 times actual recorded produced water concentrations). Actual values are likely to be less.

8.1.3 Groundwater quantity and availability

As described in Section 8.1.1, water released at the surface has the potential to infiltrate into the Bohena Creek alluvium, thereby increasing groundwater quantity.

For the simulations considered in this assessment, the water released onto the bed of Bohena Creek via the diffuser can be considered to have three possible fates within the period of the simulation:

- it can be added to groundwater storage in the subsurface;
- it can be added to surface water storage above ground; or
- it can be lost to the atmosphere by evapotranspiration.

By implementing episodic release, with releases scheduled only when Bohena Creek is flowing (≥ 100 ML/day) (and the alluvium is already saturated), then managed releases are most likely to add only to surface water stream flows (and not be transmitted by groundwater).

8.1.4 Groundwater quality

Biologically important solutes such as phosphate and nitrate are naturally at very low concentrations in the Bohena Creek system (**Appendix A**). These nutrients can be a limiting factor on the biological productivity of the system if their concentrations are too low to meet biological demands. With the exception of the natural waterholes and the anthropogenic waterholes, these nutrients are limited to being present in groundwater of the Bohena Creek alluvial aquifer over most of the year and at times at a depth that likely limits their uptake by aquatic macrophytes and riparian vegetation.

The dynamics of solutes in the system are driven by exchanges between solutes in the water column (during flow periods) and the creek substrate and between solutes in the groundwater and the aquifer matrix. These exchanges include abiotic processes, such as adsorption, desorption, precipitation, and dissolution. There are also biological exchanges involved in the dynamics, including microbial uptake and plant uptake. Adsorption (especially for phosphate) and microbial and plant uptake remove these solutes from the water, but nutrients immobilised through adsorption can be remobilised when water column conditions change. In the case of Bohena Creek, nutrients are likely temporarily immobilised by adsorption to particles in the creek substrate when the creek bed is dry and then remobilised during times of flow.

8.1.5 Significance of potential impacts to water quantity

Table 8-2 presents an assessment of significance of potential impacts to water quantity.

Overall, each of the creek trigger scenarios modelled will result in potential impacts having insignificance to low significance.

Episodic release is of short duration and is restricted to immediately downstream of the release location.

Table 8-2: Assessment of significance of potential impacts to water quantity (without mitigation)

Definition of the proposed activities;		**Episodic release to Bohena Creek with**		
		No creek trigger	**50 ML/day trigger**	**100 ML/day trigger**
Identification of **receptors** and determination of their **sensitivity** to the proposed activities		**Sensitivity = Low~** *The intermittent nature of Bohena Creek supports moderately to very disturbed ecosystems. Groundwater has good recharge, and the attributes of the creek systems are considered to be important on a local scale but abundant regionally. The intermittent nature of the creeks means that they are not used for water supply.*		
Assessment of the **magnitude** of the impacts of the proposed activities following adoption of mitigation activities	*Scale*	*Local*	*Local*	*Local*
	*Intensity and impact^*	*Mostly release of < 200 ML per event*	*Mostly release of <100 ML per event*	*Mostly release of <100 ML per event*
	*Timing, duration and frequency^*	*Possible releases only in winter and spring months*	*Possible releases year round*	*Possible releases year round*
	Magnitude	Negligible^	Negligible^	Negligible^
Determination of the **significance** of the potential impacts of the proposed activities.		**Insignificant**	**Insignificant**	**Insignificant**
Mitigation required		No	No	No

Table footnote:

~The Santos Water Resource Impact Assessment (WRIA) undertaken with the objective assessing potential risks associated with pilot activities classified Bohena Creek sensitivity as Medium (Santos Ltd., 2013). Further work conducted since the 2013 WRIA indicates that Bohena Creek is not on the National Heritage Register (required for medium significance). Additionally, the entire creek experiences good recharge into the Bohena Creek Alluvium. Bohena Creek is therefore considered to have a low sensitivity.

^ flowing creek (≥ 100 ML/day) releases considered to have negligible impact as release volumes as a fraction of flowing stream volumes are insignificant, thus will have negligible on influence significance.

8.1.6 Significance of potential impacts to water quality

Table 8-3 presents an assessment of significance of potential impacts to water quality using information presented in Section 7 and Section 8 of this report.

Mitigation measures outlining how potential impacts can be avoided and managed are described in Section 9 Risk Assessment.

Table 8-3: Assessment of significance of potential impacts to water quantity (without mitigation)

Definition of the proposed activities;		Episodic release to Bohena Creek with		
		No creek trigger	**50 ML/day trigger**	**100 ML/day trigger**
Identification of **receptors** and determination of their **sensitivity** to the proposed activities		**Sensitivity = Low~** *The intermittent nature of Bohena Creek supports moderately to very disturbed ecosystems. Groundwater has good recharge, and the attributes of the creek systems are considered to be important on a local scale but abundant regionally. The intermittent nature of the creeks means that they are not used for water supply.*		
Assessment of the **magnitude** of the impacts of the proposed activities following adoption of mitigation activities	*Scale*	*Local*		
	Intensity and impact	*Water quality impacts are possible*		
	*Timing, duration and frequency^*	*Episodic releases over several days at a time.*		
	Magnitude	Minor		
Determination of the **significance** of the potential impacts of the proposed activities.		**Low**		
Mitigation required		Yes (refer mitigation measures identified in Section 9 Risk Assessment)		

Table footnote:

~ Refer notes for Table 8 2.

8.2 Alteration to groundwater pressure and/or water table levels

There are no impacts predicted upon the Pilliga Sandstone over the project duration for any of the modelled managed release scenarios. The hydrogeological properties of the Orallo Formation suggest the unit is an effective aquitard that limits the potential for vertical flow between the alluvium and Pilliga Sandstone. Whilst there may be some small water level change (less than 0.1m when natural creek flow is 100 ML/day), the potential impact is considered to be **insignificant**.

8.3 Alteration to the ecological nature of a wetland or watercourse

The two high priority GDEs identified by DPI Water, Eather and Hardy's springs, are not considered to have a dependency on the shallow Bohena Creek alluvium and are considerable distance from the managed release site. As feedwater to these springs is not connected with the Bohena Creek alluvium, it is considered that the potential impacts on these GDEs from the managed release is **insignificant**.

8.4 Alteration to drainage patterns

The potential impacts of the managed release scheme outfall on the geomorphological processes and morphological response on the Bohena Creek have been considered and are outlined in Table 8-4, along with possible mitigation measures, where appropriate. A full description of geomorphology of Bohena Creek and possible creek response to manage release can be found in **Appendix D.**

Table 8-4: Potential impacts on geomorphology (without mitigation)

Bohena Creek	
Impact (all scenarios)	Likelihood and scale
Direct loss of bank side and habitat through the installation of the outfall	Unlikely, small-scale and localised
Development of a scour pool in the channel bed at the outfall location	Very likely, small-scale and localised
Increased sediment entrainment and transport resulting in increased sediment loads entering the Namoi River	Likely even though predicted flows will be shallow during periods when no natural creek flow is experienced.

Hydraulic modelling predicts that with the proposed release of 12.0 ML/day which represents a likely upper estimate of the managed release rate, then, there would be negligible impact on flood levels, flood extent and flood risk within Bohena Creek when the creek is flowing (assuming the release structure does not cause afflux).

Overall significance of potential impacts to drainage patterns is **insignificant**.

8.5 Reduced biological diversity or change species composition

Biological diversity is expected to remain relatively stable for episodic release, however there may be some changes in the further movement of species as documented in Table 8-5. The impact of releasing water to Bohena Creek on aquatic ecology will depend on the amount of treated water released, frequency and duration of release. For the episodic release scenario, the main biological impact that is possible, but unlikely is:

- An increase in *Phragmites australis* during wet periods, if temporary pools are created for long periods of time. Once prolonged dry conditions resume (between episodic releases), then *Phragmites australis* would recede.

As treated water will be mixed with stream water, risks related to an ion imbalance for some aquatic organisms are considered to be low.

Overall the significance of potential impact to the Bohena Creek aquatic ecosystem is **low**. Mitigation measures are proposed to reduce the significance of impacts and are detailed in Section 9.3.

Table 8-5 Significance of Potential Impacts to Aquatic Ecology

Sensitivity of the receptor	Low			
Magnitude of the impact	High adverse	Moderate adverse	Minor adverse	Negligible
	Predicted impact of managed release scenarios			
	Episodic release to flowing creek (≥ 100 ML/day)			
Potential risk/issue	Hydrological changes		Ecological response	
Higher water level in alluvial aquifer	Water level in the alluvial aquifer should already be close to saturation when the release period commences so initially there will be no additional impact. Releasing water on top of natural flow events may mean that water levels are marginally higher as flow recedes, however this impact is unlikely to be detectable.		Water will already be flowing in Bohena Creek and the aquifer below it will already saturated. Therefore there is no additional ecological impact.	
More frequent hydrological links between permanent pools	Permanent pools will already be connected during the flow period that initiates release.		The addition of treated water may marginally increase the depth of water in Bohena Creek, allowing the movement of larger aquatic species, however this impact is unlikely to be detectable.	
More temporary and permanent waterholes	The number of temporary and permanent waterholes is unlikely to change if episodic releases occur only when there is surface flow.		As no additional waterholes are likely to be created under this scenario, the ecological response will be the same as naturally occurs when waterholes are connected.	
Larger bodies of permanent water	Water released during natural flow periods will flow downstream. No impact is expected.		The release of up to 12 ML/d is unlikely to change the extent of flow Bohena Creek when it is already flowing at above 100 ML/d. The ecological response to this will be negligible.	
More frequent spates	The creek will already be flowing when water is released. Additional water from Leewood may increase the intensity of spates in the stream if rainfall occurs during discharge.		The ecological community will already be prepared for spates when the release commences, having been stimulated by the commencement of natural flow.	

Sensitivity of the receptor	Low			
Magnitude of the impact	High adverse	Moderate adverse	Minor adverse	Negligible
Potential risk/issue	Predicted impact of managed release scenarios Episodic release to flowing creek (≥ 100 ML/day) Hydrological changes		Ecological response	
Increased connectivity to Namoi River	When there is a flow of at least 100 ML/d in Bohena Creek at Newell Highway, it is assumed that there is enough water to reach the Namoi. In this case the addition of the Leewood discharge may briefly prolong the period of connectivity.		Fauna living in the Namoi will be able to move upstream from Mollee Weir into Bohena Creek and take refuge in isolate pools when water levels drop again. Under this scenario, connection is already likely to be established by the time discharge begins.	
Reduced frequency and duration of drying periods	Releasing only during natural flow periods, should allow for the natural drying cycle to be followed.		Ecological processes in Bohena Creek will retain their ephemeral stream community.	
Overall significance of the potential impacts of the proposed activities.	**Insignificant**		**Insignificant**	

8.6 Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals

The release of treated water is not expected to result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected.

Possible surface and subsurface exposure pathways were investigated as part of the assessment. Several environmental transport pathways and transformations may occur before ecological receptors are exposed to constituents in the discharge. Chemical fate processes, such as dissociation, degradation, complexation, and biotransformation may occur at all stages and in all media. The receptors potentially exposed to the managed release include vegetation, invertebrates, amphibians, reptiles, fish, birds, and mammals, in both the aquatic and riparian/terrestrial ecosystems. Potential exposure pathways are represented Figure 8-1.

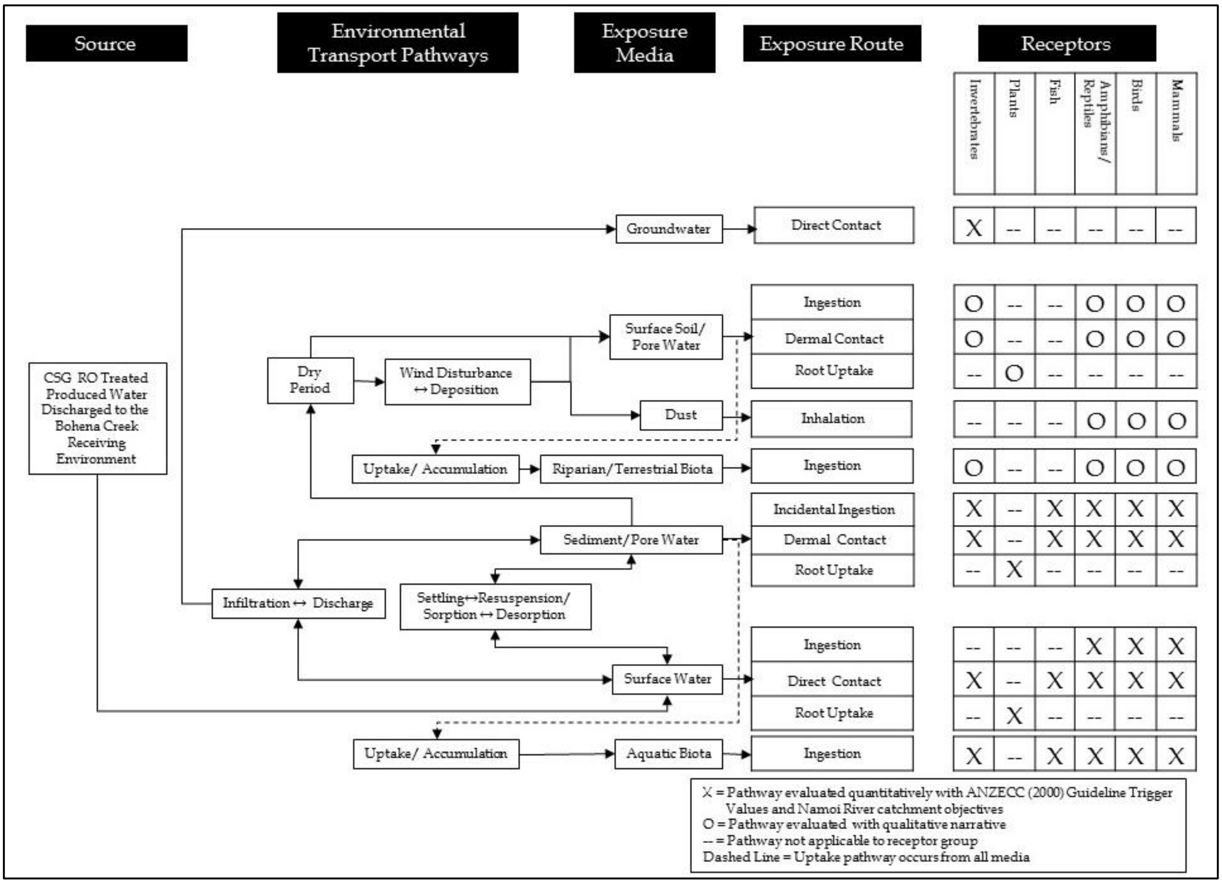


Figure 8-1: Ecological Exposure Concept Site Model

After periods of heavy rain in Bohena Creek, managed release water constituents may be transported in surface water flow to downstream locations. During periods when the creek is flowing (≥ 100 ML/day), a dilution typically in the order of a minimum of 1:9.8 is expected occur which will further reduce the concentration of any constituent in the released water.

Exposure routes include ingestion, direct contact, inhalation, and root uptake Figure 8-1. Of the pathways mentioned, surface water and sediment direct contact to aquatic plants, invertebrates, amphibian early life stages, and fish are considered to be the most significant.

As recommended by ANZECC/ARMCANZ (2000), Guideline Trigger Values with higher levels of protection will be used to evaluate bioaccumulative chemicals.

Release of treated water could thus increase levels of certain constituents. Assuming release water is amended appropriately, supra-threshold concentrations are unlikely and risks are considered low. Under the episodic release scenario with flowing conditions, dilution with receiving water will further eliminate any potential risks and this further investigated in **Appendix E**. Additional details are described below:

- Among the constituents evaluated in Table 8-1, pH, turbidity, copper and mercury have treated water levels that both exceed trigger values and the interim 80th percentile background levels observed in Bohena Creek. Electrical conductivity, TDS, alkalinity and chloride, cadmium also exceed trigger values or background levels.
- For pH, only the treated water maximum values exceed trigger values. Considering, that the treated water maximum is expected to infrequently occur (and is dependent on maximum levels in produced water inflows to the Leewood WMF in combination with low treatment

performance) and treated water pH can be adjusted prior final release, risks are considered low as levels will predominantly occur at levels below trigger values.

- Although mean and maximum treated water turbidity are outside of the trigger value preferred range and background levels. While high turbidity releases from treated water are expected to infrequently occur, the discharge of large volumes of very clear water to turbid waterways can increase light penetration and promote excessive macrophyte or algal growth (Commonwealth of Australia, 2014). Dilution and mixing under flowing conditions is expected to eliminate this concern.
- Cadmium and mercury had treated water mean LODs that exceeded trigger values.
- For cadmium, the default trigger value (0.2 µg/L) is only slightly exceeded by maximum levels (1 µg/L), which is expected to occur infrequently for the reasons noted above. Additionally, for cadmium, dilution and mixing under flowing conditions demonstrates that this concern can be eliminated.
- For mercury, projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately four times actual recorded produced water concentrations). Mean and maximum treated water values are likely therefore likely to be less than those calculated. Additionally, it is noted that dilution and mixing under flowing conditions demonstrates that this concern can be eliminated for mean values. Furthermore, maximum values are expected to infrequently occur. Mercury will predominantly occur at levels below the LOD, and, even at low detected levels is not expected to pose a bioaccumulation risk to wildlife (the primary reason for selecting a higher level of protection) since methylation rates will likely be very low because of low levels of dissolved organic carbon and neutral pH in the treated water.
- Since treated water will be released under flowing conditions with dilution levels at a mixing ratio of a minimum of approximately 10:1, the negative effects of ion imbalance are unlikely to occur, and risks are considered low.

Overall the significance of potential impact related to persistent organic chemicals, heavy metals or other potentially harmful chemicals is **low**. Mitigation measures are proposed to reduce the significance of this impact as detailed in Section 9.3.

8.7 Reduce the availability of water for human consumption

It is understood that there are bores within the Bohena Creek Alluvium that may remain in use for water supply. Inspection of the DPI Water records of registered water bores indicates that the use of these bores is likely to be limited to stock watering purposes only. There are no licensed surface water offtakes directly extracting water from Bohena Creek, although the existence and occurrence of unlicensed surface water extraction cannot be excluded.

The proposed managed release scheme does not extract water, and therefore would not reduce the quantity of water available to existing users. The managed release protocol would require advance notification of the commencement of managed release discharge to the creek.

Similarly, the episodic release scheme is unlikely to impact groundwater or surface water quality, thus not reducing the availability of water for human consumption.

As releases will only occur during periods when Bohena Creek is flowing (≥ 100 ML/day), a very small diluted volume of treated water is predicted to reach the Namoi River where it would be further diluted. In general, treated water quality is expected to match or exceed that currently recorded in Bohena Creek.

Thus the availability of water for human consumption will not be reduced. In conjunction with the flow rate constraint incorporated within the protocol for managed release (Section 7),

Overall the significance of potential impact related to a reduction of the availability of water for human consumption is **insignificant**.

8.8 Summary of potential impacts and significance level

Table 8-6 presents a summary of potential impacts and significance level. Definitions of significance are presented at the beginning of Section 7. Where items with low significance have been identified, these have been further highlighted as part of the risk assessment identification process (Section 9.2). Items that are marked as potential low significance are manageable. Mitigation measures to avoid and manage risks are described and proposed in Section 9.2 and Section 9.3.

Table 8-6: Summary of potential impacts and significance level

Objective	Potential impact		Significance
[O1]	A change in the quantity, quality or availability of surface or groundwater	Water quantity	Insignificant
		Water quality	Low
[O2]	Alteration to groundwater pressure and/or water table levels		Insignificant
[O3]	Alteration to the ecological nature of a wetland or watercourse		Insignificant
[O4]	Alteration to drainage patterns		Insignificant
[O5]	Reduced biological diversity or change species composition		Insignificant
[O6]	Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected		Low
[O7]	Reduce the availability of water for human consumption.		Insignificant

9 Risk Assessment

9.1 Santos risk assessment process

A risk is defined by the Australian/New Zealand Standard for Risk Management (AS/NZS ISO 31000:2009) as *the chance of something happening that will have an impact on objectives*. It is measured in terms of a combination of the consequences of an event and the likelihood of an event occurring.

The potential issues risks and their impacts to surface water and environmental values associated with the project were identified with Santos and technical professionals. The potential risks were then evaluated and assigned a risk rating, according to the likelihood of the risk occurring and the anticipated consequences.

The Santos risk matrix used to evaluate the likelihood and consequences of hazards occurring is presented in Section 9.1. This includes a description of the categories of likelihood and consequences considered and a description of the relative severity of consequences for each category.

Table 9-1 Risk Assessment – Santos Risk Assessment Matrix

Consequence Type			CONSEQUENCE				
			Negligible	Minor	Moderate	Major	Critical
Health and Safety			Minor injury - first aid treatment	Injury requiring medical treatment with no lost time	Injury requiring medical treatment, time off work and rehabilitation	Permanent disabling injury, long term off work	Fatality
Natural Environment			Negligible impact on fauna/flora, habitat, aquatic ecosystem or water resources. Incident reporting according to routine protocols	Impact on fauna, flora, habitat but no negative effects on ecosystem. Requires immediate regulator notification	Short term impact on sensitive environmental features (e.g. gibber plain). Triggers regulatory investigation.	Long term impact of regional significance on sensitive environmental features. Likely to result in regulatory intervention/action	Destruction of sensitive environmental features. Severe impact on ecosystem. Regulatory & high level Government intervention/action.
Reputation			Minimal impact to reputation	Some impact on business reputation	Moderate to small impact on business reputation. Regional media exposure.	Significant impact on business reputation and/or national media exposure.	Critical impact on business reputation /or international media exposure
Financial			Financial loss from $0 to $500,000	Financial loss from $500,000 to $5 Million.	Financial loss from $5 Million to $50 Million	Financial loss from $50 Million to $100 Million	Financial loss in excess of $100 Million
			I	II	III	IV	V
LIKELIHOOD	Almost Certain Is expected to occur in most circumstances	A	2	3	4	5	5
	Likely Could occur in most circumstances	B	1	3	3	4	5
	Possible Has occurred here or elsewhere	C	1	2	3	3	4
	Unlikely Hasn't occurred yet but could	D	1	1	2	2	3
	Remote May occur in exceptional circumstances	E	1	1	1	1	2

Source: Santos

9.2 Risk identification

The identification of the potential risks issues associated with the proposed managed release scheme was undertaken in consultation with Santos and is presented as Table 9-2.

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Table 9-2: Risk Assessment – Managed Release to Bohena Creek

Project Phase	Risk Ref No.	Risk/Issue	Cause	Potential Impact(s)	Without Mitigation Measures			Possible Mitigation Measures	With Mitigation Measures			
					Consequence	Likelihood	Initial Risk Rating		Consequence	Likelihood	Residual Risk Rating	Additional Mitigation Measures
Construction/Operation	MR1	Stream erosion	High outlet velocity	Loss of bank and habitat through the installation of the release structure. Development of a scour pool in the channel bed at the release structure location Increased sediment entrainment and greater suspended load reaching entering the Namoi River.	III Moderate	B Likely	3	Keep the release structure low in the channel Install suitable bank and bed protection Consider stilling pool at site to dissipate energy Consider alignment of the channel during design to minimise scour to channel bed and bank. Downstream monitoring at the Namoi.	II Minor	D Unlikely	1	Ongoing monitoring If evidence of stream erosion is attributable to the managed release during operation, them, consider release directly to creek bed through spearhead bores. Release at multiple locations. Provision of habitat offset where required.
	MR2	Short term impact on fauna and flora during construction.	Construction activities.	Disturbance of soils (erosion, sedimentation) during installation of buried pipeline Removal of vegetation/habitat	II Minor	B Likely	3	Construction sedimentation and erosion control plan Route selection to minimise disturbance/removal of vegetation/habitat Potential trenchless installation to minimise surface disturbance	I Negligible	B Likely	1	Environmental investigations to determine presence of sensitive species/ecological communities to assist in route selection.
Operation	MR3	Scour or burial of release structure	Lateral movement of stream	Temporary shutdown for maintenance/replacement of outfall infrastructure	II Minor	C Possible	2	Regular monitoring Install suitable bank and bed protection Keep the release structure low in the channel and discharge at low flow level Keep the release structure flush with the channel banks Consider a stilling pool at the site to dissipate energy locate release structure on straighter section of channel Design so that the movement of sand bars within the channel does not impact on outfall performance Consider a trash screen and regular clearance to reduce debris entering and blocking the outfall	II Minor	D Unlikely	1	None
	MR4	Sedimentation	Changes to flow regime *(e.g. when water levels decline in low velocity pools following high flow events)*	Temporary shutdown for maintenance/replacement of outfall infrastructure Changes to riparian vegetation	III Moderate	C Possible	2	Monitor downstream of release Release in Bohena Creek via diffuser	II Minor	D Unlikely	1	Ongoing monitoring

Project Phase	Risk Ref No.	Risk/Issue	Cause	Potential Impact(s)	Without Mitigation Measures			Possible Mitigation Measures	With Mitigation Measures			
					Consequence	Likelihood	Initial Risk Rating		Consequence	Likelihood	Residual Risk Rating	Additional Mitigation Measures
	MR5	Flooding	Additional water added into stream, greater than natural flows	Disruption to downstream crossings. Change to riparian vegetation	I Negligible	E Remote	1	Not required	I Negligible	E Remote	1	None
Operations	MR7	More frequent hydrological links between permanent pools	Additional volume of water into hydrological system.	Change to stream wetting/drying patterns Movement of aquatic pest flora and fauna between pools.	II Minor	D Unlikely	1	Vehicle inspections should be conducted for all vehicles accessing the site so that no new weeds are introduced.	II Minor	D Unlikely	1	Weeds and Plague Minnow are already prevalent in the area. Even if temporary drying does eliminate Plague Minnow from the discharge pool, they are probably present in many farm and fire-fighting dams in the area and can colonise Bohena Creek from the Namoi River during periods of flow.
	MR8	More temporary and permanent waterholes	Additional volume of water into hydrological system.	Change to stream wetting/drying patterns Isolation and reconnection of populations Increases in *Phragmites* density along the creek bed.	II Minor	D Unlikely	1	Release in Bohena Creek via diffuser Simulate natural drying of creek bed by “turning off” managed release to simulate a temporary drying of the creek bed (episodic release).	II Minor	E Remote	1	None
	MR9	Larger bodies of permanent water	Additional volume of water into hydrological system.	Expansion/contraction of aquatic fauna populations Persistence of plant species tolerant to permanent water.	II Minor	D Unlikely	1	Release in Bohena Creek via diffuser Episodic release	II Minor	E Remote	1	None
	MR10	More frequent flow events in intermittent environment	Additional volume of water into hydrological system.	Scouring of in-stream vegetation and changes to bed topography that result in deeper sections or less variation in relief.	II Minor	D Unlikely	1	Episodic release	II Minor	E Remote	1	None
	MR11	Increased connectivity to Namoi River	Additional volume of water into hydrological system.	Improve ability for biota to move between Bohena Creek and the Namoi	II Minor	D Unlikely	1	Episodic release to ensure creek will remain intermittent and connectivity is unlikely to change under normal dry conditions. Period of connectivity may be briefly prolonged.	II Minor	E Remote	1	None
	MR12	Reduced frequency and duration of drying periods	Additional volume of water into hydrological system.	Bacterial activity will alternate between aerobic and anaerobic depending on presence of water. Increase in *Phragmites* densities	II Minor	D Unlikely	1	Episodic release	II Minor	E Remote	1	None
	MR13	Treated water for release has higher than background temperature	‘Leewood’ WMF treatment process	More stable water temperature may favour exotic species such as Plague Minnow. Warmer winter temperatures can	II Minor	C Possible	2	Heat transfer from gathering lines to ‘Leewood WMF’. Heat transfer from ‘Leewood WMF’ ponds.	II Minor	D Unlikely	1	May still be difficult to cool to the same temperature as the receiving water if discharge water is too warm, but discharge through diffuser will quickly approach ambient temperatures.

Project Phase	Risk Ref No.	Risk/Issue	Cause	Potential Impact(s)	Without Mitigation Measures			Possible Mitigation Measures	With Mitigation Measures			
					Consequence	Likelihood	Initial Risk Rating		Consequence	Likelihood	Residual Risk Rating	Additional Mitigation Measures
				increase breeding success in this exotic species.				Heat transfer through pipeline from WMF to release point. Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.				
	MR14	Treated water for release has lower than background dissolved oxygen	'Leewood' WMF treatment process	Biota may be particularly vulnerable to anoxic conditions when the creek is drying.	II Minor	C Possible	2	Include aeration or similar treatment/end of pipe process. Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.	II Minor	D Unlikely	1	Potential oxygenation at discharge point through spraying treated water
	MR15	Treated water for release has higher than background EC levels	'Leewood' WMF treatment process	Increased salt concentrations can make the water unsuitable to some aquatic and riparian plant and animals. At the concentrations expected in release water from Leewood, this is unlikely to be a major problem for the aquatic communities of Bohena Creek as many species will already be adapted to fluctuating EC.	II Minor	C Possible	2	Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Limit EC to within guideline limits and guidance of ERA. Undertake real-time monitoring of treated water EC. Undertake real-time monitoring of Bohena Creek EC. Report any anomalies to operations staff.	II Minor	E Remote	1	None
	MR16	Treated water for release has higher than background boron and/or fluoride	'Leewood' WMF treatment process	Can adversely affect aquatic life Negative perception	III Moderate	B Likely	3	Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.	II Minor	D Unlikely	1	Once operational, undertake toxicity assessment using physical treated water samples to confirm site-specific boron or fluoride trigger values. Consider treatment process that targets boron/fluoride removal.
	MR17	Treated water for release has higher than background Mercury	'Leewood' WMF treatment process	Bioaccumulation risk to wildlife	III Moderate	C Possible	3	Maintain treated water to have close to neutral pH with low dissolved organic carbon. This will ensure methylation rates will likely be very low Report any anomalies to operations staff.	III Moderate	D Unlikely	2	Consider treatment process that ensures or targets adequate mercury removal.
	MR18	Treated water for release has higher than background Ammonia	'Leewood' WMF treatment process	Can adversely affect aquatic life, particularly fish.	III Moderate	D Unlikely	2	Breakpoint chlorination and maintenance of a free chlorine residual in the WMF will ensure removal of ammonia to below limits of detection Ensure adequate temperature equilibration prior to release. Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.	III Moderate	E Remote	1	None

Project Phase	Risk Ref No.	Risk/Issue	Cause	Potential Impact(s)	Without Mitigation Measures			Possible Mitigation Measures	With Mitigation Measures			
					Consequence	Likelihood	Initial Risk Rating		Consequence	Likelihood	Residual Risk Rating	Additional Mitigation Measures
	MR19	Treated water for release has higher than background Copper	'Leewood' WMF treatment process	Can adversely affect aquatic life including fish and aquatic organism	III Moderate	C Possible	3	Monitor and check calcium hardness and associated carbonate alkalinity as copper toxicity is largely function of these factors. Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.	III Moderate	E Remote	1	None
	MR20	Treated water for release has higher than background or other guideline trigger values	'Leewood' WMF treatment process	Can adversely affect aquatic life	III Moderate	C Possible	3	Monitor and check against site-specific guidelines. If higher than background or other guideline values persist in Leewood WMF treated water or are expected due to feed water quality spikes, consider alternative beneficial uses or alternative plant configuration (e.g. temporary treated water recirculation to produced water pond to achieve suitable water quality for release). Proceed to toxicity assessment using actual treated water samples (once Leewood WMF plant is online and physical treated water sample available) to establish further information on how ecosystems would respond to release treated water. Revise trigger values. Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Report any anomalies to operations staff.	III Moderate	E Remote	1	None
	MR21	SAR and ionic balance inappropriate for release to Bohena Creek	'Leewood' WMF treatment process	Can adversely affect flora, fauna, including aquatic life e.g. fish and aquatic organisms.	III Moderate	C Possible	3	Release only to a flowing stream to encourage mixing and dilution (episodic release). Release in Bohena Creek via diffuser Do not develop stream trigger values for TDS, alkalinity, calcium, sodium, sulphate and magnesium as adjustments to these may be required to achieve SAR appropriate for release to creek system. Check SAR and ionic balance prior to release and target a SAR similar to Bohena Creek if long duration releases are required.	III Moderate	E Remote	1	None

9.3 Mitigation measures

All risks are considered manageable and can be reduced by incorporating the following mitigation measures:

9.3.1 Design

- Adhere to the protocol of releasing treated water only to a flowing stream when the flow at the Newell Highway gauge indicates flows ≥ 100 ML/day.
- Treated water not in compliance with thresholds for specified continuous monitoring criteria within the WMF will be recirculated within the WMF to achieve suitable water quality for release.
- Design the outlet system to include a diffuser to ensure adequate mixing is effectively and rapidly achieved within moving water column.
- Discharge to the creek through a diffuser to achieve suitable mixing of treated water with flood waters.
- Ensure that the water management system has sufficient hydraulic residence time to allow for temperature equilibration with the Bohena Creek, or to dissipate during pipeline transfer.
- Install data loggers, at the release point, upstream and downstream of the managed release point (in-stream) to monitor electrical conductivity and temperature.
- Raise DO levels to be within acceptable levels through provision of an aeration system.
- Install suitable bed and bank protection around the managed release structure (where required), with consideration given to:
  - installation of the structure in a straight section of channel;
  - installation of the structure low in the channel;
  - installation of a stilling pool to dissipate energy; and
  - locating the outlet structure such that migration of sand bars within the channel does not impact on outfall performance.

9.3.2 Monitoring

- Undertake regular inspections of creek condition to monitor for morphological change (erosion and sedimentation) upstream and downstream of the outlet structure. Check if low flow channels are static or have moved.
- Undertake regular condition inspections of the managed release outlet structure to ensure that it is operable and clear of debris.
- When the Leewood WMF becomes operational, downstream and control sites should be routinely monitored in autumn and spring to determine whether release is altering aquatic ecosystems.
- Improve Bohena Creek streamflow data quality (data quality and updated rating curve) at the Bohena Creek Newell Highway gauge, or alternatively install a new gauging station between the release location and Newell Highway.
- Continue ecological and water quality sampling (at release location, upstream and downstream of the mixing zone, and at Newell Highway).

9.3.3 Management

- All results should be reported to operations staff.
- Develop environmental triggers or toxicity basis as part of threshold action response plans and/or similar documents.

- Re-appraise the toxicity of treated water for release to the creek and the specified continuous monitoring criteria and their respective thresholds on an annual basis for five years post-commissioning to confirm both that the treated water, including any treatment chemicals and residual disinfectants, remains suitable for release and the thresholds for the continuous monitoring are suitably representative of the treated water.
- Apply adaptive management techniques. For example, if monitoring detects an impact or potential for impact (by analysing trends), or vice-versa (no impact – when simulations suggested impacts may occur), then managed release may adjusted accordingly (decreased or increased). Similarly, once additional data have been collected, future monitoring could be reduced.
- If low flow channels are observed to have moved (due to stream change), consider relocating outfall structure.

9.4 Residual risks and management

The implementation of appropriate mitigation measures identified in Section 9.3 will allow Santos to avoid and manage risks associated with the managed release scheme. There remains some residual level of risk for all risks identified in Table 9-2. However, for the purposes of determining monitoring provisions, the residual risk of note is that risk identified with the residual risk level 2, relating to bioaccumulation of mercury in Table 9-2 (also identified as shaded green). Specifically, the current predicted removal of mercury by the RO membranes remains above the trigger value as a consequence of quoting to an inadequately low limit of detection. However, it is anticipated that actual removal of mercury will be to a lower level than the trigger and revised limits of detection will be obtained to demonstrate this.

Commissioning stage monitoring will be conducted and will inform a revision of the toxicity assessment based on actual data, including any treatment chemicals and residual disinfectants in the treated water.

Where low levels of residual risk remain, these risks are able to be managed via the implementation of a rigorous monitoring plan coupled with appropriate operational response plans.

9.5 Monitoring

In order to manage the remaining residual risks, a monitoring programme would be implemented in conjunction with the managed release scheme to (i) ensure that the environmental values, river flow objectives and water quality objectives are maintained in accordance with approval conditions, and (ii) allow for early detection and mitigation of any unacceptable change through Santos management responses.

CDM Smith (2016c) *Narrabri Gas Project Water Monitoring Plan (WMP)* provides an outline of monitoring activities to monitor potential impacts to water resources within the project area during operation of the approved project. Where monitoring values exceed agreed threshold values, management plans will be enacted to ensure potential harm is avoided, mitigated or managed for the protection of the receiving environment. These will include:

- Groundwater level and quality monitoring of the Bohena Creek alluvium at upstream reference locations and at pre-defined monitoring locations downstream of the managed release. The WMP will specify water quality parameters, frequency and duration of monitoring, and specific analytical measures to identify threshold exceedances.
- Surface water monitoring locations within Bohena Creek at upstream reference locations, and at a minimum of one point downstream of the managed release location. Given the

intermittent nature of Bohena Creek, monitoring will be specific to periods of release, rainfall events, and other pre-defined sampling events (e.g. routine whole of catchment sampling). Analysis will be specific to the volume and quality of the water discharged, and the water quality objectives of the receiving environment. Evidence of geomorphic change will also be captured and analysed.

- Ecological monitoring locations within Bohena Creek upstream, at the discharge location and at multiple points downstream of the managed release location and at suitable reference sites. Ecological sampling will also include the collection of concomitant dissolved oxygen, electrical conductivity, pH, and temperature data.
- Temperature and electrical conductivity would be monitored upstream of the point of release, downstream of the point of release and potentially within a persistent water body using data loggers.

10 Conclusions

To enable the effective management of produced water and maintain water management system operational reliability, managed release to Bohena Creek would be required from time-to-time as part of the project. In order to minimise the potential impacts upon the natural flow regime of the Bohena Creek and its related environmental values, Santos has elected to focus on an 'wet weather' episodic release scheme which would be initiated when natural creek flows were equal to or more than 100 ML/day, as measured at the Newell Highway gauging station.

A number of episodic release simulations were performed as part of the MRS to understand the potential for impact upon environmental receptors. A summary of these and their significance level is presented in Table 10-1.

Table 10-1: Summary of potential impacts and significance level

Objective	Potential impact		Significance
[O1]	A change in the quantity, quality or availability of surface or groundwater	Water quantity	Insignificant
		Water quality	Low
[O2]	Alteration to groundwater pressure and/or water table levels		Insignificant
[O3]	Alteration to the ecological nature of a wetland or watercourse		Insignificant
[O4]	Alteration to drainage patterns		Insignificant
[O5]	Reduced biological diversity or change species composition		Insignificant
[O6]	Result in persistent organic chemicals, heavy metals or other potentially harmful chemicals accumulating in the aquatic environments such that biodiversity, ecological integrity, human health or other community and economic use may be adversely affected		Low
[O7]	Reduce the availability of water for human consumption.		Insignificant

Overall the potential impacts from the MRS range from a significance level of **insignificant** to **low**. The MRS has demonstrated how identified potential impacts and associated risks can be effectively managed through the implementation of appropriate mitigation measures encompassing design, operations and maintenance, and monitoring and response procedures.

Future site selection will be conducted in accordance with the project field development plan, and will require detailed design of the outfall, diffuser and supporting infrastructure prior to construction.

The specific approach to monitoring will depend on the final outfall location, and will be specified in further detail in the Project Water Monitoring Plan, which provides an integrated and holistic approach to whole of Project Monitoring.

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Appendix A Ecological Risk Assessment

Managed Release Study: Bohena Creek - Ecological Risk Assessment

Narrabri Gas Project

Prepared for
Santos NSW (Eastern) Pty Ltd

September 2016

This report should be cited as 'Eco Logical Australia 2016. *Narrabri Gas Project - Managed Release Study - Bohena Creek: Ecological Risk Assessment*. Reference 2640-003. Prepared for Santos NSW Eastern Pty Ltd.'

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Abbreviations

Abbreviation	Description
ANZECC	Australian and New Zealand Environment Conservation Council
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BSAL	Biophysical Strategic Agricultural Land
CAP	Catchment Action Plan
CMA	Catchment Management Authority
CSG	Coal Seam Gas
DPI Water	Department of Primary Industries – Office of Water, formerly NSW Office of Water
DTA	Direct Toxicity Assessment
DTIRE	Department of Trade Investment Resources and Energy
EPBC	Environment Protection and Biodiversity Conservation Act
EPA	Environment Protection Act
EP&A	Environment Planning and Assessment Act
ERA	Ecological Risk Assessment

Abbreviation	Description
EPL	Environment Protection Licence
FM Act	Fisheries Management Act
GDE	Groundwater Dependent Ecosystem
GIA	Groundwater Impact Assessment
GL	Giga Litres
LGA	Local Government Area
MAR	Managed Aquifer Recharge
MDB	Murray Darling Basin
ML	Mega Litres
MNES	Matters of National Environmental Significance
MRS	Managed Release Study
NEPM	National Environment Protection Measures
NSW	New South Wales
OEH	Office of Environment and Heritage
PAL	Petroleum Assessment Lease
PEL	Petroleum Exploration Licence
POEO Act	Protection of Environment Operations Act
PO Act	Petroleum (Onshore) Act
PWMP	Produced Water Management Plan
PWMS	Produced Water Management Strategy
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SEPP	State Environment Protection Policy
SSD	State Significant Development
SSI	State Significant Infrastructure
SWD	Surface Water Discharge
TDS	Total Dissolved Solids
TJ	Terra Joules
TSC Act	Threatened Species Conservation Act
TSS	Total Suspended Solids
WSP	Water Sharing Plan
WMF	Water Management Facility
WMP	Water Management Plan

Executive summary

The Project

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

To enable gas extraction, the depressurisation of coal seams is required. The project would thus involve the extraction of produced water from coal seams that would be treated at the Leewood Water Management Facility (WMF). As part of the Project EIS, treated water would be beneficially used for drilling, dust suppression, and irrigation, with releases to Bohena Creek occurring infrequently.

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25-year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the managed release activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

Water identified as requiring release would be transported via a pipeline to the proposed outlet location in Bohena Creek from where it would be released in accordance with the managed release scheme protocols.

Managed release which is the focus of this report is required from time-to-time to maintain water management system operational reliability. Managed release will be particularly important during periods of extended wet weather during which the capacity to beneficially use treated water for irrigation or dust suppression will be constrained. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water when Bohena Creek is flowing with a natural flow of equal or greater than 100 ML/day.

Ecological Risk Assessment (ERA) and Direct Toxicity Assessment (DTA) were undertaken to investigate the toxicity of key chemical parameters that may exist in treated water prior to the design and construction of the planned Leewood Water Management Facility (WMF). This proactive approach will enable concerns regarding key chemicals to be considered at an early stage and enable planning to ensure that there will be no harm to the receiving environment once managed release operations commence.

This Ecological Risk Assessment (ERA) assesses the potential for chemical contaminants in treated water released to Bohena Creek to adversely affect aquatic and riparian ecosystems including water and soil processes, flora, and fauna (invertebrates and vertebrates). Other key studies used in the development of this ERA include:

- a Direct Toxicology Assessment (DTA) which further investigates boron and fluoride to generate data to contribute to the development of site specific trigger values for the potential release location at Bohena Creek;
- an Aquatic Ecology and Stygofauna Assessment which investigates the current ecological conditions, identifies freshwater and riparian flora and fauna species or ecological communities of local, regional or national significance and provides and assessment of impacts to these associated with the Project.

For the managed release scheme location in Bohena Creek, a key management goal is the maintenance or improvement, relative to the current or background ecosystem conditions, of natural features. Management goals include, but are not limited to, flow regimes, groundwater dependent ecosystems, riparian zones, and aquatic biota.

Although Bohena Creek is relatively undisturbed, particularly in the area immediately downstream of the Pilliga State Forest, it also receives runoff from land disturbed to varying degrees by grazing or pastoralism (pesticides have been detected in surface water samples collected from Bohena Creek) and exotic species are common. Under these circumstances, the default level of protection for a lowland river under ‘slightly to moderately disturbed systems’ is considered appropriate to meet the management goal of maintenance or improvement of ecological conditions of Bohena Creek and protect these values.

ERA Decision Tree Framework

Risks to the managed release location were determined using a Decision Tree framework similar to that presented in the ANZECC/ARMCANZ (2000) to incorporate the following lines of evidence:

- Comparison of managed release concentrations in surface water to trigger values.
- Comparison of managed release concentrations to background concentrations in Bohena Creek. The background concentration of a chemical was also compared to its trigger value (when available) to ascertain whether the creek or river may already be experiencing physicochemical or toxic stresses irrespective of the proposed treated water release.
- Direct Toxicity Assessment (DTA) results for background surface water and background surface water with added levels of boron and fluoride concentrations.

Key Results and Considerations

With adequate dilution and resultant mixing within natural flows in Bohena Creek, the risk presented by releases of treated water to the creek is assessed as low. On the basis of analysis undertaken taken to date, ecological risks from the physicochemical and chemical stressors and toxicants that may be present in the projected treated water are considered to be low when released to a flowing stream (natural flow $\geq$ 100 ML/day).

Preliminary suggested release limit trigger values for treated water at the proposed release location are presented for Bohena Creek based on the findings of this ERA, and include site-specific values for those parameters in projected treated water which otherwise may potentially pose a risk based on DTA results.

Santos would conduct toxicological assessment on treated water during commissioning stage works and routinely during the first five years of operation of the water management facility to assist in the determination of toxicity-based discharge management criteria.

1 Introduction

1.1 Background

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

To enable gas extraction, the depressurisation of coal seams is required. The Narrabri Gas Project (the project) would thus involve extraction of produced water from coal seams and would treat this water at the Leewood Water Management Facility (WMF). A full description of the project is included in the Project Environmental Impact Statement (EIS). As part of the Project EIS, treated water would be beneficially used for drilling, dust suppression, and irrigation, with releases to Bohena Creek occurring only episodically and when the creek is flowing.

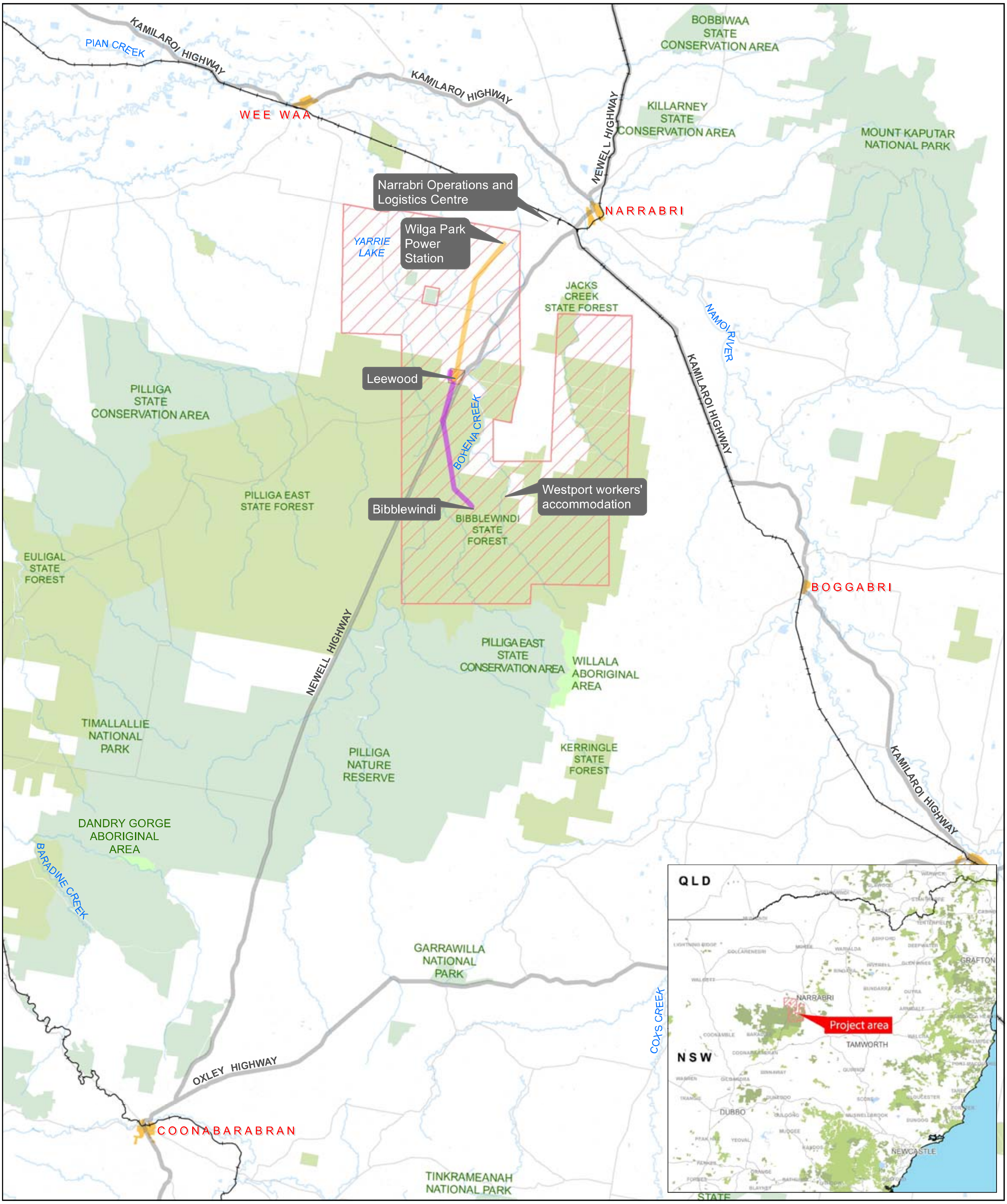
Managed release which is the focus of this report is required from time-to-time to maintain water management system operational reliability. Managed release will be particularly important during periods of extended wet weather during which the capacity to beneficially use treated water for irrigation or dust suppression will be constrained. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water when Bohena Creek is flowing with a natural flow of equal to or greater than 100 ML/day (measured at the DPI Water Newell Highway gauge).

Prior to the design and construction of the planned water management facility at Leewood WMF, Eco Logical Australia and CH2M Hill, on behalf of Santos, completed an Ecological Risk Assessment (ERA) and a Direct Toxicity Assessment (DTA) to investigate the toxicity of key chemical parameters that may exist in treated CSG water. This proactive approach will enable concerns regarding key chemicals to be considered at an early stage and enable planning to ensure that there will be no harm to the receiving environment once managed release operations commence.

This Ecological Risk Assessment forms part of the Managed Release Study (MRS) (Eco Logical Australia, 2016a) which investigates potential impacts of releasing treated water to Bohena Creek and describes how impacts can be avoided, managed and mitigated.

Of key importance to development of MRS and ERA is the project water production rate and the magnitude and frequency of treated water releases to Bohena Creek. Over the 25-year assessment period, it anticipated that 37.5 GL of produced water will be extracted, with approximately 95% of this water being made available after treatment for beneficial use including managed release. As previously stated, Santos has elected to proceed only with episodic release to Bohena Creek water when Bohena Creek is flowing with a natural flow of equal or greater than 100 ML/day. Whilst evidence indicates that flow in the creek in excess of this threshold occurs on average approximately 12% of the time, modelling indicates that managed release is likely to be invoked on average during the peak water production period approximately 7.2% of the time (Eco Logical Australia, 2016a).

Preliminary trigger values appropriate for of treated water have been developed based on the findings of this ERA, and include site-specific values based on DTA results. These triggers, specific to the Bohena Creek release, may be incorporated into the Water Monitoring Plan (WMP) (CDM Smith, 2016a) in place of threshold values for Bohena Creek.



LEGEND

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

0 5 10 20
Kilometers

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

N

GHD

Narrabri Gas Project
EIS Technical Appendix

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context and location of key infrastructure

Figure 1-1

C:\Users\AFoddy\Desktop\21_22463_KBM29.mxd [KBM: 221]

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

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

1.2 Project scope and objectives

Eco Logical Australia was commissioned by Santos Limited to complete an Ecological Risk Assessment (ERA) commenced by CH2M Hill as part of the Bohena Creek Managed Release Study to support the development of the proposed project. Release of treated water is proposed for Bohena Creek within approximately 2 km of the Leewood WMF. A location plan within in the context of the local areas is presented as Figure 1-1. The required release infrastructure (with the exception of the Leewood WMF) is likely to be located within the potential release location reach in Bohena Creek shown as Figure 1-2.

This ERA assesses the potential for chemical contaminants in treated water to adversely affect the aquatic and riparian ecosystems including water and soil processes, flora, and fauna (invertebrates and vertebrates).

In a recent review of water quality impacts of co-produced water on aquatic ecosystems, it was recommended that ERA be used to evaluate management options, with key risks to be considered including salinity, toxicity and changes in flow regime, especially for streams that are weakly perennial or ephemeral (Commonwealth of Australia, 2014).

The framework for conducting an ERA was first set out nationally in the Australian and New Zealand Environment and Conservation Council and National Health and Medical Research Council (ANZECC & NHMRC), 1992, Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (rescinded by NHMRC in 2002). It is based on the United States Environmental Protection Agency (US EPA) model and consists of four main phases (US EPA, 1989, Risk Assessment Guidance for Superfund):

Phase 1 – data collection and evaluation;

Phase 2 – toxicity assessment;

Phase 3 – exposure assessment; and

Phase 4 – risk characterisation.

The National Environment Protection Council, 1999 (2013 amendment) National Environment Protection (Assessment of Site Contamination) Measure (NEPM) refined and expanded upon this model. The tiered approach outlined in NEPM 1999 (2013 amendment) consisted of three levels of assessment, with each level consisting largely of the same basic four considerations, but incorporated an increasing degree of complexity from Level 1 to Level 3:

- Level 1 – a comparison of measured concentrations to Ecological Investigation Levels (EILs);
- Level 2 – a desktop study where site-specific factors were used to modify the EILs, which were then compared to the measured concentrations; and
- Level 3 – a detailed, site-specific, probabilistic ERA.

Figure 1-2: Bohena Creek - Potential release location and reach

Ecological risk assessment for aquatic ecosystems in Australia is broadly based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality Guidelines (ANZECC/ARMCANZ, 2000). The ANZECC/ARMCANZ (2000) Guidelines present a decision framework for applying biological, water, and sediment quality guidelines ('trigger values') that can be tailored to local conditions.

The first step in the decision framework is to define the primary management aims, environmental values, and level of protection needed, to support the selection of the appropriate trigger values in the second step. If trigger values are exceeded by contaminant concentrations, site-specific factors can be considered to revise trigger values, which can then be re-compared to contaminant concentrations. Biological effects assessment, such as Direct Toxicity Assessment (DTA) may be considered if the revised trigger values continue to be exceeded. Derivation of site-specific Water Quality Objectives (WQOs) and suggestions for continued monitoring may be recommended. It should be noted that this 'trigger rule' approach does not purport to define or represent an ecologically important change. Instead, the approach is an early warning mechanism to alert the resource manager of a potential or emerging change that should be followed up.

The approach for this ERA incorporates elements from the ANZECC/ARMCANZ (2000) Guidelines, NEPM 1999 (2013 amendment) has the five basic components from NEPM (2011):

- Problem identification is a scoping phase that establishes the objectives of the ERA and identifies the data required to achieve those objectives.
- Receptor identification focuses on 'what species may be at risk?' and 'what do we want to protect?'
- Exposure assessment characterizes the site, identifies potential exposure pathways and estimates exposure duration, concentrations, and intake.
- Toxicity assessment involves estimating the concentration of contaminants at which species and ecological functions experience no harmful effects and those at which toxic effects are caused.
- Risk characterisation involves combining data and information from the exposure and toxicity assessments to determine the risk that ecosystems at the site face from the contaminants.

In this ERA, management aims, as defined in the ANZECC/ARMCANZ (2000) guidelines, are presented in the Problem Identification (Section 2). A summary of ecological survey results is presented in the Receptor Identification (Section 3). Background levels of contaminants and the proposed managed release levels are included in the Exposure Assessment (Section 3). The selected trigger values and Direct Toxicity Assessment activities are presented in the Toxicity Assessment (Section 4). Proposed managed release limits and suggestions for additional activities are presented at the completion of the Risk Characterisation (Section 5). Further information on structure of this report is provided below.

1.3 Structure of this report

Section 1: Provides a description of the project, managed release scheme water management, and describes treated water quality and quantity. Project scope, and objectives are then established with limitations and assumptions listed.

Section 2: Identifies the problem. The local catchment and Site are described, flow scenarios introduced and receptors are identified. This then leads into formation of an ecological conceptual site model which explores surface and subsurface exposure pathways.

Section 3: Exposure Assessment describes treated water data supplied by Santos and background concentrations of chemicals present within the receiving environment.

Section 4: Toxicity Assessment determines the toxicity of the contaminants and establishes the sensitivity of the receptors. The essence of the Toxicity Assessment is estimating the relationship of effects to variance in exposure. In combination with the Exposure Assessment, the Toxicity Assessment determines the potential impact on the environmental values identified for the site.

Section 5: Risk Characterisation primarily focuses on the stresses potentially imposed on riparian and aquatic receptors by the chemical properties of the treated water; these stresses are considered in relation to the potential physical and biological changes.

1.4 Limitations of this Report

Expressions of Surface water, groundwater and ecological diversity are likely to vary spatially and to fluctuate with time. Data collection to inform these analyses was made during 2013 and 2014. Interpretations have been made based on incomplete data and partial knowledge of the surface and subsurface and of the surface and groundwater conditions therein. The interpretations made in this report are based on the data supplied and alternative interpretations may be applicable following the realisation of new or additional data.

1.5 Assumptions

The following assumptions were agreed with Santos prior to undertaking this report.

This ERA is largely based on estimated levels of contaminants in treated water and the design basis for the reverse osmosis water treatment plant provided by Santos and actual levels may differ from the estimated levels used here.

The Hydranautics IMS Design modelling software estimates average concentrations based on levels in the produced water and the design basis for the Reverse Osmosis (RO) plant which is part of the Leewood WMF. While higher concentrations are possible, and risks could therefore be underestimated, near maximum concentrations are expected to infrequently occur and are dependent on maximum levels in produced water in combination with low RO membrane and other treatment process performance. Significantly underestimated risks are therefore not expected. Final treated water chemistry will be subject to final water treatment plant design and will be confirmed with the regulator as soon as available. Water chemistry supplied is a best estimate based on current projection software and operating experience.

This ERA assesses actual exposure concentrations. In reality, treated water will also be diluted in Bohena Creek, at a mixing ratio of approximately 10:1, reducing actual exposure concentrations.

Santos has provided its best estimates of produced water production. These estimates have been used as part of this ERA.

The cumulative risk from simultaneous exposure to chemicals could occur, however this is considered to be low.

A detailed discussion of assumptions is provided in Section 5.8.

2 Problem Identification

The project will involve the extraction of gas and associated water from deep-seated coals in the Bohena sub-basin. The project includes a plan to treat produced water at the Leewood WMF and to use available treated water for beneficial uses. On some occasions, managed release to Bohena Creek may be required when Bohena Creek is flowing with natural flow of 100 ML/day or more (typically during prolonged periods of wet weather). Managed release is required to maintain project water management system operational reliability.

In the intermittent Bohena Creek, various episodic managed release scenarios were considered in order to understand surface water and groundwater interaction in the shallow alluvial soils of Bohena Creek and underlying Pilliga Sandstone aquifer (Eco Logical Australia, 2016a).

Overall risks from physical, chemical and biological effects are the focus of this ERA.

2.1 Catchment Description

The Namoi catchment drains in a westerly direction from the western flank of the Great Dividing Range, for some 400 km, to release into the Barwon River at Walgett. The main surface water system is the Namoi River with flow contributed by major tributaries including Macdonald River, Manilla River, Peel River, Mooki River, Cox's Creek, Maules Creek, Bohena Creek, Bundock Creek and Baradine Creek. The catchment is bounded to the north by the Nandewar Ranges and the New England Plateau and to the south and west by the Liverpool Plains and Warrumbungle Range.

There are five major sub-catchments in the Namoi catchment

- Macdonald/ Manilla sub-catchment
- Peel sub-catchment
- Mooki sub-catchment
- Middle Namoi sub-catchment
- Lower Namoi sub-catchment

The proposed managed release site is located in Bohena creek which is within the lower Namoi sub-catchment. Generally, all tributaries drain in a north-westerly direction towards the Namoi River floodplain. The headwaters of the tributaries are generally located in forested conservation areas (e.g. Pilliga Forest) while the unforested areas of the sub-catchments are utilised predominately for sheep and cattle grazing as well as dryland cropping.

In the northern, mainly flat areas of the sub-catchment, large areas are utilised for irrigated cotton cropping and dryland agriculture and grazing.

In these flat areas of the catchment, issues include pasture deterioration and soil degradation including dryland salinity to the west and soil structure decline and degradation to the east.

Prior to clearing for grazing, the alluvial land of the lowland plains was sparse to open *Eucalyptus coolabah* (Coolibah) woodland, or grasslands dominated by *Astrebla lappacea* (Mitchell grass) or Plains grass. Early settlers noted that the Namoi River was lined with trees and shrubs and the channels contained numerous fallen trees (Olley & Scott, 2002). Today only major streams have a narrow riparian zone supporting *Eucalyptus camaldulensis* (River Red Gum), *Acacia stenophylla* (River Coolah), *Atalaya hemiglauca* (Whitewood), *Casaurina cristata* (Belah), White Box and Grey Box (Lampert and Short, 2004).

2.2 Site Description

Bohena Creek flows in a generally northerly direction through the eastern Pilliga Forest to its confluence with the Namoi River 12km downstream of Narrabri. The greater Namoi River catchment is a highly modified landscape with a number of land uses that have the potential to impact water quality. The Namoi River Catchment has been divided into upland and lowland zones based on the variation in altitude, changes in geomorphology and the different mix of agricultural production (Green *et al.*, 2011). Bohena Creek is located within the lowland area, which also include those areas on the Liverpool Plains and from Gunnedah to the junction with the Barwon River at Walgett.

Based on data obtained from the DPI Water Newell Highway gauge, Bohena Creek experiences surface water flows on average approximately 15% of the year implying a classification as an intermittent watercourse. Bohena Creek was classified by Lampert and Short (2004) as a lowland chain of ponds with symmetrical, discontinuous ponds, separated by poorly defined channel depressions, swampy fills and/or sand deposits. Bohena Creek has a naturally low nutrient status similar to many of Australia's freshwater systems because of the sand dominated substrate lacking in organic matter and the lack of perennial flow.

Because the creek has naturally low levels of nutrients available in the system, it potentially has the capacity to assimilate some of the nutrients and other substances present in the release water. The projected quality of treated water for release is described in Section 3.

Within the study area for the proposed managed release, there is a low gradient, wide, braided channel with well-defined vegetated banks comprised of sand and organic material. The channel bed is formed predominately of sand with localised deposits of fine gravels. The creek bed is densely vegetated in many areas, which stabilises the channel bed and prevents the formation of a continuous channel. The creek contains a series of ponds that are linked by a poorly defined channel, or a series of depressions between sand bars and splays. The ponds range in size, up to about 250m in length and likely retain water throughout the year. Sand bars are prevalent and where well vegetated, appear stable under high flows, while others are partially vegetated or unvegetated, and are expected to be reworked under moderate to high flow events. During smaller flow events (<5 year ARI), the disconnected pools link together, with flow depths up to around 0.5m; in events >5 year ARI, depths may exceed approximately 0.5m.

The dynamics of solutes in the system are driven by exchanges between solutes in the water column (during flow periods) and the creek substrate and between solutes in the groundwater and the aquifer matrix. These exchanges include abiotic processes, such as adsorption, desorption, precipitation, and dissolution. There are also biological exchanges involved in the dynamics, including microbial uptake and plant uptake. Adsorption (especially for phosphate) and microbial and plant uptake remove these solutes from the water, but nutrients immobilised through adsorption can be remobilised when water column conditions change. In the case of Bohena Creek, nutrients are likely to be temporarily immobilised by adsorption to particles in the creek substrate when the creek bed is dry and then remobilised during times of flow. More information on baseline water quality used in the assessment is presented in Section 3.2 and Table 3-1.

2.3 Flow Scenario

This ERA considers episodic release to a flowing creek when flows in Bohena Creek are greater than or equal to 100 ML/day (model scenario 37GLI01-W) as measured at the DPI Water Newell Highway gauge. The Leewood WMF projected composite treated water recovery rate is estimated to be approximately 95% of the produced water rate.

Episodic releases would occur infrequently. Modelling by CH2M HILL indicates that at the hypothetical peak treated water production rate of 12.0 ML/day during years 0-4 of the project, approximately 7.2% of treated water may be directed to the Bohena Creek. The estimate of 7.2% is based on a hypothetical project peak irrigation demand of 12.0 ML/day, and adoption of a streamflow trigger of >100 ML/day. As estimates have not been performed for later years of the project (for example when average production is 3.8 ML/day and 1.7 ML/day[1], it is likely that when the production curve is below the peak, then less water will be available for all beneficial uses and managed release would be conducted less frequently.

Analysis of stream flow behaviour and initiation of surface flow in the creek suggests that if episodic releases occur only when Bohena Creek is flowing (37GLI01-W) (natural flow of ≥ 100 ML/day), then there is unlikely to be significant change in surface water quantity.

In summary, during years 0 to 4, releases would be made to a flowing creek, and modelling indicates that approximately 7.2% of all treated water may be directed to the creek. According to the production curve from year 5 onward, water extraction will reduce and as pond sizes and irrigation areas are designed to accommodate peak production years, it is therefore likely that the need to release will diminish.

As surface water quantity impacts are insignificant during years 0 to 4, and given that the quantity of treated water directed to managed release will be reduced, then surface water quantity impacts in later years of the project can also be regarded as insignificant (Eco Logical Australia, 2016a).

2.4 Mixing Zone

A mixing zone model was used to determine the dilution ratio and concentrations of key water quality parameters after the produced water discharge mixes with river flow in Bohena Creek. The assessment used the CORMIX modelling package which is recognized by the ANZECC Guidelines (2000) as a peer-reviewed model for mixing zone modelling analysis. CORMIX is an empirical model based on experimentally derived curve-fit equations that predict the dilution ratio of water quality parameters and that verify the accuracy of theoretical models. The CORMIX system's major emphasis is on the prediction of geometry and dilution characteristics of the initial mixing zone so that compliance with acute and chronic regulatory constraints may be evaluated. The system can also predict the behaviour of the discharge plume at larger distances. In general, CORMIX is suitable for calculating mixing and dilution for a number of different discharge conditions, such as open channel discharges, single pipe discharges, and multiple discharges to rivers, lakes and estuarine systems. The results of the mixing zone assessment are presented in Section 5.

2.5 Receptor Identification

The Receptor Identification component identifies the local species, communities and ecological processes that are of environmental value. Environmental values are flora, fauna and supporting ecological processes (that is, factors that influence a species' ability to grow, survive, develop and reproduce, and remain viable) that are associated with a defined piece of land and are considered to have societal, cultural, ecological and/or economic significance. Environmental values naturally vary from site to site according to variation in the natural habitat, the degree to which humans have physically altered the

[1] Beneficial use water balance estimates have been undertaken using a peak production of 12.6 ML/day. During this time up to 12.0 ML/day will be used for irrigation which is likely to be conducted over a fixed land area during these years. For later years in the project, estimates have not been performed as irrigation areas may be reduced. The extent of irrigation area reduction is dependent on crop type and a number of other factors. Refer Beneterra (2015) and GHD (2016) for further information.

natural environment and the expectations of society. An important consideration in determining the environmental values are the Management Objectives and the stakeholders in the region.

An aquatic ecology survey was conducted by Eco Logical Australia from 12-14 March and 3-5 December 2013 in Bohena Creek (Eco Logical Australia, 2016b), and the results are summarised in the following subsection. The surveys included Australian River Assessment System (AUSRIVAS) assessments of site condition and macroinvertebrate community assemblages, aquatic habitat assessment, riparian condition and floristic surveys, water quality assessments, and fish community sampling. Five sites were sampled along Bohena Creek. Sites were selected upstream and downstream of the proposed managed release point at Bohena Creek. Stygofauna samples were collected from production bores, monitoring bores and shallow pits in the project area. Further details of these sites are presented in Section 2.5.5.

2.5.1 Aquatic Habitat

The aquatic ecological communities of Barwon-Darling River systems have been subjected to increasing threats and degradation from various stressors including: modification of the natural river flow and temperature regimes, cold water releases from dams, degradation of in stream habitats through loss of riparian vegetation, sedimentation, water quality decline, and competition with introduced species (Eco Logical Australia, 2016b). The variability of the flow regime in the catchment is fundamental to the ecosystem and its biodiversity, which is common in the Murray Darling Basin where the plants and animals have evolved to cope with long droughts and sudden wet periods. This system is listed as an endangered ecosystem of fish and invertebrates by the Fisheries Scientific Committee. The area covered by this listing includes the regulated tributaries of the Barwon-Darling, including the Namoi River and encompasses all natural creeks, rivers and associated lagoons, billabongs, wetlands, tributaries, and anabranches of the Namoi River system (Schlumberger, 2011).

The sandy bed of Bohena Creek had very little topographic variation, so remnant pools were shallow, relatively uniform, and lacked riffles. Macrophyte growth was dominated by *Phragmites australis*, *Juncus spp.* and *Cyperus* spp. The main habitat features present at the four Bohena Creek sites were fringing vegetation provided by *P. australis,* which grows in low to medium densities. Overhanging and trailing vegetation was also present at the Bohena Creek upstream site.

2.5.2 Macroinvertebrate Community

Thirty-five invertebrate taxa were collected across the study sites during the survey by Eco Logical Australia. Only *Chironmodae* were present at all sites, though not on both autumn and spring sampling occasions. *Atyidae*, *Baetidae* and *Leptoceridae* were widespread, occurring at all but one of the sites sampled. The upstream site had the highest invertebrate diversity at Bohena Creek, with 16 taxa.

Bohena Creek sites sampled in autumn all had similar Stream Invertebrate Grade Number – Average Level (SIGNAL) scores, with values ranging from 4.40 to 4.56. These scores are indicative of moderate levels of disturbance. The upstream and downstream sites scored the highest. In spring, three of the original sites had dried, leaving only one of the upstream to be sampled a second time, and Teds Hole to be sampled as an alternative to the downstream site. Teds Hole had a SIGNAL score of 3.82, suggesting a poor quality aquatic ecosystem and severe disturbance. All Bohena Creek sites were in AUSRIVAS Bands B and C. This indicates that sites were in poor condition and either significantly or severely impaired, with fewer of the expected taxa and lower water quality than modelled reference sites.

2.5.3 Fin Fish Community

Spangled Perch (*Leiopotherapon unicolour)*, Carp Gudgeon (*Hypseleotris sp*.), Plague Minnow (*Gambusia holbrooki),* Common carp (*Cyprinus carpio*) occurred in Bohena Creek. Carp Gudgeon and Plague Minnow occurred at all sites.

2.5.4 Aquatic Plant Community

No threatened plant species were observed in the riparian zone within the survey sites.

Vegetation on the banks and floodplains of Bohena Creek is contiguous with large areas of relatively intact woodland of the Pilliga Forest (>1000 ha). This vegetation is generally dominated by native species, although exotic species are also present in high densities in some areas. The major disturbance regimes of this vegetation are likely to be fire, flood and weed invasion. Vegetation along the creek was in moderate condition, although played only a minor role in creating channel and in-stream habitat. Four of the Bohena Creek sites (all except the downstream location) had at least one side that was formed by a vegetated bank that adjoins the Pilliga Forest. These banks had sufficient woody vegetation to provide enough stability for the bank to develop a moderate steepness that extended into the water and gave a depth of 60 to 120 cm. Leaf litter and woody debris were present in low densities at all Bohena Creek Sites. At the upstream location, riparian shrubs overhung the water and provided shelter and shade for the aquatic community.

P. australis occurred at low to medium densities at all sites along Bohena Creek. Densities appeared to be higher at the upstream and downstream ends of Ted's Hole than at the other sites that dry out more frequently.

2.5.5 Stygofauna

Stygofauna are considered important faunal component of aquifer ecosystems, and may be vulnerable to changes in the physical and chemical properties of water. Stygofauna samples were collected from four production bores and two monitoring bores at the Leewood WMF and from three monitoring bores and five shallow pits in the bed of Bohena Creek. The monitoring bores at both locations were sampled twice yielding a total sample population of nineteen samples. Stygofauna were not present in the nineteen samples. Stygofauna generally occur in low numbers so the lack of animals from nineteen samples does not conclusively indicate their absence from the site. However, stygofauna communities are not likely because of the poor development of the aquifer and the frequency with which the aquifer dries out.

2.5.6 Reptiles and Amphibians

Chelodina longicollis (Eastern Longneck Turtle) was observed in the deepest part of a pool at one of the upstream sites. A number of threatened reptiles and amphibians are known to occur in freshwater habitats in the Namoi River catchment. Bell's Turtle is listed as Vulnerable under both the NSW TSC Act and the Federal EPBC Act. It occupies narrow sections of rivers in granite country, shallow pools in the upper reaches, or small tributaries of major rivers to the east of the study area. Bell's Turtle is considered unlikely to occur in the study area because there is no suitable habitat. Of the four amphibian species known to occur in the locality, only *Crinia sloanei* (Sloane's Froglet) is considered to have the potential to occur at the study areas. This species is listed as vulnerable under the TSC Act. It is a small, ground-dwelling frog, which was previously encountered throughout the floodplains of the Murray-Darling Basin.

2.6 Ecological Conceptual Site Model

Treated water may be released into the receiving environment of Bohena Creek after undergoing a treatment process. The treated water will add constituents to the receiving environments that can be measured directly, such as the concentration of metals, or indirectly through measurement of water quality parameters, such as electrical conductivity (EC). ANZECC/ARMCANZ (2000) Default Trigger Values and Namoi River Water Quality Objectives are used to quantitatively evaluate the measurements. Consideration is given to the use of reference sites to develop site specific values.

At the proposed release location reach (Figure 1-2), several environmental transport pathways and transformations may occur before ecological receptors are exposed to constituents in the release.

Chemical fate processes, such as dissociation, degradation, complexation, and biotransformation may occur at all stages and in all media. The receptors potentially exposed to the managed release include vegetation, invertebrates (including stygofauna), amphibians, reptiles, fish, birds, and mammals, in both the aquatic and riparian/terrestrial ecosystems. Potential exposure pathways are represented in Figure 2-1**.**

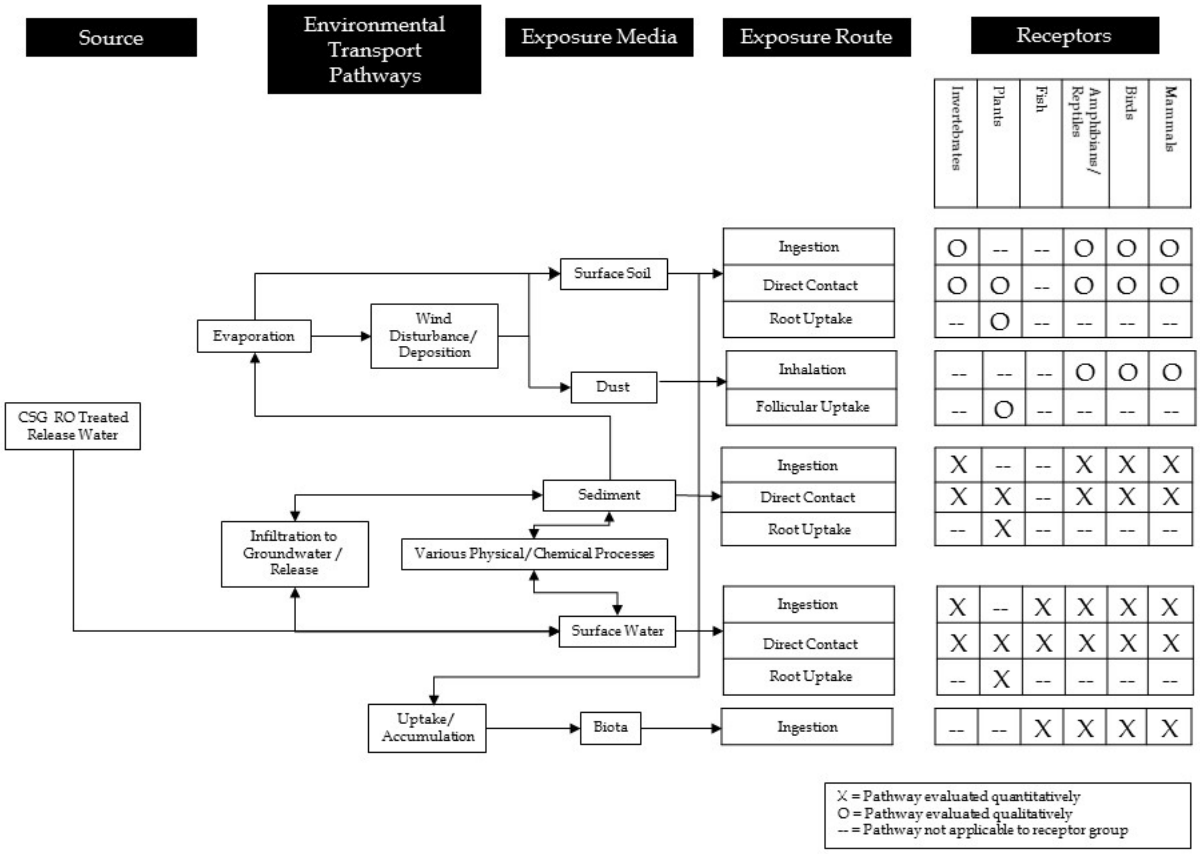


Figure 2-1: Ecological Concept Site Model

2.6.1 Exposure Pathways (Surface)

In the aquatic ecosystem, receptors may be exposed to constituents in surface water that are either freely dissolved or sorbed to suspended solids. Surface water exposure may also occur after resuspension from sediment following disturbances such as storm events or flooding, or the turbulent mixing zone itself. The surface water exposure route occurs as direct contact to dermal surfaces in all receptors, as well as respiratory surfaces in invertebrates, fish, and amphibian early life stages. Drinking water ingestion may also occur for reptiles, birds, and mammals.

Constituents may be transported to sediment through settling of suspended solids, sorption to sediment particles, or diffusion into pore water. The rates of these processes will be influenced by the physical and chemical properties of the constituents, sediment, and surface water. Higher organic carbon content in the sediment may increase organic chemical partitioning to sediment, for example. In sediment, aquatic receptors may be exposed to constituents dissolved in the pore water or as attached to sediment particles, and occurs as direct contact to dermal surfaces in all receptors, as well as respiratory surfaces in invertebrates in pore water. Invertebrates, benthic fish, such as carp, amphibian early life stages, reptiles, birds, and mammals may also incidentally ingest sediment while foraging.

After periods of heavy rain in Bohena Creek, managed release water constituents may be transported in surface water flow to downstream locations. A significant level of dilution is expected to occur to the concentration of constituents in the released water.

2.6.2 Exposure Pathways (Subsurface)

Surface water infiltration is expected to occur in the Bohena Creek, and therefore, constituents in treated water may enter the subsurface groundwater flow. The rate of infiltration could be influenced by many factors, including natural flow events and sediment geomorphology. It is considered unlikely that managed release of treated water from the Leewood WMF will significantly affect hydraulic head and flow in the Pilliga Sandstone aquifer, which underlies Bohena Creek in the project area.

Following infiltration, down gradient transport to downstream reaches and water holes (natural and anthropogenic, such as sand extraction sites) may occur where surface and sediment exposure routes, described above, will resume. Groundwater up-gradient of the managed release point may also contribute to and dilute down-gradient infiltrated groundwater. As for surface water partitioning to sediment, the rates of these groundwater processes will be influenced by the physical and chemical properties of the constituents, groundwater, and subsurface sediment/soil.

During dry periods (between episodic releases), receding water levels will allow areas that were previously inundated to regain characteristics of the riparian/terrestrial ecosystem. Precipitation events may also leach constituents residing in soil to the subsurface groundwater where groundwater pathways, described above, will resume. Riparian/terrestrial based receptors, including rooted plants, soil invertebrates, amphibians, reptiles, birds, and mammals may potentially become more abundant and may be exposed to constituents retained in the soil. In soil, these receptors may be exposed to constituents in the pore water or as attached to soil particles, and occurs as direct contact to dermal surfaces in all receptors. Reptiles, birds, and mammals may also incidentally ingest soil while foraging. Additionally, receptors may be exposed to constituents in the soil through inhalation after dust exposure from windy conditions.

Indirectly, constituents known to bioaccumulate, such as mercury and selenium, may also have accumulated in the tissues of forage and prey items, and ecological receptors may be exposed to these constituents via consumption. It should be noted that ANZECC/ARMCANZ (2000) Guideline Trigger Values and Namoi River Water Quality Objectives (New South Wales Department of Environment and Heritage, 2006) do not specifically incorporate this exposure route into their derivation. Rather, a higher level of species protection is recommended (e.g., 99% of test species) when selecting values, with the implicit assumption that this higher level of protection is likely to be protective of adverse effects from the bioaccumulative and intake exposure route. Therefore, evaluation of this exposure route is considered quantitative for the purposes of this ERA.

2.6.3 Summary

In summary, the exposure routes include ingestion, direct contact, inhalation, and root uptake (Figure 2-1). Of the pathways mentioned, surface water and sediment direct contact to aquatic plants, invertebrates, amphibian early life stages, and fish are considered to be the most significant and are evaluated quantitatively with ANZECC/ARMCANZ (2000) Guideline Trigger Values and Namoi River Water Quality Objectives (2006) in the following sections. As recommended by ANZECC/ARMCANZ (2000), Guideline Trigger Values with higher levels of protection will be used to evaluate bioaccumulative chemicals. Under the flowing creek conditions episodic release scenario (natural flow of ≥ 100 ML/day), approximately 10:1 surface water dilution will occur and the alluvial aquifer is expected already to be close to saturation. Riparian pathways from soil exposure (after drying) are expected to be insignificant because constituents in soil are expected to have very limited bioavailability due sorption and weathering and because the areas of potential exposures (dry creek bed and river bank) will be very small relative to the total aquatic ecosystem area. Inhalation pathways are also typically negligible components of the total exposure (US EPA, 1993).

2.7 Primary Management Aims

Management goals, environmental values to be protected, and the level of protection are defined in the primary management aims and are presented below in the following subsections.

2.7.1 Matters of National Environmental Significance (MNES)

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) identifies Matters of National Environmental Significance (MNES) and provides processes for assessing and controlling activities which may have a significant impact upon Matters of MNES.

MNES relate to:

- World Heritage properties;
- National Heritage places;
- Wetlands of international significance;
- Commonwealth listed threatened species and ecological communities;
- Migratory species;
- Commonwealth marine areas; and
- Nuclear actions (including uranium mining).

Eco Logical Australia (2016b) conducted a database and literature search for threatened species as part of their ecological survey. Fifteen endangered ecological plant communities may occur in the Namoi River catchment. Although none of these communities were considered likely to occur in the study area, some are likely to occur in adjoining areas (e.g. floodplains and pipeline routes). Twenty-two threatened plant species may occur within a 10km radius of the Bohena Creek study area. A search of the NPWS Wildlife Online database and review of the species risk assessment found no aquatic plant species of conservation significance likely to occur in the study area. Searches for the sedge *Cyperus conicus,* considered a terrestrial species and listed as endangered under the *Threatened Species Conservation Act* (TSC Act), were conducted at each aquatic survey site, however, since it grows in open woodland on sandy soil in the Pilliga area, and is known to grow near waterholes and on the banks of streams in sandy soils.

Among fauna, on the basis of regional records, nine threatened fauna species are known to occur or potentially occur in the Namoi River Catchment. The predicted presence is based on the known geographical distribution, preferred habitats for each species and the corresponding habitats in the study area. *Bidyanus bidyanus* (Silver Perch), *Maccullochella peelii peelii* (Murray Cod) and *Tandanus tandanus* (Freshwater Catfish) are expected to be present, while *Notopala sublineata* (River Snail) and Sloane's Froglet may occur. *Elseya belli* (Bell's Turtle), *Litoria booroolongensis* (Booroolong Frog), *Litoria daviesae* (Davies' Tree Frog), and *Adelotus brevis* (Tusked Frog) are considered unlikely to occur in the study area.

There were no records for threatened aquatic species in Bohena Creek. This does not mean Bohena Creek does not offer suitable habitat for threatened species; it is more likely a reflection of the ephemeral nature of the creek, which limits opportunities to survey for freshwater-dependent fauna.

2.7.2 Water Quality and River Flow Objectives

In 2006 the NSW Government released the Namoi River Water Quality and River Flow Objectives to guide plans and actions that aim to ensure the long-term health of NSW waterways as well as satisfying the NSW Government requirement to meet its inter-governmental obligations to improve river health, such as in the Murray-Darling Basin. The guideline is split into water quality objectives (WQOs) and river flow objectives (RFOs). The objectives are divided into categories depending on the type of stream. The Namoi River downstream of Keepit Dam is classed as a "major controlled River", the Mooki River and all other streams near to the Gunnedah and Narrabri projects are mainly "uncontrolled streams". The exception to this is Bohena and Baradine Creeks where headwaters are located in "mainly forested area". Namoi River Water Quality and River Flow objectives are provided in **Appendix A**.

The WQOs for Bohena Creek are listed below:

- Aquatic ecosystems
- Visual amenity
- Primary and Secondary contact recreation
- Drinking water

The RFOs for Bohena Creek are listed below:

- Protect pools in dry times;
- Protect natural low flows;
- Manage groundwater for ecosystems; and
- Minimise effects of weirs and other structures;

2.7.3 Murray Darling Basin Salinity Management Strategy 2011-2015

The Murray Darling Basin Salinity Management Strategy 2011-2015, sets out how Basin communities and Governments will work together to control salinity and protect important environmental values and assets. It contains accountability arrangements that are the 'first of a kind' for salinity strategies in Australia. The strategy specifies river salinity targets to be met in the year 2015. In terms of measurable salinity levels, the strategy aims to ensure levels at Morgan in South Australia should be less than 800 micro Siemens/centimetre (µS/cm), 95% of the time. Additionally, a target of 1,000 µS/cm should not be exceeded more than 20% of the time anywhere in the catchment.

For the Namoi Catchment, a median salinity target of 108% of 2000 levels has been adopted for the 2015 target measured at the Namoi at Goangra of 550 µS/cm as described in the NSW Salinity Strategy (NSW Government, 2000; NOW, 2007; Namoi CMA, 2007). The proposed managed release strategy would require consideration of these and subsequent guidelines.

2.7.4 Namoi Catchment Action Plan 2010-2020

The Namoi Catchment Action Plan 2010-2020, authored by the Namoi Catchment Management Authority contains specific thresholds and targets to meet the overall goal for the catchment of “vibrant communities and landscape for the future”. The thresholds and targets are presented in **Appendix B**.

2.7.5 Stakeholders

A list of potential stakeholders in shown below. Details on the full list of potential stakeholders is presented in **Appendix C**.

- Namoi Catchment Management Authority
- NSW EPA
- NSW Trade and Investment, Resources and Energy, Minerals and petroleum
- NSW Office of Water
- Narrabri Shire
- State Water Corporation
- Sheep and cattle farmers
- Town water users
- Surface water users
- Bohena Creek (irrigation, stock and domestic purposes)
- Bundock Creek (irrigation, stock and domestic purposes)
- Upper Namoi (irrigation, town water supply, stock and domestic purposes)
- Lower Namoi surface water users (irrigation, stock and domestic purposes)
- Irrigators
- Coal Mines
- Narrabri North
- Boggabri
- Tarrawonga

2.7.6 ANZECC/ARMCANZ (2000) Guidelines

ANZECC/ARMCANZ (2000) Guidelines provide trigger values for an extensive list of contaminants that are potentially harmful to freshwater and marine ecosystems. Within the ANZECC/ARMCANZ (2000) Guidelines there are different trigger values corresponding to different percentages of species protection. To be able to determine the appropriate trigger value in terms of species protection an assessment of biodiversity and what level of change would be considered acceptable (to all stakeholders), within the waterway, is required. The guidelines provide a framework for the assignment of an appropriate level of protection. In order to establish levels of protection the ANZECC/ARMCANZ (2000) Guidelines recognise three levels ecosystem conditions:

‘High conservation/ecological value systems’ — effectively unmodified or other highly-valued ecosystems, typically (but not always) occurring in national parks, conservation reserves or in remote and/or inaccessible locations. While there are no aquatic ecosystems in Australia and New Zealand that are entirely without some human influence, the ecological integrity of high conservation/ecological value systems is regarded as intact.

‘Slightly to moderately disturbed systems’ — ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained. Typically, freshwater systems would have ‘slightly to moderately cleared catchments’ and/or reasonably intact riparian vegetation; marine systems would have largely intact habitats and associated biological communities. ‘Slightly to moderately disturbed systems’ could include rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism, or marine ecosystems lying immediately adjacent to metropolitan areas.

‘Highly disturbed systems’ – These are measurably degraded ecosystems of lower ecological value. Examples of highly disturbed systems would be some shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture.

In regard to the level of protection, the ANZECC/ARMCANZ (2000) Guidelines make recommendations for sites which have:

- Poorly characterised reference conditions;
- Not yet gathered reference data; and
- Unavailable local biological effects data.

In this situation, there is a requirement to:

- Increase the inferential strength of the monitoring program for biological indicators;
- Apply default regional low-risk trigger values for physical and chemical stressors; and
- Apply default trigger values for toxicants.

The ANZECC/ARMCANZ (2000) Guidelines also state “that in most cases, the 95% protection trigger values should apply to ecosystems that could be classified as ‘slightly to moderately disturbed’, although a higher protection level could be applied to slightly disturbed ecosystems where the management goal is no change in biodiversity”.

2.7.7 Environmental Values to be protected

A key management goal is the maintenance or improvement, relative to the current or background ecosystem conditions, of natural features. These include, but not limited to, flow regimes, groundwater dependent ecosystems, riparian zones, and aquatic biota and must be protected. Research informing the Managed Release Study (Eco Logical Australia, 2016a) found that no existing documentation establishes the current ecosystem condition, however given the extensive agricultural use of the catchment, it is likely that many of the streams within the Namoi catchment would be described as ‘slightly to moderately disturbed systems’. Neither waterway is considered to be unmodified or have high conservation value. Although Bohena Creek is relatively undisturbed, particularly in the area immediately downstream of the Pilliga State Forest, it also receives runoff from land disturbed to varying degrees by grazing or pastoralism (pesticides have been detected in surface water samples collected from Bohena Creek) and exotic species are common. Under these circumstances, the default level of protection for ‘slightly to moderately disturbed systems’ is considered appropriate to meet the management goal of maintenance or improvement of ecological conditions.

3 Exposure Assessment

3.1 Exposure point concentrations

For this ERA, the exposure point concentrations are the modelled treated water projections (unamended treated water) from the Hydranautics IMS Design modelling software provided by Santos. Projections are presented in Table 3-1.

Table 3-1: Treated Water (post chlorination)

Constituent	Units	Mean	Maximum
pH		7.1	9.2
Electrical conductivity (EC)	µS/cm	357	645
TDS (calculated)	mg/L	232	419
Turbidity	NTU	<0.5	1.0
Boron	mg/L	0.12	0.68
Sodium	mg/L	77	140
Magnesium	mg/L	0.01	0.01
Aluminium	mg/L	<0.001	0.01
Silica	µg/L SiO2	23	27
Potassium	mg/L	0.8	1.0
Calcium	mg/L	0.01	0.01
Chromium (III+VI)	mg/L	<0.001	0.001
Manganese	mg/L	<0.001	0.001
Iron	mg/L	<0.001	0.005
Cobalt	mg/L	<0.001	-
Nickel	mg/L	<0.001	0.000
Copper	mg/L	<0.001	0.002
Zinc	mg/L	<0.001	0.003
Arsenic	mg/L	<0.001	0.001
Selenium	mg/L	<0.001	0.001
Molybdenum	mg/L	<0.001	0.000
Cadmium	mg/L	<0.001	0.00056
Barium	mg/L	<0.001	0.027
Mercury	mg/L	0.0000067	0.0002
Lead	mg/L	<0.001	0.000
Uranium	µg/L	-	0.003
Alkalinity (Carbonate as CaCO3)	mg/L	139	-
Alkalinity (total) as CaCO3	mg/L	139	193
Ammonia	µg/L	15	50
Nitrate (as N)	mg/L	-	-
Nitrogen (Total Oxidised)	mg/L	-	-
Total Nitrogen	µg/L	-	-
Sulphate	mg/L	0.003	0.532
Chloride	mg/L	15	83
Fluoride	mg/L	0.08	0.16
Phosphorus	mg/L	0.01	<0.01

Notes:

[a] Final treated water chemistry will be subject to final water treatment plant design and will be confirmed with the regulator. Water chemistry supplied is a best estimate based on current projection software and operating experience.

[b] Modelled projections do not reflect further post treatment for SAR or pH. All treated water values are calculated from the Hydranautics IMS Design modelling software output and increased by at least 15%, based on Stage 1 and 2 values and the recovery ratios. The model was run assuming 30°C water temperature and SWC4B MAX membranes in both stages.

\- Blank cells indicate values could not be calculated.

< indicates concentrations are below the limit of detection (LOD)

The Hydranautics IMS Design modelling software output is based on the design parameters for the Leewood WMF. The output concentrations are mean and maximum concentrations. For several metals, treatment will reduce the concentrations to below the limit of detection (LOD), and the concentrations are therefore assumed to occur at mean levels below the LOD.

Dilution of the treated water with surface water in the receiving environment was not incorporated into this ERA, although a minimum mixing ratio of approximately 10:1 (surface water : treated water) would occur. Refer Eco Logical Australia (2016a) for further information.

3.2 Background Data

Surface water samples have been collected at several locations in the Namoi River Catchment, including Bohena Creek, and analysed for nutrients, physio-chemical indicators (e.g., dissolved oxygen and suspended solids), major anions/cations, total and filtered (dissolved) metals, monocyclic aromatic hydrocarbons (benzene, toluene, ethylbenzene and xylenes [BTEX]), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), pesticides, and VOCs. A figure depicting the sample locations is presented in Figure 3-1**.** All surface water monitoring results are presented in **Appendix D**.

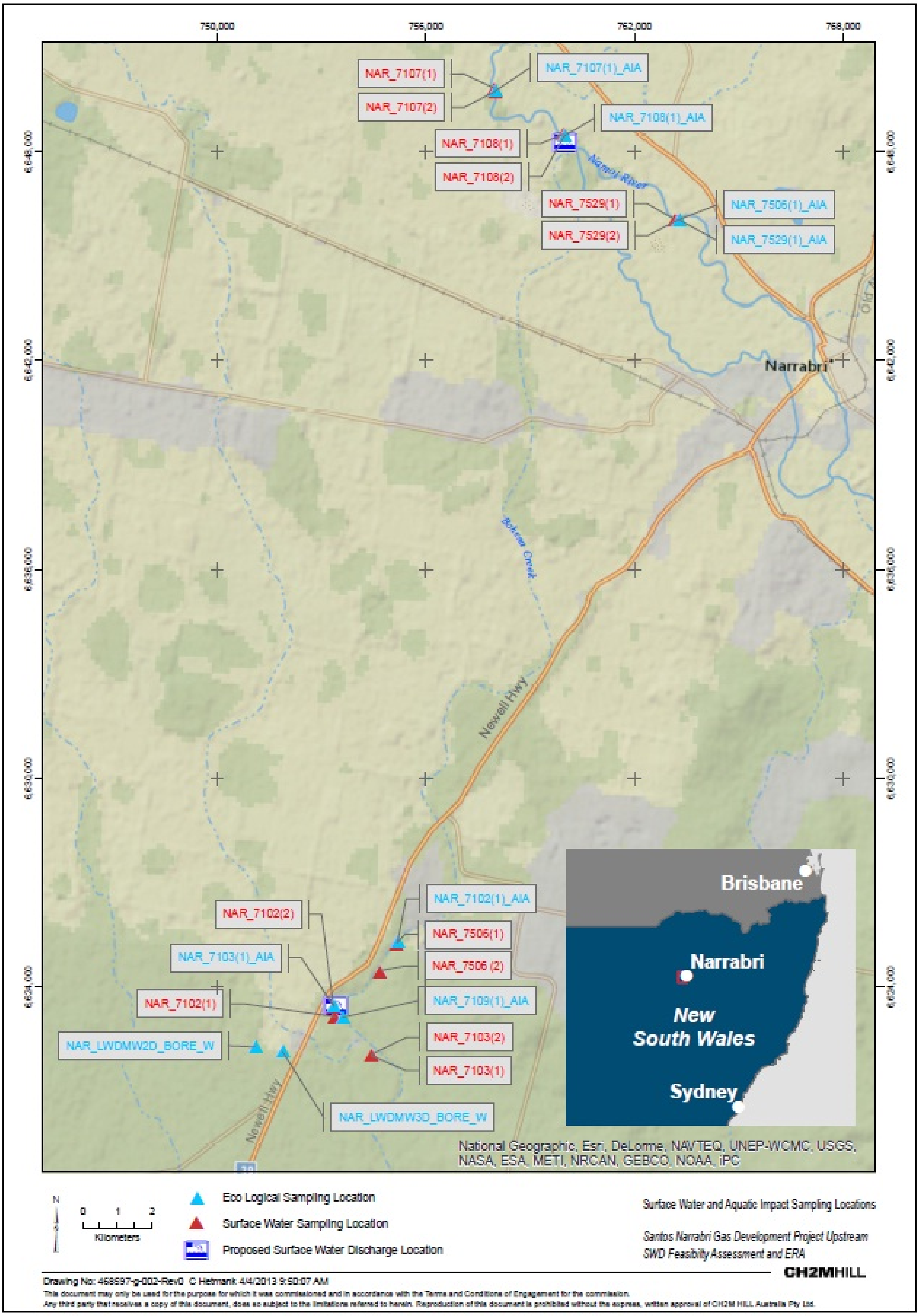


Figure 3-1: Surface Water and Aquatic Impact Sampling Locations

Surface water and sediment samples were collected in Bohena Creek during 11 to 15 March 2013 at locations corresponding to the aquatic ecological survey, and corresponding to baseline water quality monitoring sample locations (CDM Smith, 2016b). At each of three sites (upstream, adjacent to, and downstream of the potential managed release locations) along Bohena Creek, two surface water and two sediment samples were collected (12 samples total, plus quality assurance/quality check samples). Surface water samples were grab samples collected from below the water surface and were also analysed for Direct Toxicity Assessment (described in **Section 4.2** below) in addition to uranium. All surface water results are presented in **Appendix D**. Surface (0-15 cm) sediment samples were collected using a mini-sonar device and analysed for total organic carbon, grain size distribution, total metals, including uranium, PAHs, PCBs, and pesticides. All sediment results are presented in **Appendix E**.

Surface water results from samples collected in March 2013 are similar to previously collected baseline data, suggesting that survey results for the aquatic ecological survey and DTA samples are representative of typical conditions of the site. PAHs, PCBs, VOCs and SVOCs were not detected, and pesticides were infrequently detected.

Two pesticides, chlorothalonil and Benomyl were detected in surface water from Bohena Creek in March 2013 that were not previously detected in other baseline samples.

Chlorothalonil is a non-systemic foliar fungicide used for controlling fungal pathogens at a variety of crop sites and on various non-crop sites. Chlorothalonil contamination of the aquatic environment may occur from direct application or indirectly from processes such as spray drift and runoff. Chlorothalonil concentrations measured in Bohena Creek ranged from 4 to 37 μg/L and. As these concentrations are above both the Canadian guideline (CEQG, 2004) (no Australian Guideline exists), they suggest that this fungicide has the potential to affect aquatic species in both of these systems.

Benomyl (also marketed as Benlate) is a systemic foliar benzimidazole fungicide that is selectively toxic to microorganisms and invertebrates. It is used to control a wide range of fungal diseases of fruits, nuts, vegetables, field crops, turf, and ornamentals. Concerns about its teratogenicity, oncogenicity, reproductive toxicity, and adverse effects on the liver from chronic exposure caused DuPont to voluntarily cancel its U.S. registration effective January 15, 2002. DuPont (Australia) Ltd., ceased manufacture of benomyl in Australia in 2001 and sought voluntary cancellation of its registrations in September 2003. In December 2004, the registrant subsequent (Farmoz Pty Ltd) voluntarily withdrew all benomyl products from the Australian market and requested that the Australian Pesticides and Veterinary Medicines Authority (APVMA) cancel the approvals for benomyl. It became illegal to supply or use products containing benomyl in Australia after 6 December 2006 and currently there are no products containing benomyl registered for use in Australia. Benomyl concentrations measured in Bohena Creek were 0.04 μg/L. As these concentrations are well below the lowest values available for benomyl toxicity in freshwater species, they suggest that this fungicide has little, if any, potential to affect aquatic species in either of these systems.

As described in the ANZECC/ARMCANZ (2000) Guidelines, the 80th percentile of the background concentrations is the appropriate test statistic for comparison to solute concentrations and to establish site-specific guideline values. For reliability, two years of monthly background sample concentrations are recommended to derive the 80th percentile. However, due to the intermittent nature of Bohena Creek, it has not been possible to collect two years of data. The ANZECC guidelines make provisions for where few data are available and seasonal/event influences are poorly defined, suggesting a single trigger value should be derived from available data as an interim measure. The calculation of the interim 80th percentile value is presented in summarising data where available. It is noted, however, that little variation has been observed in existing data and therefore the interim 80th percentile is used for comparison in this ERA.

This approach, in combination with the comparison to default trigger values and DTA analysis, is considered suitable for protection of the environmental values. A hierarchical approach is taken to using triggers. Where DTA analysis has been undertaken, these values have priority due to the utilisation of site specific assessment. Subsequently, the published ANZECC default triggers are used. Where published default triggers are not available, the P80 of the background data is utilised to provide an interim trigger. This approach is considered appropriate, with the exception of where measured concentrations of solutes in Bohena Creek in baseline data already exceed the ANZECC default triggers.

4 Toxicity Assessment

The Toxicity Assessment determines the toxicity of the contaminants and establishes the sensitivity of the receptors. The essence of the Hazard Assessment is estimating the relationship of effects to variance in exposure. In combination with the Exposure Assessment, the Toxicity Assessment determines the potential impact on the environmental values identified for the site.

4.1 ANZECC / ARMCANZ Guideline Trigger Values

For this ERA, the toxicity of the contaminants and sensitivity of the receptors were first evaluated with ANZECC/ARMCANZ (2000) Guideline Trigger Values for surface water and sediment. Namoi River Water Quality Objectives for lowland rivers were also used for total phosphorous, total nitrogen, turbidity, salinity, and pH. The Water Quality Objectives note that '*The ANZECC Guidelines (2000) define upland streams as those above 150 m altitude. However it is noted in the objectives that recent information suggests that for the NSW Murray-Darling Basin, within which Bohena Creek sits, 250 m may be a scientifically more appropriate altitudinal trigger to distinguish between lowland and upland rivers*'. This corresponds with the description of a lowland catchment in Lampert and Short (2004) and the findings of ecological survey in Bohena Creek.

Trigger values are thresholds or a range of desirable values that indicate a potential environmental problem if exceeded or if the indicator is outside of the desirable range, and so 'trigger' a management response, e.g., further investigation and subsequent refinement of the guidelines according to local conditions.

Trigger values for surface water were selected for each indicator based on those developed for *slightly to moderately disturbed aquatic ecosystems* (ANZECC/ARMCANZ, 2000). The default 95% Level of Protection of species is considered appropriate for surface water in Bohena Creek, except for bioaccumulative chemicals, such as selenium and mercury. For bioaccumulative chemicals, 99% Level of Protection Guideline Trigger Values for surface water are used as a more conservative and protective approach, as recommended by the ANZECC/ARMCANZ Guidelines (2000). For arsenic and chromium, the Guideline Trigger Values for arsenic V and chromium VI, which are the more toxic forms, were used for evaluating the total concentrations, as a conservative assumption. For sediment, interim sediment quality guideline (ISQG) - Low values were selected as the trigger values. If default trigger values are exceeded, site-specific considerations, such as hardness adjustments for metals and pH adjustment for ammonia, can be taken into consideration. The site-specific considerations are discussed in the Risk Characterization section.

The trigger values for surface water and sediment are included in Appendices D and E.

4.2 Site Specific Direct Toxicity Assessment (Phase 1)

Key chemical parameters that may exist in treated CSG water were concurrently investigated with DTA. This proactive approach will enable concerns regarding key chemicals to be considered at an early stage and enable planning to ensure that there will be no harm to the receiving environment once operations commence. The chemicals investigated in the Phase 1 assessment were boron, which was expected[2] to

[2] Water quality from other CSG projects in QLD indicate that after treatment the boron trigger value of 0.370 mg/L is consistently exceeded.

exceed the ANZECC/ARMCANZ (2000) default trigger value of 0.37 mg/L, and fluoride for which there is no ANZECC/ARMCANZ (2000) trigger value but whose concentrations were expected to exceed the Canadian guideline of 0.12 mg/L (CCME, 2009). DTA (or whole effluent toxicity [WET]) testing elsewhere (Grothe *et al*., 1995) evaluates the aggregate toxicity of the mixture of all macro and micro-pollutants in an effluent sample using a suite of standardised aquatic toxicity assays. DTA is also one of a number of tools for deriving site specific guideline trigger values together with chemical measurement and biological survey (Van Dam and Chapman, 2001). DTA testing evaluates the adverse effects or toxicity to a population of aquatic organisms determined experimentally in the laboratory with surrogate organisms representative of those in the environment exposed to the effluent managed release. Standardised methods (selection of species and endpoints to be measured) were used for the DTA to provide results that are site-specific for Bohena Creek. Acute and chronic tests were conducted using creek water with the addition of boron and fluoride (separately). The acute tests conducted included the following:

- 48 hour acute *Ceriodaphnia dubia* survival;
- 48 h acute toxicity *Chironomus tepperi* (freshwater midge); and
- Freshwater shrimp *Paratya sp*. 96 h acute survival.

The chronic tests conducted included the following:

- 10 day embryo development *Melanotaenia splendida* (rainbow fish)
- 7 day *Ceriodaphnia dubia* partial life cycle;
- 72 hour algae *Selanastrum capricornia* using algal cell yield; and
- Seven day growth inhibition test using a freshwater duckweed (*Lemna disperma*).

Laboratory toxicity values for Bohena Creek and boron and fluoride are summarised in Table 4-1. The protective concentrations calculated using the EC_{10} data for the Bohena Creek water are above the concentrations expected to be released from the Leewood WMF based on design specifications.

Table 4-1: Summary of Boron and Fluoride DTA results for Bohena Creek

	Guidelines	Produced water (average)	Treated water (average)	Bohena Creek background (average)	Most sensitive test species and endpoint	Protective Concentration (Bohena Creek water)
Boron (mg/L)	0.37	0.86	0.116	<0.5	*Lemna disperma* (7 day plant growth)	1.8
Fluoride (mg/L)	0.12	5.8	0.08	<0.1	*Ceriodaphnia dubia* (10 day reproduction)	0.46

Additional details of the DTA testing are presented in the Managed Release - Direct Toxicity Assessment Report (Acqua Della Vita, 2016).

5 Risk Characterisation

Release of treated water have the potential to impose physical (e.g., increases in water volume), chemical (e.g., increases in conductivity, heavy metal toxicity), or biological (e.g., competition) stresses on riparian and aquatic biota in Bohena Creek. The potential for physical stresses is discussed in the Aquatic Ecological and Stygofauna Assessment (Eco Logical Australia 2016b). The release of treated water could potentially impose stress on the aquatic ecology. Since releases will occur when Bohena Creek is flowing at 100 ML/day or more, the increased flow periods and water depths will allow for more movement of larger aquatic species, however, the intermittent properties of Bohena Creek will remain largely intact and the physical ecological response will be negligible.

This Risk Characterisation primarily focuses on the stresses potentially imposed on riparian and aquatic receptors by the chemical properties of the treated water, but are considered in relation to the potential physical and biological changes described above. It uses the information gathered during the exposure and toxicity assessments to estimate the magnitude and significance of ecological impacts occurring as a result of the physicochemical and chemical stressors and toxicants that may be present in treated water.

A Decision Tree framework similar to that presented in the ANZECC/ARMCANZ Guidelines (2000) was used to undertake the assessment. Table 5-1 presents a summary of the modelled treated water concentrations in comparison to trigger values and background concentrations. Risks are considered low for chemicals in the proposed release that do not exceed trigger values.

5.1 Treated water comparison to Guideline Trigger Values

A comparison of the treated water concentrations from the Hydranautics IMS Design modelling software output from Santos and surface water Guideline Trigger Values is presented in Table 5-1. The Hydranautics IMS Design modelling software output is based on the design parameters for the Leewood WMF. The output concentrations are mean and maximum concentrations. For several metals, treatment will reduce the mean concentrations to below the limit of resolution (LOD) and are assumed to occur at levels below the LOD. As shown in Table 5-1, pH, copper, silver, cadmium, copper, and mercury, had concentrations (mean or maximum) in treated water above trigger values.

Several parameters do not have associated ANZECC/ARMCANZ (2000) trigger values and could not be evaluated against these guidelines (TDS, alkalinity, calcium, chloride, magnesium, sodium, potassium, fluoride, sulphate, silica, barium, cobalt, iron, and molybdenum). For these parameters, comparison to background concentrations was undertaken as discussed in Section 5.2.

5.2 Treated water Comparison to Background

Treated water data are also compared to background concentrations in Table 5-1. Treated water levels (mean and maximum) of pH, electrical conductivity, copper, alkalinity, and chloride exceed the background levels in Bohena Creek.

Background data exceed default trigger values for, turbidity, phosphorus, aluminium, and chromium in Bohena Creek (**Appendix D**).

5.3 Mixed water Comparison to Background

Mixed water data were compared to background concentrations in Table 5-1. A total of ten water quality parameters after mixing were compared against suggested trigger values. For mean treated water quality, the concentrations of all ten water quality parameters were below the suggested trigger values. Under the maximum treated water quality, only the concentration of mercury was slightly higher than suggested trigger values after mixing. It is however noted that projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately 4 times actual recorded produced water concentrations). Therefore, mercury is unlikely to trigger values.

5.4 Trigger Value Comparison to Baseline

Baseline concentrations were also compared to trigger values (when available) to ascertain whether the creek or river may already be experiencing chemical stresses irrespective of the proposed treated water release. Comparison of background concentrations to trigger values suggests that Bohena Creek may already be under stress from increased levels of total nitrogen, phosphorus aluminium, and chromium from sources unrelated to the project.

5.5 Site Specific Direct Toxicity Assessment (Phase 1)

No toxicity due to Bohena Creek test water alone was observed. The protective concentrations for boron and fluoride calculated using the EC_{10} data for the Bohena Creek water are higher than the projected treated water concentrations of these analytes (mean and maximum).

Table 5-1: Trigger Values Comparison Summary

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for *'slightly to moderately disturbed systems'*	Bohena Creek background (interim 80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is interim 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed ANZECC default trigger?
pH		6.5-8.0	7.43	7.10	9.2	MAX	MAX			
EC	uS/cm	125-2,200	197	357	645		MEAN/MAX		224	No
TDS	mg/L		184 115 [d]	232 [c]	419 [c]		MEAN/MAX		170	
Turbidity	NTU	6.0-50.0	59.2	<0.5	<1.0	MEAN/MAX	MEAN/MAX	YES		
Boron	mg/L	1.8 [a]	-	0.12	0.68				0.09	No
Sodium	mg/L		18 [f]	77	140				28.7	
Magnesium	mg/L		7 [f]	0.01	0.01				5.928	No
Aluminium	mg/L	0.055	1.95	<0.001	0.01			YES		
Silica	µg/L SiO2		16220	23.3	27.3					
Potassium	mg/L		2.8 [f]	0.8	1.0					
Calcium	mg/L		6.8 [f]	0.01	0.01					
Chromium (III+VI)	mg/L	0.001	0.004	<0.001	0.001			YES		
Manganese	mg/L	1.9	0.248	<0.001	0.001					
Iron	mg/L		7.742	<0.001	0.005					
Cobalt	mg/L		0.004	<0.001	-					
Nickel	mg/L	0.011	0.006	<0.001	0.000					
Copper	mg/L	0.0014	0.001	<0.001	0.002	MEAN/MAX	MAX		0.0012	No
Zinc	mg/L	0.008	0.003	<0.001	0.003					
Arsenic	mg/L	0.013	-	<0.001	0.001					
Selenium	mg/L	0.005	-	<0.001	0.001					
Molybdenum	mg/L		-	<0.001	0.000					
Cadmium	mg/L	0.0002	-	<0.001	0.00056	MEAN/MAX			0.00010	No
Barium	mg/L		0.055 [f]	<0.001	0.027					
Mercury	mg/L	0.00006	-	0.0000067	0.0002	MEAN/MAX	MEAN/MAX		0.000065	Yes [g]
Lead	mg/L	0.0034	-	<0.001	0.000					

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems*'	Bohena Creek background (interim 80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is interim 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed ANZECC default trigger?
Uranium	µg/L		-	-	0.003					
Alkalinity (Carbonate as CaCO3)	mg/L		-	139	-		MEAN			
Alkalinity (total) as CaCO3	mg/L		52	139	193		MEAN/MAX			
Ammonia as N	µg/L	900	20	15	50					
Nitrate (as N)	mg/L		0.03	-	-					
Nitrogen (Total Oxidised)	mg/L	0.04	0.04	-	-					
Nitrogen (Total)	µg/L	500	800	-	-			YES		
Sulphate	mg/L		-	0.003	0.532					
Chloride	mg/L		29	15	83		MAX		33.6	
Fluoride	mg/L	0.46 [a]	-	0.08	0.16				0.061	No
Phosphorus	mg/L	0.05	0.094	0.010	<0.01			YES		

Notes:

1. Blank cells and cells with '-' indicate value is not available or could not be calculated because it was not detected.
2. 80th percentile calculations use 0.5 x LOD
3. Max = Maximum

[a] Site-specific Boron and Fluoride Protective Concentrations developed in the DTA were used in place of ANZECC/ARMCANZ (2000) Guideline Trigger Values

[b] With 10:1 background dilution (surface water: treated water). Calculation uses mean background concentrations. Refer to Appendix E for further detail.

[c] Calculated

[d] Measured at @180°C

[e] Based on post chlorination treated water quality projections.

[f] Based on filtered measurements.

[g] Projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately 4 times actual recorded produced water concentrations). Actual values are likely to be less.

5.6 Risk estimation

Release of treated water could potentially increase levels of certain constituents and create an ionic imbalance in Bohena Creek, if undiluted, but problematic levels are unlikely and risks are considered low. With episodic release and flowing conditions (natural flow of ≥ 100 ML/day), dilution with receiving water will further eliminate potential risks. Additional details are described below:

- The projected treated water maximum value for pH exceeds the default ANZECC trigger value. Considering that the projected treated water maximum pH is expected to occur infrequently (and is dependent on maximum levels in produced water inflows to the Leewood WMF in combination with low treatment performance) and that treated water pH can be adjusted prior final release, risks are considered low as levels will predominantly occur at levels below the trigger value.
- Projected treated water (mean and maximum values) exceed the default ANZECC trigger for turbidity, cadmium, copper and mercury;
- Projected treated water (mean and maximum) turbidity values are outside of the trigger value preferred range and background levels. While high turbidity releases from treated water are expected to infrequently occur, the discharge of large volumes of very clear water to turbid watercourses can increase light penetration and promote excessive macrophyte or algal growth (Commonwealth of Australia, 2014). Dilution and mixing under flowing conditions is expected to eliminate this concern. Adherence to the Managed Release Protocol will ensure that the proportion of low turbidity treated water released to the flowing creek will remain small by comparison with the natural flow, with a minimum ratio of 10:1 dilution, and commonly significantly greater.
- Cadmium and mercury projected treated water mean concentrations were provided by IMS Hydranautics at limits of reporting (LOR) that exceed ANZECC trigger values. Future analytical testing should seek to rectify this to gain appropriate LORs for assessment;
- For cadmium, the default trigger value (0.2 µg/L) is only slightly exceeded by maximum levels (1 µg/L), which is expected to occur infrequently for the reasons noted above. Additionally, for cadmium, dilution and mixing under flowing conditions demonstrates that this concern can be effectively eliminated.
- For mercury, projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately four times actual recorded produced water concentrations). Mean and maximum treated water values are therefore likely to be less than those calculated. Predicted dilution and mixing under flowing conditions demonstrates that this concern can be eliminated for mean values. Furthermore, maximum values are expected to infrequently occur. Mercury will predominantly occur at levels below the LOD, and, even at low detected levels is not expected to pose a bioaccumulation risk to wildlife (the primary reason for selecting a higher level of protection) since methylation rates will likely be very low due to low levels of dissolved organic carbon and neutral pH in the treated water.
- The interim P80 value indicates that Bohena Creek may have naturally or anthropogenically-derived turbidity and aluminium, chromium, and phosphorus concentrations above the default ANZECC trigger. As treated water contains little or no detectable levels of aluminium, chromium, or phosphorus, it is highly unlikely that these chemicals would add to whatever stresses these currently extant chemicals may pose to aquatic life in the creek once treated water is released. The source of these chemical stressors is not known exactly at this time, but may be due to natural conditions. Detected levels of pesticides in surface water are evidence of the agricultural sources.

- The treated water has higher levels of sodium, TDS, and EC, and lower levels of calcium, magnesium, and potassium, which suggests the possibility of an ion imbalance if the water were released either undiluted or unamended. Adverse effects can occur in aquatic organisms when common ions exceed a certain concentration, when the normal composition (ratio) of ions is not correct, or when ion concentrations are too low. Ion imbalance can directly affect receptors through osmotic stress and competition of anion gill sites, and indirectly through a decrease in the bioavailability of essential elements. The impact of ion-poor water on Australian native fish species is understudied and poorly understood. The temporary release in Bohena Creek in 2011 and subsequent aquatic ecological survey provides some indication of the potential effects (AECOM, 2011). The temporary release pool had a similar ion composition as treated water evaluated in this ERA, with samples dominated by sodium and alkalinity, and low levels of calcium, magnesium, potassium, and sulphate. Nineteen different macroinvertebrate taxa were identified and assessed against community descriptors and results indicated that the macroinvertebrate community sampled was largely dominated by pollution and disturbance tolerant taxa. Fish survey of the pool habitat in the study area identified six species of fish including three native species and three introduced species. The fish community within this pool had few or no small individuals. This observation was expected as the pool was thought to provide only short term refuge for migrating fish until the recommencement of flows in Bohena Creek trigger dispersal in response to spawning cues or general life cycle requirements (i.e. potamodromous species) to more productive habitats. None of the fish species observed were threatened species.

Since treated water will be released under flowing conditions with dilution levels at a mixing ratio of a minimum of approximately 10:1, the negative effects of ion imbalance are unlikely to occur, and risks are considered low.

5.7 Summary of Key Findings

On the basis of analysis undertaken taken to date, ecological risks from the physicochemical and chemical stressors and toxicants that may be present in projected treated water are considered low, particularly when released to a flowing stream.

It is noted that without dilution, some toxicity from treated water, or excessive macrophyte or algal growth, may be possible due to a potential ion imbalance and low turbidity, but these risks are expected to be eliminated in wet conditions by dilution and mixing.

5.8 Assumptions and Uncertainties

Estimates of the true risk are always uncertain to some extent because of limited available data, the need to make certain assumptions and extrapolations to compensate for incomplete information ("data gaps"), and the natural variability and complexity of ecological systems. The risk estimates offered by this ERA should therefore be interpreted in the context of the primary uncertainties discussed below.

5.8.1 Modelled output treated water data

This ERA is based on estimated levels of contaminants in projected treated water and the design basis for the Leewood WMF, and actual levels may differ from the estimated levels used here. The Hydranautics IMS Design modelling software projections provided by Santos estimate average concentrations based on levels in the produced water and the design basis for the Leewood WMF. While higher concentrations are possible, and risks could therefore be underestimated. Near maximum concentrations are expected to infrequently occur and are dependent on maximum levels in raw (untreated) produced water in combination with low WMF treatment performance. Significantly underestimated risks are therefore not expected. In addition, the treated water will also be diluted by a minimum of 10:1 in actual exposure concentrations to varying degrees in Bohena Creek.

5.8.2 Treated Water Quantity

A number of steps have been taken to reduce uncertainties related to treated water quantity by performing scenario simulations related to episodic release. Further information on these can be found in Eco Logical Australia (2016a).

5.8.3 Cumulative effects

The cumulative risk from simultaneous exposure to chemicals that co-occur in the treated water is considered low because individual risks were also considered low. Since treated water will be diluted in actual exposure concentrations in Bohena Creek the treated water addition is not expected to introduce problematic levels.

6 Conclusions

6.1 Risks

On the basis of analysis undertaken taken to date, overall ecological risks from the physicochemical and chemical stressors and toxicants that may be present in projected treated water are considered low.

6.2 Risk Management Decisions

The results of the ERA are used to inform one of four risk management decisions, specifically:

- **To take no action**. Managed release would commence with no additional action needed.
- **To monitor the site.** Managed release would commence but additional monitoring would be needed.
- **To remediate or actively manage the site**. Managed release would not proceed without more thorough active management of the treated water, such as additional treatment, amendment or reduced treated water release rates.
- **To proceed to detailed ERA.** Following discussions with regulators, a more detailed ERA may be required if risks are present.

6.2.1 Monitoring

As described in Eco Logical Australia (2016a), the need to monitor the release site has been identified and a water monitoring plan (CDM Smith, 2016a) has been developed as part of the Project EIS (GHD, 2016).

6.2.2 Interim trigger values

Interim release limit trigger values of treated water at proposed release locations are presented in Table 6-1 until further development of trigger values is established (for example ecotoxicity or reference site based). Interim triggers are based on adopting the ANZECC Default Trigger in the first instance. Where either an ANZECC default trigger is not available, or if the baseline P80 value is higher than the ANZECC trigger (i.e. as a result of upstream influences) the calculated interim 80th percentile background value is taken. For boron and fluoride, they represent the protective concentration developed in the DTA. Molybdenum and sulphate were not detected in Bohena Creek and, therefore, the proposed release limits should not be above LODs.

Table 6-1 Interim trigger values for mixed water in Bohena Creek

Constituent	Units	Basis of trigger value selection	
		Interim trigger value	Basis
Electrical conductivity	µS/cm	125-2,200	ANZECC/ARMCANZ (2000)
pH	pH Units	6.5-8.0	ANZECC/ARMCANZ (2000)
Total Dissolved Solids	mg/L	[see note 1]	
Turbidity	NTU	6.0-50.0	ANZECC/ARMCANZ (2000)
Alkalinity (Carbonate as CaCO3)	mg/L	[see note 1]	
Ammonia as N	µg/L	900	ANZECC/ARMCANZ (2000)
Calcium (Filtered)	mg/L	[see note 1]	
Chloride	mg/L	29	80th percentile background levels
Fluoride	mg/L	0.46	DTA
Nitrogen (Total)	µg/L	800	80th percentile background levels
Phosphorus	µg/L	94	80th percentile background levels
Potassium (Filtered)	mg/L	2.8	80th percentile background levels
Silica	µg/L	16,220	80th percentile background levels
Sodium (Filtered)	mg/L	[see note 1]	
Sulphate	mg/L	[see note 1]	
Aluminium	mg/L	1.95	80th percentile background levels
Arsenic	mg/L	0.013	ANZECC/ARMCANZ (2000)
Barium	mg/L	0.055	80th percentile background levels
Boron	mg/l	1.8	DTA
Cadmium	mg/L	0.0002	ANZECC/ARMCANZ (2000)
Chromium (III+VI)	mg/L	0.001	ANZECC/ARMCANZ (2000)
Cobalt	mg/L	0.004	80th percentile background levels
Copper	mg/L	0.0014	ANZECC/ARMCANZ (2000)
Iron	mg/L	7.742	80th percentile background levels
Lead	mg/L	0.0034	ANZECC/ARMCANZ (2000)
Magnesium (Filtered)	mg/L	[see note 1]	
Manganese	mg/L	1.9	ANZECC/ARMCANZ (2000)
Mercury	mg/L	0.00006	ANZECC/ARMCANZ (2000)
Molybdenum	mg/L	LOD	<LOD
Nickel	mg/L	0.011	ANZECC/ARMCANZ (2000)
Selenium	mg/L	0.005	ANZECC/ARMCANZ (2000)
Zinc	mg/L	0.008	ANZECC/ARMCANZ (2000)

Notes:

General: Proposed managed release limits represent the ANZECC default trigger value. Where an ANZECC value is not available or where background observed data exceed the ANZECC default trigger, the 80th percentile background concentration is used for the assessment.

DTA: Managed release limits for boron and fluoride based on DTA results.

1. Suggested triggers are not provided for TDS, alkalinity, calcium, sodium, sulphate and magnesium. These parameters are expected to approach Bohena Creek concentrations after mixing, at a mixing ratio of a minimum of 10:1.

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Appendix A - Water Quality & River Flow Objectives

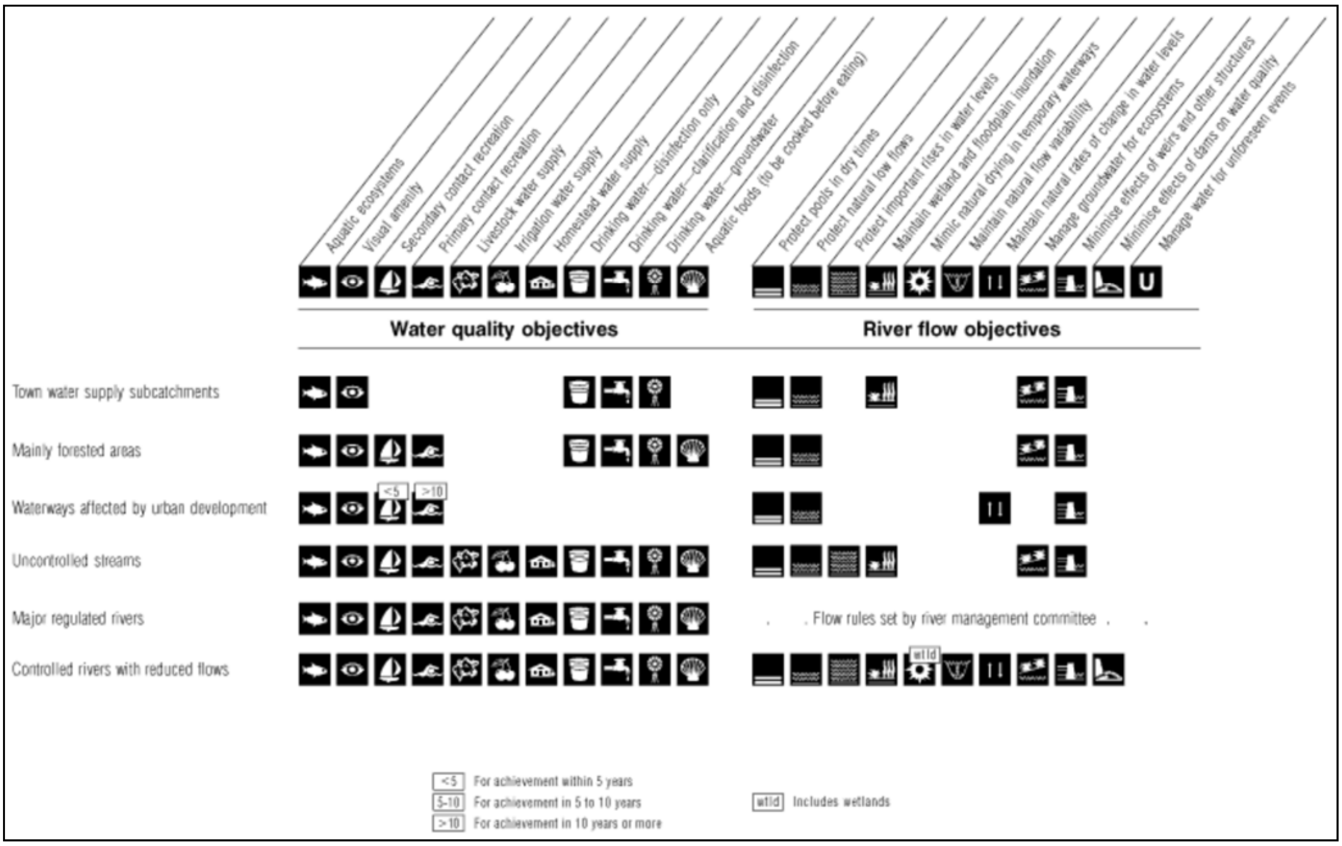

Figure A1: Namoi River Water Quality and River Flow Objectives

Appendix B – Namoi Catchment Action Plan (2010-2020): Thresholds & Targets

Table B1: Namoi Catchment Action Plan 2010-2020 Thresholds and Targets

Thresholds		Targets
Biodiversity	• Woody vegetation cover at 30% in cleared sub-catchments. • Woody vegetation cover at 70% in intact sub-catchments. • 61% of Regional Vegetation Communities maintain 30% extent. • Population size of individual threatened species. • Habitat area for individual threatened species or population. • Area of endangered or vulnerable community. • Presence of individual invasive species. • Population extent of individual invasive species.	1. By 2020 there is an increase in native vegetation extent and vegetation does not decrease to less than 70% in less cleared sub-catchments and 30% in over cleared sub-catchments and no further Regional Vegetation Community decreases to less than 30% extent as identified by 2010 baseline. 2. By 2020 maintain sustainable populations of a range of native fauna species by ensuring that no further Regional Vegetation Community decreases to less than 30% extent as identified by 2010 baseline. 3. By 2020 contribute to the recovery of priority viable threatened species, populations and communities. 4. By 2020 no new invasive species are established in the Catchment and the spread of key emerging invasive plants and animals is limited.
Land	• Ground cover is at least 70%.	1. By 2020 there is an improvement in soil health as measured by an increase in ground cover at the paddock, sub-catchment and catchment scales.
Water	• Surface water flow quantity is at 66% of natural (pre-development) condition with a sensitivity to natural frequency and duration. • Geomorphic condition is good (against benchmark condition). • Recruitment of riparian vegetation is higher than attrition of individual trees, shrubs or ground cover species. • Agricultural and urban supply aquifers do not cross into lower levels of beneficial use regarding quality. • Alluvial aquifers are not drawn down below long term historical maximum draw down levels. • Groundwater is within 30m of surface where there are identified groundwater dependent ecosystems. • Wetland is not drained, dammed or otherwise physically modified.	1. By 2020 there is an improvement in the condition of those riverine ecosystems that have not crossed defined geomorphic thresholds as at the 2010 baseline 2. By 2020 there is an improvement in the ability of groundwater systems to support groundwater dependent ecosystems and designated beneficial uses 3. By 2020 there is an improvement in the condition of regionally important wetlands and the extent of those wetlands is maintained.
People	• There is no clearly defined threshold relating to people. Rather, there is a focus on the generalities of building resilient social capital by increasing adaptive capacity and sustaining or improving wellbeing.	1. Natural resource management decisions contribute to social wellbeing. 2. There is an increase in the adaptive capacity of the Catchment Community.

Appendix C – Stakeholders

Table C1: Stakeholders

Stakeholder	Location	Goals
Namoi Catchment Management Authority	Responsible for the entire Namoi catchment	Engage community in key natural resource management issues
NSW EPA	NSW-wide	Leading business and the community to improve their environmental performance and for managing waste to deliver a healthy environment
NSW Trade and Investment, Resources and Energy, Minerals and petroleum	NSW-wide	Responsible for facilitating profitable and sustainable mineral resources development, effective environmental management and safe and responsible mining and petroleum production in NSW.
NSW Office of Water	NSW-wide	Responsible for the regulation of water resources under the *Water Management Act 2000 and Water Act 1912*
Narrabri Shire	Namoi Valley in North West NSW	“Narrabri Shire will be a strong and vibrant regional growth centre providing a quality living environment for the entire Shire community”
State Water Corporation	New South Wales’ rural bulk water delivery business.	State Water owns, maintains, manages and operates major infrastructure to deliver bulk water to approximately 6,300 licensed water users on the state’s regulated rivers along with associated environmental flows. State Water own and operate Mollee Weir on the Namoi River.
Sheep and cattle farmers	Borah Ck subcatchment	Successful grazing and raising of sheep and cattle
Town water users	Narrabri (Extracted from 3 bores from an aquifer within the lower Namoi catchment)	No health impacts to water source
	Pilliga (Extracted from 1 bore from the GAB aquifer)	
	Bellata (Extracted from 1 bore from the GAB aquifer)	
	Boggabri (Extracted from 1 bore within the lower Namoi catchment)	

Stakeholder	Location	Goals
	Gwabegar (Extracted from 1 bore from the GAB aquifer)	
	Wee Waa (Extracted from 3 bores from the lower Namoi catchment)	
Bohena Creek surface water users (995.5 ML/yr) (99% for irrigation purposes, 1% for stock and domestic purposes)	Along Bohena Creek	Irrigation, raising cattle/sheep
Bundock Creek surface water users (5,142.5 ML/yr) (99.3% for irrigation purposes, 0.7% for stock and domestic purposes)	Along Bundock Creek	Irrigation, raising cattle/sheep
Upper Namoi surface water users (10,333.5 ML/yr) (94.1% for irrigation purposes, 5.5% for town water supply, 0.4% for stock and domestic purposes)	Along Upper Namoi River	Irrigation, raising cattle/sheep
Lower Namoi surface water users (2,689.5 ML/yr) (98% for irrigation purposes, 1.6% for stock and domestic purposes)	Along Lower Namoi River	Irrigation, raising cattle/sheep
Irrigators	NE and SW of Narrabri	Successful raising and harvesting of crops
Coal Mines		
Narrabri North	18km from Leewood	To effectively mine coal
Boggabri	57km from Leewood	
Tarrawonga	60km from Leewood	
Rocglen	68km from Leewood	
Sunnyside	71km from Leewood	
Cargill Grain Processing Plant (town water)	22km from Leewood	Crush canola, soybeans, sunflower and cottonseed and produce protein meal for animal feed and vegetable oils for foods such as margarine, salad dressings and frying.

Stakeholder	Location	Goals
Friends of Pilliga Forest	Focused on Pilliga Forest	Maintaining ecological values of Pilliga State Forest; ensuring CSG does not impact upon values
The Wilderness Society	Focused on Pilliga Forest	Maintaining ecological values of Pilliga State Forest; ensuring CSG does not impact upon values
Traditional owners, the Kamilaroi people	People from land between Tamworth and Goondiwindi, and west to Narrabri, Walgett and Lightning Ridge, in northern NSW	Maintain aboriginal culture and significant sites (Gins Leap,
Population of Narrabri	26km from Leewood	Live a happy and productive life
Fishing enthusiasts	Narrabri township, Narrabri creek	Ensure habitat for fish populations to flourish to promote leisure
Narrabri Fish Farm	10km from Narrabri on Jacks Creek Road	To effectively farm fish
Birdwatchers	State Forests and Pilliga Forest	Watch birdlife and ensure a healthy avian community
Picnickers	State Forests and Pilliga Forest	Socialize in nature and enjoy natural surroundings
Wildflower enthusiasts	State Forests and Pilliga Forest	Enjoy wildflowers and ensure a healthy floral community
Tourists	State Forests and Pilliga Forest, Narrabri town	Enjoy tourist attractions around Narrabri

Appendix D – Bohena Creek Surface Water Quality Data

Table D1: Bohena Creek Surface Water Quality Data

Chem_Group	ChemName	Units	EQL/ LOD	16/04/2012 NAR_7506_SURF_W	17/05/2012 NAR_7506_SURF_W	12/06/2012 NAR_7506_SURF_W	16/07/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	11/02/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(2)_SURF_W	12/03/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(1)_SURF_W	12/03/2013 NAR_7103(1)_SURF_W	12/03/2013 NAR_7103(2)_SURF_W	12/03/2013 NAR_7506(1)_SURF_W	12/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7103(1)_SURF_W	14/03/2013 NAR_7103(2)_SURF_W	14/03/2013 NAR_7102(1)_SURF_W	27/02/2012 NAR_7505_SURF_W_1 205302_001	16/07/2012 NAR_7505_SURF_W_1 217499_001	14/03/2013 NAR_7102(2)_SURF_W
	>C10 - C40 Fraction (sum)	mg/L	0.1	-	-	-	-	<0.1	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	-
	Cyprodinil	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Fipronil	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Scheduled chemicals (NSW Waste 2008)	mg/L		<0.008	<0.008	<0.008	<0.008	<0.0085	-	<0.0085	-	<0.0085	-	<0.0085	<0.0085	<0.0085	<0.0085	<0.0085	<0.0085	<0.0085	<0.0085	-	-	-	-	-	-	-
	>C16 - C34 Fraction	mg/L	0.1	-	-	-	<0.1	<0.1	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.12	<0.1	-
	>C34 - C40 Fraction	mg/L	0.1	-	-	-	<0.1	<0.1	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.1	<0.1	-
	C6 - C10 Fraction	mg/L	0.02	-	-	-	<0.02	<0.02	-	<0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.02	<0.02	-
	Benzo(a)pyrene TEQ (WHO)	µg/L	0.5	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Brodifacoum	mg/L	0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	-	<0.00005	-	<0.00005	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	-	-	-	-	-	<0.00005	-
	Chlorothalonil	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	37	<2	9	24	4	19	16	-	-	-	-	-	<2	-
	Cyproconazole	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Demeton-O & Demeton-S	mg/L	0.00002	-	-	-	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Diflufenican	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Dissolved Organic Carbon	mg/L	1	9	-	-	10	9	-	11	-	11	-	12	16	18	9	7	7	9	12	-	-	-	-	36	15	-
	Dissolved Oxygen ppm	ppm		-	-	-	-	-	9.47	-	-	-	8.23	-	-	-	-	-	-	-	-	-	-	-	-	3.4	11.2	-
	Field Dissolved Oxygen	mg/L	0.1	-	4.98	7.07	7.52	9.47	-	9.23	-	8.23	-	-	2.58	7.47	2.26	5.41	5.23	6.39	4.29	-	-	-	2.26	7.58	9.38	-
	Hexaconazole	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Irgarol	mg/L	0.000002	<0.000002	<0.000002	<0.000002	<0.000002	<0.000002	-	<0.000002	-	<0.000002	-	<0.000002	<0.000002	<0.000002	<0.000002	<0.000002	<0.000002	<0.000002	<0.000002	-	-	-	-	-	<0.000002	-
	Langelier Index	-		1.53	2.33	1.79	-	1.34	-	-	-	1.69	-	-	3.11	0.99	3.82	2.32	2.1	2.78	1.84	-	-	-	-	-2.490	-0.210	-
	Metribuzin	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Oryzalin	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Paclobutrazol	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Pyrimethanil	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.02	-
	Total Dissolved Solids (Calc.)	mg/L		-	-	-	-	-	-	-	-	-	120.9	-	-	-	-	-	-	-	-	-	-	-	-	-	586	-
	Total Dissolved Solids @180°C	mg/L	10	116	114	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86	-	-
	>C10 - C16 Fraction	mg/L	0.1	-	-	-	<0.1	<0.1	-	<0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.120	<0.1	-
	Penconazole	mg/L	0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Sum of polycyclic aromatic hydrocarbons	mg/L	0.0005	-	-	-	<0.0005	<0.0005	-	<0.0005	-	<0.0005	-	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	-	-	-	-	<0.0005	<0.0005	-
	Sulfate as SO4 - Turbidimetric (Filtered)	mg/L	1	-	-	-	-	-	-	-	-	<1	-	<1	<10	<1	<1	<1	<1	<1	<10	-	-	-	-	<1	10	-
	Sulfate Reducing Bacteria	MPN/100mL		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Thiamethoxam	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	C10 - C36 Fraction (sum)	µg/L	50	-	-	-	-	-	-	<50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	<50	-
	Benzene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Ethylbenzene	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	<2	<2	-
	Toluene	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	<2	<2	-
BTEX	Sum of BTEX	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Xylene (m & p)	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	-	-
	Xylene (o)	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	-	-
	Xylene Total	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	<2	<2	-
Carbamates	Methiocarb	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-

Chem_Group	ChemName	Units	EQL/ LOD	16/04/2012 NAR_7506_SURF_W	17/05/2012 NAR_7506_SURF_W	12/06/2012 NAR_7506_SURF_W	16/07/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	11/02/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(2)_SURF_W	12/03/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(1)_SURF_W	12/03/2013 NAR_7103(1)_SURF_W	12/03/2013 NAR_7103(2)_SURF_W	12/03/2013 NAR_7506(1)_SURF_W	12/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7103(1)_SURF_W	14/03/2013 NAR_7103(2)_SURF_W	14/03/2013 NAR_7102(1)_SURF_W	27/02/2012 NAR_7505_SURF_W_1 205302_001	16/07/2012 NAR_7505_SURF_W_1 217499_001	14/03/2013 NAR_7102(2)_SURF_W
Field	Dissolved Oxygen	mg/L	0.1	7.6	6.4	9.5	10	8.4	-	9.2	-	7.6	-	8.1	6.9	9.9	8.1	10.1	9.9	10.2	10.3	-	-	-	-	-	-	-
	Dissolved Oxygen2																									-	-	
	Dissolved Oxygen3																									-	-	
	EC (field)	uS/cm		-	-	-	-	-	127.1	-	159.5	-	144.7	-	-	-	-	-	-	-	-	-	-	-	-	158.8	375.3	-
	pH (Field)	pH_Units		-	-	-	-	-	7.72	-	-	-	5.91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Temp	oC		-	-	-	-	-	7.9	-	18.1	-	13.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Turbidity	ntu	0.1	19.1	101	29.5	18.6	7.2	-	11.5	-	50.1	-	59.2	-	2.5	-	-	-	-	-	8.7	25.7	19.5	20.5	165	109	7.1
Fungicides	Benomyl	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	-	-	-	-	-	<0.01	-
	Difenoconazole	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Fenarimol	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Iprodione	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Flusilazole (NuStar)	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Propiconazole	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
Halogenated Benzenes	Hexachlorobenzene	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
Herbicides	Ametryn	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Asulam	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	<2	-
	Atrazine	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Bromacil	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Bromoxynil	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Chlorsulfuron	µg/L	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	1.3	-
	Cyanazine	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Diclofop-methyl	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Diuron	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Fluometuron	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Hexazinone	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Metolachlor	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Molinate	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	-	-	-	-	<0.1	-
	Oxyfluorfen	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	-	<1	-
	Pendimethalin	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Prometryn	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Propazine	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Simazine	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Tebuthiuron	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	<0.00002	-
	Terbutryn	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Thiobencarb	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Trifluralin	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
Inorganics	Alkalinity (Bicarbonate as CaCO3)	mg/L	1	42	36	53	34	-	-	48	-	44	-	41	23	71	17	30	28	26	50	-	-	-	-	29	81	-
	Alkalinity (Carbonate as CaCO3)	mg/L	1	<1	<1	<1	<1	54	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Alkalinity (Hydroxide) as CaCO3	µg/L	1000	<1000	<1000	<1000	<1000	<1000	-	<1000	-	<1000	-	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	-	-	-	-	<1000	<1000	-
	Alkalinity (total) as CaCO3	mg/L	1	42	36	53	34	54	-	48	-	44	-	41	23	71	17	30	28	26	50	-	-	-	-	29	81	-
	Ammonia as N	µg/L	10	<10	50	<10	10	70	-	<10	-	10	-	30	<10	<10	<10	<10	10	10	<10	<10	<10	<10	-	50	20	<10
	Anions Total	meq/L	0.01	1.46	1.51	1.82	1.5	1.78	-	1.86	-	1.73	-	1.5	0.69	2.12	0.82	1.05	1.01	1	1.79	-	-	-	-	1.28	4.70	-

Chem_Group	ChemName	Units	EQL/ LOD	16/04/2012 NAR_7506_SURF_W	17/05/2012 NAR_7506_SURF_W	12/06/2012 NAR_7506_SURF_W	16/07/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	11/02/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(2)_SURF_W	12/03/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(1)_SURF_W	12/03/2013 NAR_7103(1)_SURF_W	12/03/2013 NAR_7103(2)_SURF_W	12/03/2013 NAR_7506(1)_SURF_W	12/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7103(1)_SURF_W	14/03/2013 NAR_7103(2)_SURF_W	14/03/2013 NAR_7102(1)_SURF_W	27/02/2012 NAR_7505_SURF_W_1 205302_001	16/07/2012 NAR_7505_SURF_W_1 217499_001	14/03/2013 NAR_7102(2)_SURF_W
	BOD	mg/L	2	4	6	<2	<2	<2	-	<2	-	4	-	<2	-	<2	-	-	-	-	-	<2	3	3	3	-	-	<2
	Cations Total	meq/L	0.01	1.5	1.58	1.67	1.31	1.62	-	1.72	-	1.53	-	1.59	0.73	2.1	0.86	1.05	1.1	1.11	1.79	-	-	-	-	1.31	4.68	-
	Chloride	mg/L	1	22	28	27	29	25	-	32	-	30	-	24	8	25	17	16	16	17	28	-	-	-	-	25	102	-
	Cyanide Total	mg/L	0.004	-	-	-	-	<0.004	-	<0.004	-	<0.004	-	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	-	-	-	-	-	-	-
	Electrical conductivity *(lab)	uS/cm	1	158	172	167	151	199	-	189	-	195	-	147	76	224	102	117	115	118	197	-	-	-	-	147	512	-
	Fluoride	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	<0.1	<0.1	-
	Ionic Balance	%	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.27	-
	Kjeldahl Nitrogen Total	mg/L	0.1	0.8	1.1	0.5	0.4	0.4	-	0.4	-	0.8	-	0.4	1	0.8	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.8	-	1.3	0.5	0.4
	Nitrate (as N)	mg/L	0.01	0.03	0.01	0.01	0.14	<0.01	-	0.02	-	<0.01	-	0.11	-	<0.01	-	-	-	-	-	<0.01	0.03	0.02	<0.01	<0.01	0.23	<0.01
	Nitrite (as N)	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	-	<0.01	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Nitrogen (Total Oxidised)	mg/L	0.01	0.03	0.01	0.01	0.14	<0.01	-	0.02	-	<0.01	-	0.11	<0.01	<0.01	0.12	0.07	<0.01	0.02	0.03	<0.01	0.03	0.02	<0.01	-	-	<0.01
	Nitrogen (Total)	µg/L	100	800	1100	500	500	400	-	400	-	800	-	500	1000	800	600	600	600	600	600	600	500	800	-	1300	700	400
	pH (Lab)	pH_Units	0.01	7.37	6.71 - 7	6.97 - 7.08	7.24 - 7.35	7.59 - 7.72	-	7.43	-	5.91 - 7.36	-	7.33	6.21 - 6.51	5.59 - 7.69	5.89 - 6.01	6.96 - 7.04	7.27 - 7.34	6.81 - 6.82	6.86 - 7.02	-	-	-	5.89	6.97	8.03	-
	Reactive Phosphorus as P	mg/Lf	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	0.04	-	<0.01	-	<0.01	-	-	-	-	-	<0.01	<0.01	<0.01	0.04	<0.01	0.08	<0.01
	Silica	µg/L	100	15,200	14,500	13,700	15,700	11,600	-	13,000	-	12,200	-	17,600	11,400	16,200	16,300	15,500	14,500	25,700	14,300	-	-	-	-	-	-	-
	Sodium (Filtered)	mg/L	1	14	17	17	15	16	-	17	-	17	-	16	7	19	13	9	10	14	18	-	-	-	-	21	37	-
	Sulphate	mg/L	1	<1	<1	<1	<1	<1	-	<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TDS	mg/L	10	-	-	110	87	139	-	90	-	126	-	172	86	164	93	160	202	220	192	-	-	-	-	-	-	-
	TOC	mg/L	1	10	12	10	10	11	-	11	-	12	-	11	16	17	9	6	6	8	12	-	-	-	-	36	13	-
	TSS	mg/L	5	14	49	17	16	8	-	<5	-	27	-	28	20	6	26	16	18	29	<5	-	-	-	-	19	130	-
Lead	Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	0.005	<0.001	-
	Lead (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
Metals	Aluminium	mg/L	0.01	0.12	0.25	0.25	0.5	0.3	-	0.24	-	0.28	-	2.88	0.23	0.07	0.19	0.51	0.18	2.31	0.11	-	-	-	-	7.46	5.48	-
	Aluminium (Filtered)	mg/L	0.01	0.02	0.02	0.04	0.07	0.08	-	0.12	-	0.01	-	1.07	0.04	0.04	0.05	0.06	0.08	0.23	0.12	-	-	-	-	0.25	0.13	-
	Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	0.002	<0.001	-
	Arsenic III	mg/L																								-	-	
	Arsenic V	mg/L																								-	-	
	Arsenic (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Barium	mg/L	0.001	0.056	0.095	0.048	0.026	0.038	-	0.032	-	0.056	-	0.052	0.032	0.025	0.029	0.037	0.029	0.04	0.037	-	-	-	-	0.052	0.108	-
	Barium (Filtered)	mg/L	0.001	0.042	0.049	0.039	0.023	0.033	-	0.027	-	0.041	-	0.039	0.025	0.023	0.023	0.031	0.023	0.022	0.034	-	-	-	-	0.024	0.066	-
	Beryllium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Beryllium (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Boron	mg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	-
	Boron (Filtered)	mg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	<0.05	<0.05	-
	Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	-	-	-	<0.0001	<0.0001	-
	Cadmium (Filtered)	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	0.0003	-	-	-	-	<0.0001	<0.0001	-
	Calcium (Filtered)	mg/L	1	7	6	6	4	6	-	7	-	5	-	6	2	7	2	4	4	3	6	-	-	-	-	2	21	-
	Chromium (III+VI)	mg/L	0.001	<0.001	<0.001	<0.001	0.001	<0.001	-	<0.001	-	0.006	-	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	-	-	-	-	0.011	0.009	-
	Chromium (III+VI) (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Cobalt	mg/L	0.001	0.003	0.02	0.003	<0.001	<0.001	-	0.001	-	0.004	-	0.003	0.004	0.001	0.004	0.001	<0.001	0.002	<0.001	-	-	-	-	0.004	0.004	-
	Cobalt (Filtered)	mg/L	0.001	0.002	0.004	0.001	<0.001	<0.001	-	<0.001	-	0.002	-	0.001	0.002	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-

				16/04/2012	17/05/2012	12/06/2012	16/07/2012	21/08/2012	21/08/2012	17/09/2012	17/09/2012	23/10/2012	23/10/2012	11/02/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	14/03/2013	14/03/2013	14/03/2013	14/03/2013	27/02/2012	16/07/2012	14/03/2013
Chem_Group	ChemName	Units	EQL/ LOD	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7102(2)_SURF_W	NAR_7506_SURF_W	NAR_7102(1)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7506(1)_SURF_W	NAR_7506(2)_SURF_W	NAR_7506(2)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7102(1)_SURF_W	NAR_7505_SURF_W_1 205302_001	NAR_7505_SURF_W_1 217499_001	NAR_7102(2)_SURF_W
	Copper	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.002	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	0.004	0.005	-
	Copper (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	-	-	-	-	<0.001	0.002	-
	Iron	mg/L	0.05	3.79	11.2	5.14	2.85	1.28	-	2.77	-	9.8	-	3.78	7.63	1.22	4.31	3.49	1.59	5.76	1.99	-	-	-	-	16.3	7.77	-
	Iron (Filtered)	mg/L	0.05	0.81	1.8	0.66	0.27	0.46	-	1.34	-	1.27	-	0.69	2.55	0.86	0.96	0.48	0.42	0.3	1.01	-	-	-	-	1.68	0.15	-
	Lithium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	<0.001	-	-	-	-	0.003	<0.001	-
	Lithium (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Magnesium (Filtered)	mg/L	1	6	6	7	5	7	-	7	-	6	-	6	3	10	2	5	5	4	8	-	-	-	-	3	23	-
	Manganese	mg/L	0.001	0.483	2.04	0.257	0.064	0.066	-	0.108	-	0.321	-	0.16	0.198	0.178	0.123	0.126	0.067	0.172	0.147	-	-	-	-	0.122	0.212	-
	Manganese (Filtered)	mg/L	0.001	0.338	0.396	0.139	0.047	0.024	-	0.056	-	0.222	-	0.106	0.085	0.129	0.105	0.079	0.013	0.053	0.056	-	-	-	-	0.072	0.007	-
	Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	-	-	-	<0.0001	<0.0001	-
	Mercury (Filtered)	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	-	-	-	<0.0001	<0.0001	-
	Molybdenum	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	0.002	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Molybdenum (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Nickel	mg/L	0.001	0.003	0.005	0.003	0.003	0.002	-	0.003	-	0.004	-	0.004	0.007	0.006	0.006	0.002	0.001	0.005	0.003	-	-	-	-	0.003	0.012	-
	Nickel (Filtered)	mg/L	0.001	0.003	0.003	0.003	0.002	0.002	-	0.003	-	0.002	-	0.003	0.006	0.005	0.005	0.001	<0.001	0.003	0.002	-	-	-	-	0.006	0.002	-
	Phosphorus	mg/L	0.01	0.07	0.2	0.06	0.04	0.02	-	0.12	-	0.17	-	0.03	0.06	0.03	0.01	<0.01	0.03	0.09	0.02	0.03	0.02	0.1	-	-	-	0.04
	Potassium (Filtered)	mg/L	1	2	2	2	2	2	-	2	-	2	-	4	3	4	1	2	2	1	2	-	-	-	-	2	5	-
	Selenium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	<0.01	<0.01	-
	Selenium (Filtered)	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	<0.01	<0.01	-
	Silver	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Silver (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Strontium	mg/L	0.001	0.109	0.096	0.08	0.068	0.105	-	0.096	-	0.102	-	0.076	0.04	0.116	0.031	0.064	0.055	0.049	0.104	-	-	-	-	0.048	0.320	-
	Strontium (Filtered)	mg/L	0.001	0.101	0.086	0.078	0.065	0.093	-	0.087	-	0.092	-	0.07	0.036	0.113	0.03	0.06	0.052	0.043	0.1	-	-	-	-	0.034	0.295	-
	Tin	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Tin (Filtered)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-	-	-	<0.001	<0.001	-
	Uranium	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Uranium (Filtered)	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Vanadium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	0.02	<0.01	-
	Vanadium (Filtered)	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	<0.01	<0.01	-
	Zinc	mg/L	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	<0.005	-	<0.005	-	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	-	-	-	-	0.011	0.008	-
	Zinc (Filtered)	mg/L	0.005	<0.005	0.01	0.005	<0.005	<0.005	-	<0.005	-	<0.005	-	<0.005	0.006	<0.005	0.015	<0.005	<0.005	<0.005	0.037	-	-	-	-	0.008	<0.005	-
Organic	Terbutylazine	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	0.00005	-
Organochlorine Pesticides	4,4-DDE	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	a-BHC	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Aldrin	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Aldrin + Dieldrin	µg/L	0.5	<1	<1	<1	<1	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	b-BHC	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	chlordane	µg/L	0.5	-	-	-	-	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Chlordane (cis)	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Chlordane (trans)	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	d-BHC	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-

				16/04/2012	17/05/2012	12/06/2012	16/07/2012	21/08/2012	21/08/2012	17/09/2012	17/09/2012	23/10/2012	23/10/2012	11/02/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	14/03/2013	14/03/2013	14/03/2013	14/03/2013	27/02/2012	16/07/2012	14/03/2013
Chem_Group	ChemName	Units	EQL/ LOD	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7102(2)_SURF_W	NAR_7506_SURF_W	NAR_7102(1)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7506(1)_SURF_W	NAR_7506(2)_SURF_W	NAR_7506(2)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7102(1)_SURF_W	NAR_7505_SURF_W_1 205302_001	NAR_7505_SURF_W_1 217499_001	NAR_7102(2)_SURF_W
	DDD	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	DDT	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	<2	-
	DDT+DDE+DDD	µg/L	0.5	<3	<3	<3	<3	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Dieldrin	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Endosulfan I	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Endosulfan II	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-
	Endosulfan sulphate	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Endrin	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Endrin aldehyde	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Endrin ketone	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	g-BHC (Lindane)	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Heptachlor	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Heptachlor epoxide	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Methoxychlor	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	<2	-
Organophosphorous Pesticides	Azinophos methyl	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Bolstar (Sulprofos)	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-
	Bromophos-ethyl	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-
	Carbophenothion	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Azinphos Ethyl	mg/L	0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	<0.00002	-	<0.00002	-	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	<0.00002	-	-	-	-	-	0.00002	-
	Chlorfenvinphos	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Chlorpyrifos	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Chlorpyrifos-methyl	mg/L	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	-	<0.0002	-	<0.0002	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	-	-	-	-	-	<0.0002	-
	Coumaphos	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Demeton-O	µg/L	0.02	<0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.02	-
	Diazinon	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Dichlorvos	µg/L	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	<0.2	-
	Dimethoate	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Disulfoton	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Ethion	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Ethoprop	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Fenitrothion	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	<2	-
	Fensulfothion	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Fenthion	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Malathion	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Methyl parathion	µg/L	2	<2	<2	<2	<2	<2	-	<2	-	<2	-	<2	<2	<2	<2	<2	<2	<2	<2	-	-	-	-	-	-	-
	Mevinphos (Phosdrin)	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Monocrotophos	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Omethoate	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Phorate	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-
	Prothiofos	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-
	Ronnel	µg/L	10	<10	<10	<10	<10	<10	-	<10	-	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	-	-	-	-	-	-	-
	Terbufos	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-

Chem_Group	ChemName	Units	EQL/ LOD	16/04/2012 NAR_7506_SURF_W	17/05/2012 NAR_7506_SURF_W	12/06/2012 NAR_7506_SURF_W	16/07/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	21/08/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	17/09/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	23/10/2012 NAR_7506_SURF_W	11/02/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(2)_SURF_W	12/03/2013 NAR_7506_SURF_W	12/03/2013 NAR_7102(1)_SURF_W	12/03/2013 NAR_7103(1)_SURF_W	12/03/2013 NAR_7103(2)_SURF_W	12/03/2013 NAR_7506(1)_SURF_W	12/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7506(2)_SURF_W	14/03/2013 NAR_7103(1)_SURF_W	14/03/2013 NAR_7103(2)_SURF_W	14/03/2013 NAR_7102(1)_SURF_W	27/02/2012 NAR_7505_SURF_W_1 205302_001	16/07/2012 NAR_7505_SURF_W_1 217499_001	14/03/2013 NAR_7102(2)_SURF_W
	Trichloronate	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	-
	Tetrachlorvinphos	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
Other	Tebuconazole	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Triazophos	mg/L	0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	-	<0.000005	-	<0.000005	-	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005	-	-	-	-	-	<0.000005	-
PAH/Phenols	PAH (total, NSW Waste 2008)	mg/L		<0.0155	<0.0155	<0.0155	<0.0155	<0.0155	-	<0.0155	-	<0.0155	-	<0.0155	<0.0155	<0.0155	<0.0155	<0.0155	<0.0155	<0.0155	<0.0155	-	-	-	-	-	-	-
	Acenaphthene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Acenaphthylene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Anthracene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Benz(a)anthracene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Benzo(a) pyrene	µg/L	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	<0.5	-	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-	<0.5	<0.5	-
	Benzo(b)fluoranthene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Benzo(g,h,i)perylene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Benzo(k)fluoranthene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Chrysene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Dibenz(a,h)anthracene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Fluoranthene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Fluorene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Indeno(1,2,3-c,d)pyrene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Naphthalene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	PAHs (Sum of total)	µg/L	0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Phenanthrene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Pyrene	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
Pesticides	Pesticides (total, NSW Waste 2008)	mg/L		<0.00567	<0.00567	<0.00567	<0.00567	<0.00567	-	<0.00567	-	<0.00567	-	<0.00567	0.00284	<0.00567	<0.00567	<0.00567	<0.00567	<0.00567	<0.00567	-	-	-	-	-	-	-
	3-Hydroxy Carbofuran	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Aldicarb	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Bendiocarb	µg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-
	Carbaryl	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Carbofuran	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Cyromazine	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	Demeton (total)	µg/L	0.02	<0.02	<0.02	<0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Demeton-S-methyl	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	-	-
	Fenamiphos	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Methomyl	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Oxamyl	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Parathion	µg/L	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	<0.2	-
	Pirimiphos-methyl	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Pirimphos-ethyl	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Profenofos	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	-
	Sulfotepp	µg/L	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	<0.005	-	<0.005	-	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	-	-	-	-	<0.005	-
	Temephos	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-
	Trichlorfon	µg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-

				16/04/2012	17/05/2012	12/06/2012	16/07/2012	21/08/2012	21/08/2012	17/09/2012	17/09/2012	23/10/2012	23/10/2012	11/02/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	12/03/2013	14/03/2013	14/03/2013	14/03/2013	14/03/2013	27/02/2012	16/07/2012	14/03/2013
Chem_Group	ChemName	Units	EQL/ LOD	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7506_SURF_W	NAR_7102(2)_SURF_W	NAR_7506_SURF_W	NAR_7102(1)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7506(1)_SURF_W	NAR_7506(2)_SURF_W	NAR_7506(2)_SURF_W	NAR_7103(1)_SURF_W	NAR_7103(2)_SURF_W	NAR_7102(1)_SURF_W	NAR_7505_SURF_W_1 205302_001	NAR_7505_SURF_W_1 217499_001	NAR_7102(2)_SURF_W
	Thiodicarb	mg/L	0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001	-	<0.00001	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	<0.00001	-
	Arochlor 1016	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Arochlor 1221	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Arochlor 1232	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Arochlor 1242	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
Polychlorinated Biphenyls	Arochlor 1248	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Arochlor 1254	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Arochlor 1260	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	Aroclor 1262	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	<1	<1	-
	PCBs (Sum of total)	µg/L	1	<1	<1	<1	<1	<1	-	<1	-	<1	-	<1	<1	<1	<1	<1	<1	<1	<1	-	-	-	-	-	-	-
SVOCs	EPN	µg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	-
	C10-C16	mg/L	0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-			-
	C16-C34	mg/L	0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
	C34-C40	mg/L	0.1	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
	C6 - C10 Fraction minus BTEX (F1)	µg/L	20	<20	<20	<20	<20	<20	-	<20	-	<20	-	<20	<20	<20	<20	<20	<20	<20	<20	-	-	-	-	<20	<20	-
	C10 - C14	µg/L	50	<50	<50	<50	<50	<50	-	<50	-	<50	-	<50	<50	<50	<50	<50	<50	<50	<50	-	-	-	-	-	-	-
TPH	C6 - C9	µg/L	20	<20	<20	<20	<20	<20	-	<20	-	<20	-	<20	<20	<20	<20	<20	<20	<20	<20	-	-	-	-	<20	<20	-
	C15 - C28	µg/L	100	<100	<100	<100	<100	<100	-	<100	-	<100	-	<100	<100	<100	<100	<100	<100	<100	<100	-	-	-	-	110	<100	-
	C29-C36	µg/L	50	<50	<50	<50	<50	<50	-	<50	-	<50	-	<50	<50	<50	<50	<50	<50	<50	<50	-	-	-	-	<50	<50	-
	+C10 - C36 (Sum of total)	µg/L	50	<50	<50	<50	<50	<50	-	<200	-	<50	-	<50	<50	<50	<50	<50	<50	<50	<50	-	-	-	-	-	-	-
	C10 - C40 (Sum of total)	µg/L	100	<100	<100	<100	-	-	-	-	-	<100	-	<100	<100	<100	<100	<100	<100	<100	<100	-	-	-	-	-	-	-
	C6-C10	mg/L	0.02	<0.02	<0.02	<0.02	-	-	-	-	-	<0.02	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	-	-

Appendix E – Sediment Quality Data

Table E1: Bohena Creek Sediment Quality Data

				Field_ID	NAR_7102(1)_SEDS	NAR_7102(2)_SEDS	NAR_7103(1)_SEDS	NAR_7103(2)_SEDS	NAR_7506(1)_SEDS	NAR_7506(2)_SEDS	NAR_DS_SEDS
				LocCode	NAR	NAR	NAR	NAR	NAR	NAR	NAR
				Sample_Depth_Range	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm
				Sampled_Date-Time	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013
				Matrix_Description	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
ChemName		**Units**	**EQL**	**Trigger Value**							
	+75µm	%	1		99	93	98	96	100	100	99
	+150µm	%	1		99	93	98	96	100	100	99
	+300µm	%	1		94	86	87	90	98	99	97
	+425µm	%	1		81	74	64	73	93	97	88
	+600µm	%	1		53	51	34	41	79	85	63
	+1180µm	%	1		10	14	4	4	36	35	10
	+2.36mm	%	1		2	2	<1	<1	8	7	<1
	+4.75mm	%	1		<1	<1	<1	<1	2	<1	<1
	+9.5mm	%	1		<1	<1	<1	<1	<1	<1	<1
	+19.0mm	%	1		<1	<1	<1	<1	<1	<1	<1
	+37.5mm	%	1		<1	<1	<1	<1	<1	<1	<1
	+75.0mm	%	1		<1	<1	<1	<1	<1	<1	<1
	Cobbles (>6cm)	%	1		<1	<1	<1	<1	<1	<1	<1
	Fines (<75 µm)	%	1		<1	7	2	4	<1	<1	<1
	Gravel (>2mm)	%	1		2	2	<1	<1	8	7	<1
	Sand (>75 µm)	%	1		97	92	98	96	92	93	99
Halogenated Benzenes											
	Hexachlorobenzene	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Inorganics											
	Ammonia as N	mg/kg	1		<1	<1	<1	<1	<1	<1	<1
	TOC	mg/kg	0.02		0.12	0.3	0.17	0.11	0.07	0.11	0.18
Lead											
	Lead	mg/kg	1	50	<1	<1	<1	<1	<1	<1	<1
Metals											
	Aluminium	mg/kg	50		540	1140	660	600	350	230	560
	Antimony	mg/kg	0.5	2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Arsenic	mg/kg	1	20	<1	<1	<1	<1	<1	<1	<1
	Cadmium	mg/kg	0.1	1.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Chromium (III+VI)	mg/kg	1	80	1.1	2.4	1.3	1.2	<1	<1	1.3
	Cobalt	mg/kg	0.5		1.1	0.7	1	0.9	0.7	<0.5	1.5
	Copper	mg/kg	1	65	<1	<1	<1	<1	<1	<1	<1
	Iron	mg/kg	50		2360	3470	2030	1560	850	470	3100
	Manganese	mg/kg	10		17	<10	26	20	50	<10	24
	Mercury	mg/kg	0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Nickel	mg/kg	1	21	1.4	1.6	<1	<1	<1	<1	1.6
	Selenium	mg/kg	0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Silver	mg/kg	0.1	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

					NAR_7102(1)_SEDS	NAR_7102(2)_SEDS	NAR_7103(1)_SEDS	NAR_7103(2)_SEDS	NAR_7506(1)_SEDS	NAR_7506(2)_SEDS	NAR_DS_SEDS
				Field_ID	NAR_7102(1)_SEDS	NAR_7102(2)_SEDS	NAR_7103(1)_SEDS	NAR_7103(2)_SEDS	NAR_7506(1)_SEDS	NAR_7506(2)_SEDS	NAR_DS_SEDS
				LocCode	NAR	NAR	NAR	NAR	NAR	NAR	NAR
				Sample_Depth_Range	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm
				Sampled_Date-Time	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013
				Matrix_Description	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
	Uranium	mg/kg	0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Vanadium	mg/kg	2		2	3.7	2.5	2.4	<2	<2	2.5
	Zinc	mg/kg	1	200	1.3	3.2	1.1	1.1	<1	<1	1.5
Organochlorine Pesticides											
	4,4-DDE	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	a-BHC	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Aldrin	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	b-BHC	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	chlordane	mg/kg	0.00025	0.0005	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
	Chlordane (cis)	mg/kg	0.00025		<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
	Chlordane (trans)	mg/kg	0.00025		<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
	d-BHC	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	DDD	mg/kg	0.0005	0.002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	DDT	mg/kg	0.0005	0.0016	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	DDT+DDE+DDD	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Dieldrin	mg/kg	0.0005	0.00002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endosulfan	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endosulfan I	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endosulfan II	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endosulfan sulphate	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endrin	mg/kg	0.0005	0.00002	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endrin aldehyde	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Endrin ketone	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	g-BHC (Lindane)	mg/kg	0.00025	0.00032	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
	Heptachlor	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Heptachlor epoxide	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Methoxychlor	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Oxychlordane	mg/kg	0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Organophosphorous Pesticides											
	Azinophos methyl	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Bromophos-ethyl	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Carbophenothion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Chlorfenvinphos E	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Chlorpyrifos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Chlorpyrifos-methyl	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Diazinon	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	cis-Chlorfenvinphos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Dichlorvos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Dimethoate	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

				Field_ID	NAR_7102(1)_SEDS	NAR_7102(2)_SEDS	NAR_7103(1)_SEDS	NAR_7103(2)_SEDS	NAR_7506(1)_SEDS	NAR_7506(2)_SEDS	NAR_DS_SEDS
				LocCode	NAR	NAR	NAR	NAR	NAR	NAR	NAR
				Sample_Depth_Range	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm
				Sampled_Date-Time	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013
				Matrix_Description	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
	Ethion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Fenthion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Malathion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Methyl parathion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Monocrotophos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Prothiofos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH/Phenols											
	2-methylnaphthalene	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Acenaphthene	mg/kg	0.004	0.016	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Acenaphthylene	mg/kg	0.004	0.044	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Anthracene	mg/kg	0.004	0.085	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Benz(a)anthracene	mg/kg	0.004	0.261	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Benzo(a) pyrene	mg/kg	0.004	0.43	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Benzo(b)fluoranthene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Benzo(g,h,i)perylene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Benzo(k)fluoranthene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Chrysene	mg/kg	0.004	0.384	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Dibenz(a,h)anthracene	mg/kg	0.004	0.063	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Fluoranthene	mg/kg	0.004	0.6	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Fluorene	mg/kg	0.004	0.019	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Naphthalene	mg/kg	0.005	0.16	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	PAHs (Sum of total)	mg/kg	0.004	4	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Phenanthrene	mg/kg	0.004	0.24	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Pyrene	mg/kg	0.004	0.665	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Pesticides											
	Demeton-S-methyl	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Fenamiphos	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Parathion	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Pirimphos-ethyl	mg/kg	0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Polychlorinated Biphenyls											
	Arochlor 1016	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1221	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1232	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1242	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1248	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1254	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Arochlor 1260	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	PCBs (Sum of total)	mg/kg	0.005	0.023	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

				Field_ID	NAR_7102(1)_SEDS	NAR_7102(2)_SEDS	NAR_7103(1)_SEDS	NAR_7103(2)_SEDS	NAR_7506(1)_SEDS	NAR_7506(2)_SEDS	NAR_DS_SEDS
				LocCode	NAR	NAR	NAR	NAR	NAR	NAR	NAR
				Sample_Depth_Range	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm	0-15 cm
				Sampled_Date-Time	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013	3/14/2013
				Matrix_Description	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
SVOCs											
	Benzo(e)pyrene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
	Coronene	mg/kg	0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Perylene	mg/kg	0.004		<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

Notes:
All Trigger Values are ISQG-Low values from ANZECC/ARMCANZ (2000)
Shaded cells are for detected results that exceed trigger values

eco logical AUSTRALIA

ISO 14001 Environmental Management

AS/NZS 4801:2001 Occupational Health and Safety Management

ISO 9001 Quality Management

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Appendix B Direct Toxicity Assessment

Toxicity Assessment of River Water with the Addition of Boron and Fluoride

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Acronyms and abbreviations

ANZECC/ARMCANZ	Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.
BCF	Bio-concentration factor
CSG	Coal seam gas
DTA	Direct toxicity assessment
EC50	Effective concentration to 50% of the test population
EEC	Estimated environmental concentration
ERA	Ecological risk assessment
ESA	Ecotox Services Australia
IC10	Concentration causing inhibition to 10% of the test population
IC50	Concentration causing inhibition to 50% of the test population
K_{ow}	Octanol water partition coefficient
LC50	Lethal concentration to 50% of the test population
LOEC	Lowest observable effect concentration
LOR	Limit of reporting
ML	Mega litre
NOEC	No observable effect concentration
PNEC	Predicted no effect concentration
RO	Reverse osmosis
SSD	species sensitivity distribution
TIE	Toxicity identification evaluation
TT	Toxicity threshold
WQO	Water Quality Objective

Executive Summary

Santos has elected to investigate the toxicity of key chemical parameters that may exist in treated CSG water prior to the design and construction of a new reverse osmosis treatment facility at Leewood, NSW. This proactive approach will enable concerns regarding key chemicals to be considered at an early stage and enable planning to ensure that there will be no harm to the receiving environment once operations commence.

Guideline trigger values are intended to be protective of a broad range of ecosystem type but may be overly conservative for some individual ecosystem types. ANZECC/ARMCANZ (2000) provides methodology to determine site specific trigger values that are protective of the receiving environment using the steps outlined in Figure 1 in this report.

The initial chemicals assessed are boron for which the maximum concentration in the produced water is expected to exceed the present ANZECC/ARMCANZ (2000) default trigger value of 0.37 mg/L, and fluoride for which there is no ANZECC/ARMCANZ (2000) trigger value but fluoride concentrations are expected to exceed the Canadian guideline of 0.12 mg/L (CCME 2009) based on the review and data in Section 2.4 of this document. Site specific values can then be used to guide the treatment requirements for this water.

The aim of this work was to generate data to develop site specific trigger values for boron and fluoride for a potential discharge location at Bohena Creek. Whilst the laboratory assessment was conducted during the period 2013 to 2014, a recent review of the work has confirmed that all of the analysis and the findings of the study remain current and in accordance with current guidance / best practice (ANZECC/ARMCANZ 2000). The 2000 guidelines are presently under review and change to the boron default guideline is expected to be revised upwards to 0.9 mg/L (Graeme Batley, CSIRO pers.comm.).

Test species included in the direct toxicity assessment were

Acute tests

- 48 h acute toxicity – survival *Ceriodaphnia dubia* (water flea)
- 48 h acute toxicity – survival *Chironomus tepperi* (freshwater midge)
- 96 h acute toxicity - survival *Paratya australiensis* (freshwater shrimp)

Chronic tests

- 10 day embryo development *Melanotaenia splendida* (rainbow Fish)
- 7 day partial life cycle *Ceriodaphnia dubia* (water flea)
- 72 hour algal cell yield *Selanastrum capricornia* (microalgae)
- 7 day growth inhibition test *Lemna disperma* (duckweed)

The experimentally derived protective concentrations (PC_{95}) generated by this study for Bohena Creek are PC_{95} = 1.8 mg/L for boron and PC_{95} = 0.46 mg/L for fluoride. These values are both greater than the default guideline trigger value for boron (0.37 mg/L ANZECC/ARMCANZ 2000) and the anticipated revised value under the revision, plus the Canadian guideline value for fluoride of 0.12 mg/L (CWQG 2014). These values are also both greater than the maximum concentrations expected in the treated water from the Leewood

Water Treatment Plant once constructed. This indicates that there is low risk to ecosystem health from boron or fluoride on release to Bohena Creek, even during no flow periods within the river where minimal dilution with natural waters will occur.

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1 INTRODUCTION

Santos has elected to investigate the toxicity of key chemical parameters that may exist in treated CSG water prior to the design and construction of a new reverse osmosis treatment facility at Leewood, NSW. This proactive approach will enable concerns regarding key chemicals to be considered at an early stage and enable planning to ensure that there will be no harm to the receiving environment once operations commence. The initial chemicals assessed are boron for which the maximum concentration in the feed pond is expected to exceed the ANZECC/ARMCANZ (2000) default trigger value of 0.37 mg/L, and fluoride for which there is no ANZECC/ARMCANZ (2000) trigger value but fluoride concentrations are expected to exceed the Canadian guideline of 0.12 mg/L (CCME 2009).

The aim of this work is to generate data to contribute to the development of site specific trigger values for boron and fluoride for the potential discharge location at Bohena Creek.

The Australian and New Zealand Guidelines for the Protection of Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) recommend the use of DTA as a tool for deriving site-specific guidelines when the default trigger are expected to be exceeded. The following steps are followed when applying the guidelines for the protection of aquatic ecosystems

- Define primary management aims – this requires definition of the water body to be protected, determination of environmental values, level of protection and management goals.
- Determine appropriate guideline trigger values for selected indicators – this is initially conducted as a desk top exercise using existing reference data, including biological, chemical and physical data about the system itself.
- Apply the decision tree framework as outlined in the ANZECC/ARMCANZ (2000) guidelines (Figure 1) including Direct Toxicity Assessment (DTA) if required.

Stages of a chemical risk assessment include measurement, evaluation, identification of causal agent and mitigation. The process is iterative and as knowledge is gained, refinement of the procedure is made so they are relevant to the specific scheme.

2 BACKGROUND

2.1 Treatment plant and discharge water quality

Santos Limited (Santos) is currently exploring for Coal Seam Gas (CSG) within the Gunnedah Basin in the area of Narrabri, New South Wales.

2.2 Narrabri Gas Project

The Narrabri Gas Project is located in an area known as the “Pilliga Forest” approximately 30 kilometres to the south west of Narrabri in Petroleum Exploration Licence (PEL) 238. The project involves extraction of natural gas and water from deep-seated coals within the Bohena sub-basin. Exploration activities in the Pilliga commenced in 1998 and have included seismic surveys, stratigraphic core-hole drilling, pilot well drilling and production appraisal activities including management of water and gas products. Santos is undertaking a range of water management studies and scientific assurance studies which will assist the project to proceed.

2.3 Receiving environment

The overarching goal of ecological risk assessment is to protect biodiversity. An important component of this is a thorough characterisation of the ecosystem that it is sought to protect and the environmental values placed on that ecosystem. Important environmental values include aquatic ecosystems, primary industries, recreation and aesthetics and cultural and spiritual values (ANZECC/ARMCANZ 2000). All water resources are subject to at least one environmental value and in most cases, several. It is essential that the needs of all stakeholders are understood at the time these values are identified. In Australia aquatic ecosystems are supported by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000). These guidelines are presently undergoing review. The guidelines are applied by first defining the primary management aims and determining the appropriate guideline trigger value and finally the water quality objectives (WQO) are determined. The national guidelines are not mandatory and application of the guidelines is a state or territory responsibility.

2.4 Aims of project

The aim of this work is to provide data to contribute to the derivation of site specific trigger values for Bohena Creek, NSW for boron and fluoride following the methodology shown in Figure 1.

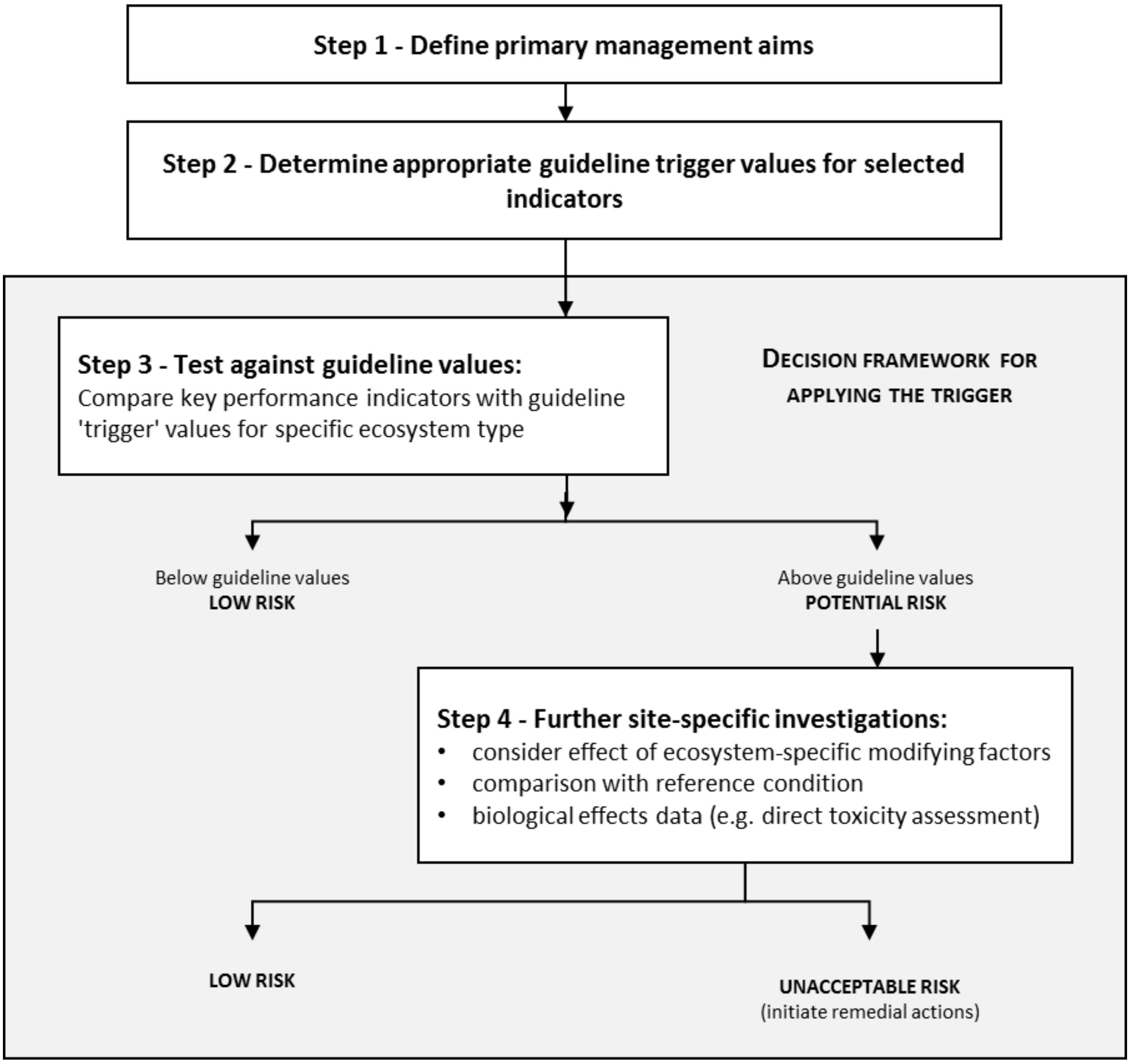

Figure 1 Decision tree for assessing physicochemical stressors in ambient waters (Modified from Figure 3.3.1, page 3.3-2 Volume 1, Australia & NZ Guidelines for Marine & Freshwater Quality ANZECC/ARMCANZ (2000))

2.5 Identification of key chemicals

Key chemical parameters that were identified during initial screening were investigated using direct toxicity assessment (DTA). These were boron, which was expected to exceed the ANZECC/ARMCANZ (2000) default trigger value of 0.37 mg/L, and fluoride for which there is no ANZECC/ARMCANZ (2000) trigger value but whose concentrations were expected to exceed the Canadian guideline of 0.12 mg/L (CCME, 2009). DTA evaluates the aggregate toxicity of the mixture of all macro and micro-pollutants in an effluent sample using a suite of standardised aquatic toxicity assays. DTA is also one of a number of tools for deriving site specific guideline trigger values together with chemical measurement and biological survey (Van Dam and Chapman, 2001).

2.5.1 Boron

2.5.1.1 Boron concentrations in water

Boron (B) is a metalloid that is not found in nature in elemental form but as borate (B-O) salts of magnesium, sodium and calcium. Boron compounds are highly soluble in water and form essentially only two species, un-disassociated boric acid (H_3BO_3) and borate anion ($B(OH^-_4)$ with the relative abundance of these being pH dependent (Soucek et al, 2011). In Europe, South America, Asia and the United States of America natural concentrations of boron in freshwaters are typically 100 – 500 ug/L and rarely exceeding 1000 ug/L (Maier & Knight, 1991; Howe 1998, IPCS 1998). In natural freshwater systems boron is generally in the form of boric acid at concentrations that do not present a risk to aquatic organisms (Schoderboeck et al, 2011) but boron can be at toxic concentrations as a result of discharge attributed to anthropogenic activities such as agriculture and mining. Concentrations of boron expected to be in produced water and permeate, and measured for Bohena Creek are provided in Table 1.

2.5.1.2 Boron guidelines

Various guidelines for boron have been derived for a range of water end uses including drinking water, water used in primary industries, ecosystem protection and irrigation (Table 2). The guideline values are based on a concentration that is expected to be safe to water users under a range of exposure scenarios.

2.5.1.3 Boron toxicity

Boron is an essential nutrient for plants but there is a small range between deficiency and toxicity. Boron plays a role in carbohydrate metabolism, pollen germination and normal growth and functioning of plants. Although boron is an essential trace element, certain plants (e.g. citrus fruit, stone fruit and some nut trees) are sensitive to the toxic effects of boron if irrigation water has concentrations higher than about 500ug/L (Lazarova et al 2005).

Toxicity thresholds (TT) in water for microorganisms are high (TT = 290 mg/L boron), but significantly lower for aquatic organisms such as fish (Soucek et al, 2011). A variety of species have been tested for sensitivity to boron with algae, fish and microcrustaceans being most sensitive and amphibians, insects and molluscs being the least sensitive (Soucek et al 2011). In studies with fish the most sensitive fish species and life stage identified so far are rainbow trout embryos. Lowest observed effect concentrations (LOEC) have been reported as low as 100ug/L in reconstituted water (Butterwick et al 1989). This value is not consistent with other toxicity data reported even within the same publication. This has been commented on in ANZECC/ARMCANZ (2000), Chapter 8 as a possible anomalous result that required further investigation (Table 3).

Black et al (1993) conducted tests with trout embryos to compare toxicity from reconstituted water to natural dilution waters. Consistent LOECs ranged from 0.1 - >18 mg/L boron across the various dilution waters. The wide range of LOEC values was attributed to different types of dilution water and differential sensitivities of the trout strains used in the study. Based on the results of these tests, together with data from field surveys the authors concluded that a concentration of between 0.75 and 1.0 mg/L was a reasonable environmentally acceptable limit for boron in aquatic ecosystems.

Table 1 Concentrations of boron in water

Water type	Location	Concentrations (mg/L)	Data source
Produced water	Leewood	Average (0.86), maximum (1.7)	Output from Hydranautics IMS Design modelling software, supplied by Santos, 2013.
Permeate	Leewood	Average (0.116), maximum (0.67)	Output from Hydranautics IMS Design modelling software, supplied by Santos, 2013.
River water	Bohena Creek	Not detected (LOR 0.05)	Eco Logical Australia, 2016b. Narrabri Gas Project, Managed Release Study (Bohena Creek) Ecological Risk Assessment.

Table 2 Guideline values for boron

Environmental Value	Guideline value (mg/L)	Guideline / reference
Aquatic ecosystems (freshwater)	0.37 Trigger value for 95% species protection	Australia and New Zealand Guidelines for Marine and Fresh Water Quality. (ANZECC/ARMCANZ 2000)
Aquatic wildlife	1.5	Canadian Council of Ministers of the Environment (CCME 2009)
Aquatic wildlife	1	Illinois EPA (1972 and reconfirmed in 2011) (cited in Soucek et al, 2011)
Drinking water	4	Australian Drinking Water Guidelines (ADWG 2011)
Drinking water	2.4 (updated from 4 in 2004 version)	WHO Guidelines for Drinking Water Quality (WHO 2011)
Primary industries	Livestock drinking: 5 Irrigation: 0.5	Australia and New Zealand Guidelines for Marine and Fresh Water Quality (ANZECC/ARMCANZ 2000)
Irrigated crops	1	Californian State Water Quality Control Board (cited in Soucek et al, 2011)
Various end uses	4	Australian Guidelines for Water Recycling Guidelines (AGWR 2008)

Table 3 Toxicity data for freshwater aquatic species to boron in water

Test species	Endpoint	Boron toxicity* (mg/L)	Reference
Chironomus decorus (4^{th} instar larvae)	Insect – acute lethal (LC_{50})	1376 (1298 – 1453)	Maier and Knight (1991)
Allocapnia vivipara Winter stone fly	96 h LC_{50}	476 (401-566)	Soucek et al (2011)
Lampsilis siliquoidea and *Ligumia recta* (mussels)	96 h LC_{50}s	137 and 147 respectively	Soucek et al (2011)
Toads	EC_{50}	123 – 148	WHO (1998)
Frogs	EC_{50}	54 – 157	WHO (1998)
Onorynchus mykiss Rainbow trout larvae	28 day flow through - EC_{50}	27 – 100	WHO (1998)
Chironomus decorus	Acute lethal – 96 h EC_{50}	20	WHO (1998)
Fathead minnows	30 day NOEC	14	WHO (1998)
Pimephales promelas (fathead minnow)	acute lethal (LC_{50})	7.97 (7.2–8.8)	Soucek et al (2011)
Daphnia magna (micro crustacean)	Chronic – reproduction (NOEC)	6	ANZECC/ARMCANZ (2000) chapter 8
Daphnia magna	Various endpoints	6 – 10	WHO (1998)
Chlorella vulgaris (unicellular algae)	Population growth (NOEC)	5.2	ANZECC/ARMCANZ (2000) chapter 8
Daphnia magna (micro crustacean)	Predicted no effect concentration (PNEC)	1.3 mg/L	Dyer 2001
Rainbow trout embryo	LOEC	0.1** - >18	Black et al (1993)

*****includes confidence intervals where reported

** value may be anomalous (refer to text)

2.5.2 Fluoride

2.5.2.1 Fluoride in water

Fluoride is a naturally occurring substance and is also intentionally added to drinking water to promote strong teeth. It is derived from weathering of natural deposits or discharge from fertiliser and aluminium factories. Of all of the elements in the periodic table fluoride is the most electronegative and is not found in its elemental state existing either as inorganic fluorides including the free ion or as organic fluoride compounds (e.g. freons). In water fluoride usually remains in solution (as fluoride ions) under conditions of low pH and low hardness and in association with humics and clays (CEPA, 1994 cited in Camargo 2003). Inorganic fluorides however may be removed from solution by precipitation of calcium fluoride or magnesium fluoride (Stumm and Morgan, 1996). Fluoride concentrations in fresh water typically range from 0.01 – 0.03mg/L F^- and in seawater from 1.2 – 1.5 mg/L F^-. Fluoride can inhibit or enhance population growth of algae, depending on the algal species, exposure concentration and time of exposure but can tolerate exposures up to 200 mg/L.

Concentrations of fluoride expected to be in produced water and permeate, and measured for Bohena Creek are provided in Table 4.

2.5.2.2 Fluoride guidelines

There is no ecosystem guideline for fluoride in Australia; however, guidelines exist in other national and international jurisdictions (Table 5).

2.5.2.3 Fluoride toxicity

Fluoride toxicity to aquatic organisms increases with increasing concentration, exposure duration and water temperature (Camargo et al, 1992 a, b) and has been studied in a variety of aquatic species (Table 6).

Table 4 Concentrations of fluoride in water

Water type	Location	Concentrations (mg/L)	Data Source
Produced water	Leewood	Average (5.8), maximum (9.7)	Output from Hydranautics IMS Design modelling software, supplied by Santos, 2013.
Permeate	Leewood	Average (0.08), maximum (0.16)	Output from Hydranautics IMS Design modelling software, supplied by Santos, 2013.
River water	Bohena Creek	Not detected (LOR 0.1)	Eco Logical Australia, 2016b. Narrabri Gas Project, Managed Release Study (Bohena Creek) Ecological Risk Assessment.

Table 5 Guideline values for fluoride

Environmental Value	Guideline value (mg/L)	Source / reference
Ecosystems	No guideline	Australia and New Zealand Guidelines for Marine and Fresh Water Quality (ANZECC/ARMCANZ 2000)
Aquatic ecosystem	Interim guideline 0.12	Canadian WQ Guidelines for protection of aquatic life (CWQG 2014)
Recycled water	1.5	Australian Guidelines for Water Recycling: Phase 2a (AGWR 2008)
Primary industries	Irrigation short term: 2 Irrigation long term: 1 Livestock drinking water: 0.4 (sheep), 1 (cattle), 5 (pigs and poultry)	Australia and New Zealand Guidelines for Marine and Fresh Water Quality (ANZECC/ARMCANZ 2000)
Drinking water	1.5	WHO Guidelines for Drinking Water Quality (WHO 2011)

Table 6 Toxicity data for freshwater aquatic species to fluoride

Species	Endpoint	Value (mg/L F)	Reference
Daphnia magna	Reproduction and growth (NOEC)	3.7 – 7.4 at 250 mg/L $CaCO_3$	Dave (1984)
Hydropsyche bronta (caddis fly)	96 h LC_{50}	17 at 12-40 mg/L $CaCO_3$	Reported in Carmago et al (1992)
Daphnia magna	Reproduction and hatching	34 from day 12 of a 21 day test	Fieser et al (1986)
Daphnia magna	NOEC	50	Le Blanc (1980)
Rainbow trout	Acute (96 h LC50)	51.0 at 17 mg/L $CaCO_3$	Pimentel and Bulkley (1983)*
Hydropsyche bronta (caddis fly)	48 h LC_{50}	52.6 at 12-40 mg/L $CaCO_3$	Reported in Carmago et al (1992)
Rainbow trout and brown trout	Acute (72-192h)	72-223	Wright (1977)
Daphnia magna	48 h LC50	98 – 304	Feisler et al (1986)
Daphnia magna	24 h LC50	205 – 352	Feisler et al (1986)
Oncorhynchus mykiss (rainbow trout)	Not specified	223	Camargo (2003)
Daphnia magna	NOEC	231	Kuhn et al (1989)
Chlorella pyrendoidoidosa (algae)	Growth inhibition	37% after 48 h exposure to 2 mg/L	Smith and Woodson (1965)

*These authors reported a liner relationship between water toxicity and hardness

3 DIRECT TOXICITY ASSESSMENT

3.1 Overview of DTA

Direct toxicity assessment (DTA) refers to the aggregate toxicity of the mixture of all macro and micro-pollutants in an effluent sample using a suite of standardised aquatic toxicity assays. DTA as a method of assessment is also known as whole effluent toxicity (WET) testing in other parts of the world (see Grothe et al, 1995). DTA is also one of a number of tools for deriving site specific guideline trigger values together with chemical measurement and biological survey (van dam and Chapman, 2001). DTA testing evaluates the adverse effects or toxicity to each of a group of aquatic species determined experimentally in the laboratory with surrogate organisms representative of those in the environment exposed to the effluent discharge. The methods can be used, for example, to derive guidance on the amount of dilution required to safely discharge an effluent to an aquatic environment or for monitoring the effectiveness of an effluent discharge management program. The method can also be used as a monitoring tool, testing ambient water that has or is suspected of receiving a chemical pollutant discharge. In this case the data will eventually be used to derive water quality objectives (WQOs) for Bohena Creek.

Acute and subacute toxicity of effluents is generally measured using the original sample and a minimum of five dilutions. The tests are designed to produce concentration-effect data expressed as a percentage dilution that affects 50% of the test organisms within a specified time interval (e.g. 24 h – 96 h). The data can be expressed as an effective concentration for 50% of the population (EC_{50}) or what-ever reporting metric applies to a particular test (for example for a lethal endpoint the test reports an LC_{50} (lethal concentration to 50% of the test population). The result can also be expressed as the highest concentration that is not statistically different from the control expressed as a no effect concentration (NOEC). A negative result in a single acute test does not preclude the possibility of chronic toxicity or the possibility of temporal variability in an effluent discharge. It also does not preclude the possibility of effects with some taxa groups (*e.g.*, plants), while others such as fish or crustaceans, may go unaffected. Therefore a suite of tests is required. Tests conducted are representative of the different trophic levels (*i.e.,* position in the aquatic food chain).

3.2 Toxicity testing methods

In brief it is proposed to initially use standardised methods (selection of species and endpoints to be measured), which use the same testing conditions for each of the samples and provide results that are site specific for Bohena Creek, NSW. Tests were conducted using river water with the addition of boron and fluoride (separately).

The DTA methods will consider the following

- Test species selection
- Identification of key chemicals of concern
- Dilution water
- Test methods
- Chemical analysis of test waters
- Data analysis and interpretation

3.2.1 Test species selection

Test species were selected to be representative of different trophic levels (i.e. position in the aquatic food chain). The three most common taxonomic groups are green algae representative of primary producers (photosynthetic organisms), aquatic invertebrates such as micro-crustaceans representing primary consumers (e.g. water fleas) and fish representing aquatic invertebrates and secondary consumers. It is important to note that acute toxicity testing of fish is illegal in Queensland and New South Wales and therefore only sub-lethal (surrogate acute) tests are allowed to be conducted.

Tests were selected using the following criteria.

- Include acute and chronic endpoints
- Species representative of those that occur in the receiving environment
- Methods for tests need to be have been validated and standardised to enable repeat sampling and comparison to other data
- Test species suite is expected to be sensitive to the contaminants being investigated.

Acute tests included

- 48 h acute toxicity – survival — *Ceriodaphnia dubia* (water flea)
- 48 h acute toxicity – survival — *Chironomus tepperi* (freshwater midge)
- 96 h acute toxicity - survival — *Paratya australiensis* (freshwater shrimp)

Chronic tests included

- 10 day embryo development — *Melanotaenia splendida* (rainbow Fish)
- 7 day partial life cycle — *Ceriodaphnia dubia* (water flea)
- 72 hour algal cell yield — *Selanastrum capricornia* (microalgae)
- 7 day growth inhibition test — *Lemna disperma* (duckweed)

Ecotox Services Australia (http://www.ecotox.com.au) is the nominated supplier of the laboratory services. The Ecotox Services Australasia (ESA) laboratory is an independent, NATA endorsed toxicity testing facility specifically designed to offer state-of-the-art testing facilities for the assessment of effluents, leachates, ground waters, receiving waters, chemicals and sediments using Australasian test species.

A description of the individual tests is provided below.

Ceriodaphnia cf dubia **(cladoceran) - 48 h acute immobilisation based on USEPA 2002.**

The *Ceriodaphnia cf. dubia* freshwater cladoceran 48 hour acute survival test is one of the most commonly used tests to assess the potential for harm to freshwater aquatic ecosystems. The test is based on and modified from a U.S. EPA protocol (USEPA 2002). Laboratory reared juvenile *Ceriodaphnia* are exposed to a test substance, effluent or reference toxicant for 48 hours. At the end of the exposure the number surviving is counted. Statistical analysis is then applied to determine the concentration that produces 50% response in the test population (LC_{50}), as well as LC_{10} (concentration producing a response to 10% of the test population), NOEC and LOEC.

Ceriodaphnia cf dubia **(cladoceran) - reproduction test based on USEPA Method 1002.0 (2002)**

This test begins with asexually producing female cladocerans that are less than six hours old (i.e. neonates). The neonate females are exposed to a dilution series of test substance, effluent or reference compound under 'static renewal' conditions. The females are transferred daily to new solutions at the same concentration. Each day observations are made of survival of each female, the number of neonates produced and neonate survival. The test is terminated when three broods have been produced by each surviving control female (normally over a 5-6 day period). The method is based on the *Ceriodaphnia* Survival and Reproduction test developed by the USEPA (2002). Effect concentrations are calculated and EC_{10}, EC_{50}, NOEC and LOEC reported.

Chironomus tepperi **(freshwater midge) - 48 h acute toxicity test based on OECD Method 219**

The fly larvae (*Chironomus tepperi*), has been widely used for direct toxicology assessment in Australia (e.g. Hughes et al. 2005). This test involves exposing third or fourth instar larvae of the freshwater chironomid to the test solutions series for 48 hours, and assessing immobilisation. For this test, four samples, each containing five randomly selected larvae (i.e. twenty larvae in total), are exposed to the different test solutions. The condition of animals is assessed at 24 hours and again at 48 hours, at which time the test is terminated. The results are used to calculate the LC_{10}, LC_{50}, NOEC and LOEC.

Selenastrum capricornutum **(freshwater alga) - 72 hour algal growth inhibition test based on USEPA Method 1003.0**

The green alga (*Selenastrum capricornutum*), is a non-motile unicellular alga common in freshwater systems. This species can easily be cultured in the laboratory and its uniform morphology makes it easy to identify and enumerate. This species is moderately sensitive to toxic substances and has been widely used in direct toxicology assessments.

The chronic toxicity test using microalga measures the effect of the test material on growth over a 72 hour period. The test is undertaken at a range of concentrations/dilutions. At the end of the exposure period algae growth yield is determined. Statistical analyses are then applied to the data to determine the concentration/dilution of the material that causes 50% inhibition in algal yield in the test population (IC_{50}). Inhibition of growth of microalgae has been demonstrated to be sensitive to a wide range of organic and inorganic contaminants (Stauber, 1995). Results will be expressed as NOEC, LOEC or IC_{50} and IC_{10}.

***Macrobrachium australiense* or *Paratya australiensis* - 96hr freshwater shrimp acute toxicity test**

The freshwater shrimp (*Macrobrachium australiense*) is widely distributed in Australian freshwater systems. This species is found in streams, still water bodies, estuaries and intertidal marine waters. This is a static acute test conducted over a 96 h period. Observations are taken daily to produce LC_{10}, LC_{50}, LOEC and NOEC data.

***Lemna disperma* (freshwater duckweed) - seven day growth inhibition test using a based on OECD Method 221 and USEPA Method OOPTS 850.4300**

Freshwater duckweed (*Lemna dispersa*), is a small aquatic macrophyte that commonly occurs in fresh waters across tropical and temperate Australia. This species is minute, free-floating and typically inhabits still waters (e.g. lakes, wetlands and swamps). The test species is a small aquatic flowering plant commonly known as duck weed. The duck weed is an ecologically relevant test organism in that they are primary producers and provide a source of food for water fowl, fish and invertebrates. By producing floating mats on the water surface they also provide shelter for many small organisms. They are small and rapidly growing plants making them suitable for toxicity testing. A standard number of vegetatively producing *Lemna* plants are exposed to a concentration, dilution or reference toxicant under controlled conditions. The number of fronds is counted at the end of the test and the increase in biomass is calculated and compared to the control to assess the percentage inhibition of growth. The test is based on an OECD (2006) protocol.

***Melanotaenia splendida* (Rainbow fish) 10 day embryo development and survival**

This test determines the survival of embryos exposed to the test solutions over 10 days. Test results are based on the frequency of mortality and morphological deformities of the fish. Four samples for each test solutions, each containing five rainbow fish (i.e. 20 fish in total) will be examined for this test. The condition of the test animals (i.e. deformity and mortality) will be assessed at each 24-hour interval until day 10, at which time the test will be terminated. The average death and deformity data are analysed using a one-way ANOVA to see if the differences of exposure between the concentrations are significantly different to the control. The assumptions of normality are tested using Shapiro-Wilk’s test, and homogeneity of variance is tested using Bartlett’s test.

3.2.2 Test and dilution waters for DTA

Toxicity test waters included

- Water from Bohena Creek with the addition of fluoride and boron (separately)
- River water control
- Laboratory water control

3.2.3 Sampling and transportation

- A sampling kit containing test containers, chain of custody documentation and eskies was shipped to the nearest depot to the collection sites by Ecotox Services.
- Water samples were collected in the field and stored in containers appropriate to the expected analytes (e.g. solvent rinsed glass for organics or acid rinsed plastic for inorganics)
- Chain of custody paperwork was completed and shipped with the samples as part of the laboratory quality control
- To minimise the potential for sample degradation, water samples were chilled on ice, and transported in insulated packaging with fresh ice bricks to the laboratory via express (overnight) courier.

3.2.4 Chemical analysis of toxicity test water

Test solutions were submitted for analysis of dissolved boron and fluoride and forwarded to an analytical laboratory by Ecotox Services Australia staff. Toxicity calculations were based on measured concentrations.

3.2.5 Data analysis and interpretation

All measures of toxicity (LC, EC, IC percentiles) were calculated using ToxCalc (Tidepool Software). The concentration causing no significant toxicity (no observed effect concentration – NOEC) and the lowest concentration causing a significant effect (lowest observed effect concentration – LOEC) was determined by performing Dunnett's Test or equivalent. The ICx (the effective concentration giving x% reduction in the endpoint compared to the controls were calculated using Trimmed-Karber analysis or Maximum Likelihood Probit Analysis.

The most widely used method of Ecological Risk Assessment (ERA) is the use of the hazard quotient (HQ) method by which the environmental concentration of a stressor, either measured or estimated, is compared to an effect concentration. These are simple ratios of single exposure and effect values and are used to express hazard or relative safety (Urban and Cook, 1986). Deterministic methods such as the hazard quotients have given way to probabilistic methods over the last decade resulting in the calculation of protective concentrations for a given ecosystem. A recognised (i.e. ANZECC/ARMCANZ, 2000) method for assessing the risk of contaminants to communities is the species sensitivity distribution (SSD).

Species sensitivity distributions (SSDs) are models of the variation in the sensitivity of a suite of species to particular stressors (Posthuma et al, 2002). SSDs are generated by fitting a statistical or empirical distribution function to the proportion of species affected as a function of stressor concentration or dose. Traditionally, SSDs are created using data from single-stressor laboratory toxicity tests, such as median lethal concentrations (LC_{50}s; see Figure 2). SSDs are cumulative distribution functions of the (usually laboratory measured) sensitivity of a sample of species to a contaminant. The percentage of species that can tolerate a given concentration of a contaminant can be estimated and used to set environmentally relevant guidelines for chemicals to protect a % of species (95% is the default).

As per the methods in the current ANZECC/ARMCANZ (2000) guidelines it is recommended that protective concentrations be calculated based on NOEC data. The validity of the use of

NOECs has been questioned in the last decade in part because the NOECs and LOECs are constrained by being one of the test concentrations (Fox 2008, Warne and van Dam 2008). The use of EC_{10}s is now a preferred approach. Both have their strengths and limitations (refer to Fox, 2008 and references therein for further discussion on this topic). EC10s have been used for the analysis in this report.

Species sensitivity distributions were generated using the USEPA software *CADDIS* (Causal Analysis/Diagnosis Decision Information System) (USEPA 2010). The CADDIS software uses a log-probit distribution in the regression to quantify stressor-response relationships. This software was used (in preference to BurrliOz) as the total sample size was 6 and therefore the Burr III distribution was unsuitable for this purpose (ANZECC/ARMCANZ 2000). BurrliOz (version 1.0.14) is based on a Burr III distribution and only suitable for sample sizes of ≥8 (Campbell et al, 2000). Like any application of laboratory toxicity data to the field, it depends on a reasonable concordance of physical, chemical, and biological conditions between the laboratory and field. As field collected water was used in the laboratory testing this was in accord with field conditions and relevant to the site of interest.

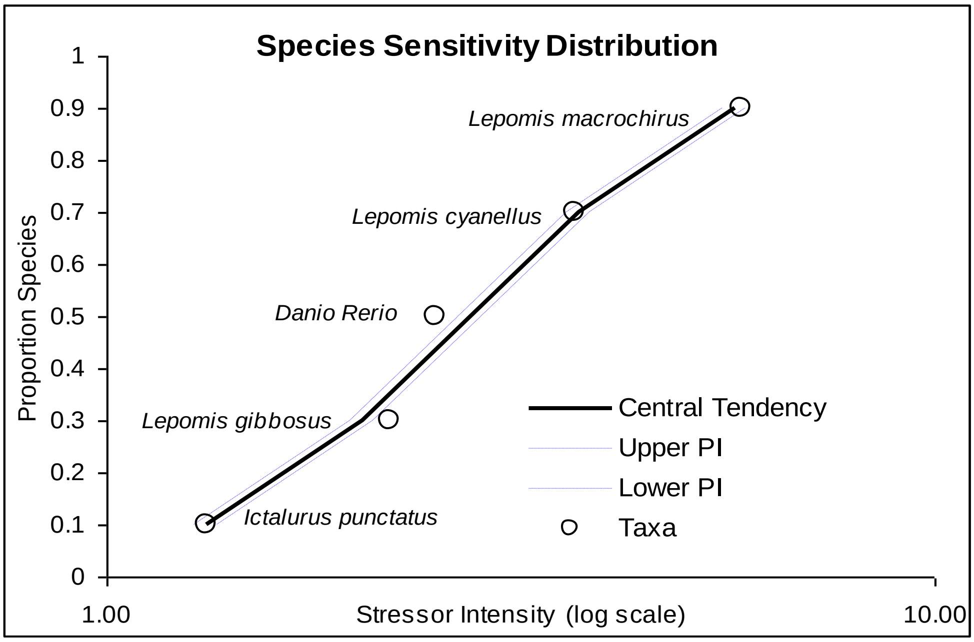

Figure 2 An SSD plot showing the distribution of LC_{50}s for species exposed to dissolved cadmium with 95% confidence limits (protective intervals). Data generated from the USEPA Ecotox data base (USEPA 2010).

RESULTS

3.3 Test water quality

Results for the chemical analyses conducted at the Symbio Laboratory for waters collected from Bohena Creek are reported in the Managed Release Study (Eco Logical Australia, 2016a). The concentrations of boron from the upstream and downstream collection sites in Bohena Creek were below the limit of reporting (<0.05 mg/L) in both cases. Fluoride was below the limit of detection (<0.1 mg/L).

On arrival at the test laboratory, water quality measurements were taken for pH, conductivity and total ammonia (Table 7).

Table 7 Water quality for Bohena Creek test water

Parameter	Bohena Creek
pH	6.7
EC (µs/sec)	73.9
Ammonia (mg/L)	<2

3.4 Quality assurance / quality control

Specific procedures for undertaking toxicity testing activities, procurement and culturing of test organisms, maintenance and calibration of instruments, cleaning, chain of custody and sample handling is carried out by ESA as per their procedural manual. Quality assurance was carried out for all toxicity tests and the QA/QC criterion for survival of laboratory water and river water controls was met in all cases (Appendix 2 DTA lab report). This indicated that there was no observable toxicity due to the test water itself for the test species.

3.5 Toxicity testing results

3.5.1 Boron

The results for the site specific toxicity testing for boron for Bohena Creek water are shown in Table 8. The most sensitive test result for boron was the chronic test with the macrophyte *Lemna dispersum* and the least sensitive test was the *Paratya australiensis* acute test. *Lemna dispersum* is a small floating plant that commonly occurs in inland rivers and was used to represent macrophytes in this system. *Paratya australiensis* is a small ubiquitous shrimp species that occurs in freshwater streams and rivers in Australia.

Table 8 Toxicity test results for dissolved Boron (mg/L) for Bohena Creek

Test species and endpoint	EC_{10}±CI [1]	EC_{50}±CI [2]	NOEC [3]	LOEC [4]
Lemna disperma (7 day growth inhibition)	3.3 [5]	7.3 (2.8 - 15.2)	9.6	18
Ceriodaphnia cf dubia (partial life cycle)	8.8 (6.3 - 16.6)	29.5 (25.4 - 32.0)	12	24
Selanastrum capricornutum (microalgae growth inhibition)	7.0 (4.6 - 19.5)	23.1 (21.3 - 24.4)	14	28
Ceriodaphnia cf dubia (7 day survival)	47.2 (44.0 - 58.8)	60.1 (52.5 - 68.7)	44	94
Ceriodaphnia cf dubia (48hr survival)	67.4 (46.7 - 82.2)	106.3 (88.4 - 127.9)	78	170
Chironomus tepperi survival (48 h survival)	67.4 [5]	166.65[5]	170	310
Melanotaenia splendida (embryo development)	57.0 (29.8 - 166.4)	145.7 (127.2 - 167)	120	240
Paratya australiensis (96 h survival)	101.3 [5]	445.3 (353.9 - 560.2)	430	940

[1] EC_{10} : 10% of maximal effect concentration determined through regression analysis of the dose response curve (mg/L boron)

[2] EC_{50} : half maximal effect concentration determined through regression analysis of the dose response curve (mg/L boron)

[3] NOEC: no observed effect concentration (mg/L boron)

[4] LOEC: lowest observed effect concentration (mg/L boron)

[5] 95% confidence intervals not available

3.5.2 Fluoride

The results for the site specific toxicity testing for fluoride for Bohena Creek water are shown in Tables 9. The most sensitive acute test was that for the freshwater shrimp *Paratya australiensis* acute test and the most sensitive chronic test were the growth test for the microalgae *Selanastrum capricornutum.*

Table 9 Toxicity tests results for dissolved fluoride (mg/L) for Bohena Creek

	EC_{10}±CI [1]	EC_{50}±CI [2]	NOEC [3]	LOEC [4]
Ceriodaphnia cf dubia (partial life cycle)	9.1 (3.5-9.5)	13.2 (12.4 - 13.8)	8.5	17
Paratya australiensis (96 h survival)	7.9 (2.3 - 15.2)	14.5 (12.9 - 16.3)	10	21
Ceriodaphnia cf dubia (7 day survival)	>33 [5]	>33[5]	33	>33
Chironomus tepperi (48 h survival)	23.8 (12.5 - 48.8)	64.9 (50.6 - 83.2)	<61	61
Lemna disperma (7 day growth inhibition)	45.3 (31.8 - 88.4)	>110[5]	110	>110
Ceriodaphnia cf dubia (48hr survival)	156.3[5]	169.4 (120 - 240)	120	240
Selanastrum capricornutum (microalgae growth inhibition)	<96[5]	402 (334.8 - 488.2)	190	400
Melanotaenia splendida (embryo development)	41.8 [5]	78.7 (68.8 - 90)	64	120

[1] EC_{10} : 10% of maximal effect concentration determined through regression analysis of the dose response curve (mg/L fluoride)

[2] EC_{50} : half maximal effect concentration determined through regression analysis of the dose response curve (mg/L fluoride)

[3] NOEC: no observed effect concentration (mg/L fluoride)

[4] LOEC: lowest observed effect concentration (mg/L fluoride)

[5] 95% confidence intervals not available

3.6 Species sensitivity distributions and protective concentrations

3.6.1 Dilution water from Bohena Creek

There was no toxicity observed due to the dilution water from Bohena Creek (as sampled for testing) or from the laboratory controls. QA/QC criterion was met for all tests. Refer to Appendix 2 for test details.

3.6.2 Protective concentrations based on EC_{10} data

3.6.2.1 Boron

The EC_{10} data used to construct the cumulative frequency distribution for river water with added boron is given in Table 10. The acute data (for *Paratya australiensis* and *Chironomus tepperi*) was first converted to chronic equivalents using the default acute to chronic ratio (ACR) of 10.

Table 10 Data (EC10s) used for calculation of protective concentration (PC_{95}) for boron added to water from Bohena Creek.

Test species and endpoint	EC_{10}s Boron (mg/L)
Lemna disperma (7 day growth inhibition)	3.3
Selanastrum capricornutum (microalgae growth inhibition)	7.0
Ceriodaphnia cf dubia (partial life cycle)	8.8
Chironomus tepperi survival (48 h survival)	8.8[1]
Paratya australiensis (96 h survival)	13.2[1]
Melanotaenia splendida (embryo development)	57

[1] Chronic equivalent calculated from acute data

The protective concentration (PC) for Bohena Creek water with added boron was PC_{95}% = **1.8 mg/L B**. A full output of the analysis is provided in Appendix 3. This concentration is above the default guideline trigger value of 0.37 mg/L (ANZECC/ARMCANZ 2000).

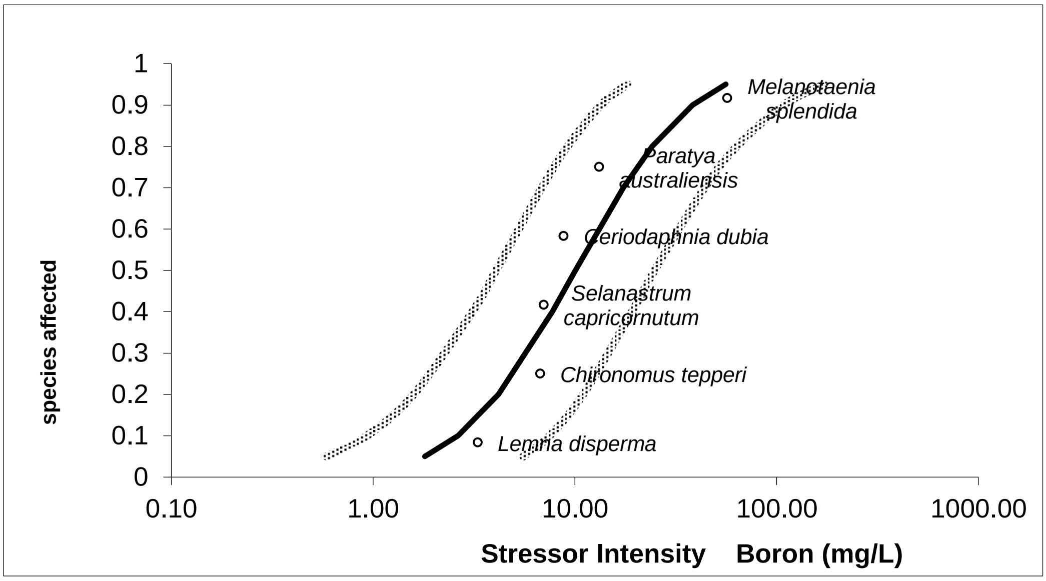

Figure 3 SSD plot (solid line) showing the distribution of EC_{10}s for test species exposed to boron in river water with 95% confidence limits (dotted lines).

3.6.2.2 Fluoride

The EC_{10} data used to construct the cumulative frequency distribution for river water with added fluoride is given in Table 11. The acute data (for *Paratya australiensis* and *Chironomus tepperi*) was first converted to chronic equivalents using the default acute to chronic ratio (ACR) of 10.

Table 11 Data (EC10s) used for calculation of protective concentration (PC95) for fluoride added to water from Bohena Creek.

Species and endpoint	**Fluoride EC_{10}s (mg/L)**
Paratya australiensis (96 h survival)	0.79[1]
Chironomus tepperi (48 h survival)	2.4[1]
Ceriodaphnia cf dubia (partial life cycle)	9.1
Melanotaenia splendida (embryo development)	41.8
Lemna disperma (7 day growth inhibition)	45.3
Selanastrum capricornutum (microalgae growth inhibition)	96

1. Chronic equivalent calculated from acute data

The protective concentration (PC_{95}) for Bohena Creek water with added fluoride was PC_{95}% = **0.46mg/L** (Figure 4). This concentration is above the default guideline in Canada of **0.12 mg/L** (CWQG 2014). There is presently no ecosystem guideline for fluoride in Australia.

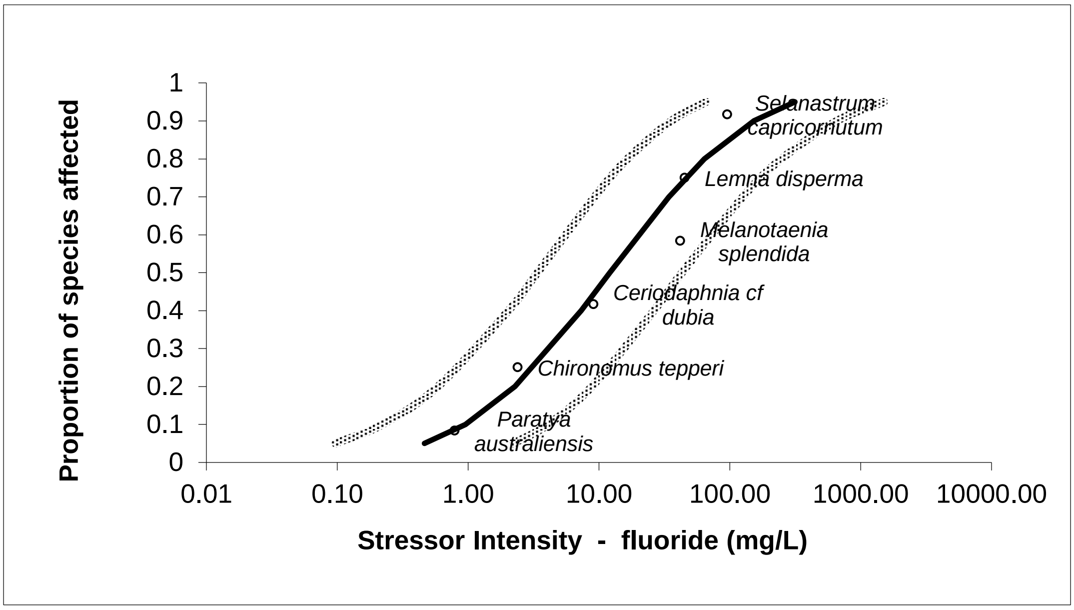

Figure 4 SSD plot (solid line) showing the distribution of EC_{10}s for test species exposed to fluoride in river water with 95% confidence limits (dotted lines).

4 SUMMARY AND DISCUSSION

4.1 Boron

The experimentally derived protective concentration (PC_{95}) for boron generated by this study for Bohena Creek is **PC_{95} = 1.8 mg/L B** (Table 12). This indicates boron toxicity to Bohena Creek would be lower than the present ANZECC guideline trigger value of **0.37 mg/L B.** This is in accord with the Canadian Water Quality Guidelines for boron derived from species sensitivity distributions have been set at **1.5 mg/L** for long term exposure (CCME 2009). The average and maximum concentrations expected to be present in the treated water from Leewood are **0.116 and 0.67** mg/L respectively (Table 1 of this report).

Table 3 (this report) shows the results from this study for boron compare well to that of the published literature. There is presently no data for comparison for the rainbow fish. The low toxicity observed for rainbow fish in this study may have been due to the water quality characteristics of the water (Bohena Creek) used in the DTA testing. Water quality parameters such as hardness, alkalinity and pH can have a modifying effect on toxicity. Schoderboeck et al (2011) reported higher (i.e. less toxic) median acute lethal concentrations (LC_{50}) in natural waters than in reconstituted water laboratory waters that matched natural water except for its dissolved organic carbon (DOC) content. Some studies have shown that the low level effects observed in reconstituted water are not predictive of much higher level effects found under natural water exposure conditions (Black et al, 1993). The specific component of the water chemistry responsible for this is unknown (CCME 2009).

4.2 Fluoride

The experimentally derived PC_{95} for fluoride generated by this study for Bohena Creek (**PC_{95} = 0.46 mg/L**). This is higher (i.e. less toxicity) than the present Canadian guideline trigger value for 95% protection of aquatic species of **0.12** mg/L. The average and maximum concentrations expected to be present in the treated water are **0.08 and 0.16 mg/L** fluoride respectively (Table 4 this report).

The toxicity data in Table 6 suggests that the results of these tests show greater toxicity to fluoride than the general literature, particularly for the freshwater shrimp *Paratya australiensis*. It was necessary to convert the acute data for the shrimp to its chronic equivalent and that resulted in a conservative value for the shrimp being used in the species sensitivity distribution. This information is based on a single data set and the trigger value could be more reliable with additional data. However given the large margin of safety this is not considered necessary to conduct further tests at this time.

Table 12 Summary of results for Bohena Creek

	Default guidelines	Site specific trigger value[1]	Permeate (maximum)	Permeate (average)	Bohena Creek background
Boron (mg/L)	0.37 (Australia)	1.8	0.67	0.116	<0.5
Fluoride (mg/L)	0.12 (Canada)	0.46	0.16	0.08	<0.1

[1] Based on data in this report

4.3 Conclusions

The site specific (Bohena Creek) trigger values calculated from the data in this study indicate that there is low risk to ecosystem health from boron or fluoride during the occurrence of release to Bohena Creek, even during no flow periods within the river where minimal dilution with natural waters will occur.

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Appendix 1 Fact sheets for NATA registered toxicity tests.

Fact sheet #1	48 hour acute *Ceriodaphnia dubia* survival
Fact sheet #2	7 day *Ceriodaphnia dubia* partial life cycle
Fact sheet #3	72 hour algae *Selanastrum capricornia* using algal cell yield
Fact sheet #4	7 day growth inhibition test using a freshwater duckweed (*Lemna disperma*)
Fact sheet #11	96 hour *Melanotaenia splendia* (Rainbow Fish) fish imbalance test
Fact sheet #13	10 day *Melanotaenia splendida* (Rainbow Fish) embryo development and survival

ecotox
SERVICES AUSTRALASIA

TOXICITY TEST FACT SHEET #1 - Freshwater

Acute Toxicity Test With *Ceriodaphnia dubia*

The acute toxicity test using the freshwater crustacean *Ceriodaphnia cf. dubia* is one of the most commonly used tests for the assessment of potential harm posed by contaminants to freshwater aquatic ecosystems. Acute tests using *Daphnia carinata* or *Daphnia magna* are also available upon request

This test is commonly used throughout North America using USEPA protocols and is an important test in US effluent discharge licensing programme. Consequently, an enormous amount of toxicity data is available for this species, making the acute *Ceriodaphnia* test ideal for validating ecological risk assessments. In Australia, *Ceriodaphnia cf. dubia* has also become widely used in toxicity assessment programs using the 'Sydney Clone' isolated from waters in the Sydney region.

In summary, this test involves exposing laboratory reared juvenile *Ceriodaphnia* to the test material for 48 hours. The test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. At the end of the exposure period, the number of surviving *Ceriodaphnia* is counted.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% mortalities in the test population (LC50 estimate). The test data can then be used to estimate concentrations of the test material likely to cause acute toxicity in the environment.

The acute *Ceriodaphnia* test may be used to assess the toxicity of:
• Chemicals
• Effluents
• Leachates and groundwater
• Sediments

If toxicity is detected using the acute *Ceriodaphnia* test, a Toxicity Identification Evaluation (TIE) programme can be initiated to identify the cause of the observed toxicity.

Acute Toxicity Test With *Ceriodaphnia dubia*	
Test type	Acute static
Test end-point	Mortality at 48 hrs
Test duration	48 hours
Test Temperature	25 ± 1^{o}C
Sample volume required	1 litre for full EC50 determination
Test availability	24hrs notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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Phone +61 2 9420 9481 Facsimile +61 2 9420 9484
e-mail: info@ecotox.com.au

TOXICITY TEST FACT SHEET #2 - Freshwater

Chronic Toxicity Test With *Ceriodaphnia dubia*

The Chronic (7-day partial life-cycle) toxicity test using the freshwater crustacean *Ceriodaphnia dubia* is one of the most commonly used tests for the assessment of potential harm posed by contaminants to freshwater aquatic ecosystems. Chronic tests using *Daphnia carinata* or *Daphnia magna* are also available upon request

This test is commonly used throughout North America using USEPA protocols and is usually performed along side the 48 hour acute test using the same species (see Test Fact Sheet #1). In Australia, *Ceriodaphnia cf. dubia* has also become widely used in toxicity assessment programs using the 'Sydney Clone' isolated from waters in the Sydney region.

In summary, this test involves exposing laboratory reared juvenile *Ceriodaphnia* to the test material for 7 to 8 days. The test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. The test solutions are renewed every day. At the end of the exposure period, the number of surviving *Ceriodaphnia* and the number of young produced are counted.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% decrease in number of young produced (LC50 estimate). The test data can then be used to estimate concentrations of the test material likely to cause chronic toxicity in the environment.

The chronic *Ceriodaphnia* test may be used to assess the toxicity of:
• Chemicals
• Effluents
• Leachates and groundwater
• Sediments

If toxicity is detected using the chronic *Ceriodaphnia* test, a Toxicity Identification Evaluation (TIE) programme can be initiated to identify the cause of the observed toxicity.

Chronic Toxicity Test With *Ceriodaphnia dubia*	
Test type	Chronic static
Test end-point	Mortality and number of young produced
Test duration	7-8 days
Test Temperature	25 ± 1ºC
Sample volume required	10 litre for full EC50 determination
Test availability	24hrs notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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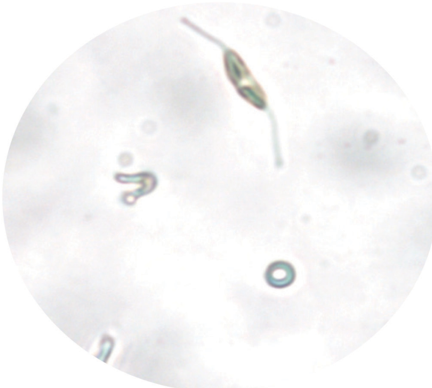

TOXICITY TEST FACT SHEET #3 – Freshwater & Marine

Chronic Toxicity Test With Algae

The chronic toxicity test using the micro alga measures the effect of test materials on growth over a 72 hour period. The test can be run using the freshwater green algae *Selenastrum capricornutum*, the marine diatom *Nitzschia closterium* or the marine flagellate *Isochrysis aff. Galbana.*

Algae are primary producers of organic matter upon which animals depend either directly or indirectly through the food chain. In Australia, the test using the freshwater *S. capricornutum* has been widely used in toxicity assessment of sewage treatment plant effluents discharging into freshwater streams and rivers. The tests using the marine algae have been widely used along side invertebrate toxicity tests.

In summary, this test involves exposing laboratory cultured algae to the test material for 72 hours. The test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. At the end of the exposure period, algae cell yield is determined.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% inhibition in algal cell yield in the test population (IC50 estimate). The test data can then be used to estimate concentrations of the test material likely to cause chronic toxicity in the environment.

The algae growth test may be used to assess the toxicity of:
- Chemicals
- Effluents
- Leachates and groundwater
- Sediments

If toxicity is detected using the chronic algae test, a Toxicity Identification Evaluation (TIE) programme can be initiated to identify the cause of the observed toxicity.

Chronic Toxicity Test With Micro Algae	
Test type	Chronic static
Test end-point	Cell yield
Test duration	72 hours
Test Temperature	18 ± 1°C or 25 ± 1°C
Sample volume required	1 litre for full EC50 determination
Test availability	24hrs notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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TOXICITY TEST FACT SHEET #4 – Freshwater

Chronic Toxicity Test With *Lemna minor*

The chronic toxicity test using the freshwater duckweed *L.minor* measures the effect of test materials on growth over a 7 days period. The common duckweed *Lemna sp*. is a small aquatic macrophyte occurring in quiescent fresh waters in both tropical and temperate regions.

In addition to being an ecologically important group, duckweeds are a sensitive and useful test organisms for testing turbid and coloured waters. This gives the duckweed an advantage over algal toxicity tests which may require filtering, compromising the sample integrity.

In summary, this test involves exposing laboratory cultured duckweed to the test material for 7 days. The test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. At the end of the exposure period, specific growth rate and frond dry weight are determined.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% inhibition in specific growth rate in the test population (IC50 estimate). The test data can then be used to estimate concentrations of the test material likely to cause chronic toxicity in the environment.

The duckweed growth test may be used to assess the toxicity of:

- Chemicals
- Effluents
- Leachates and groundwater
- Sediments

If toxicity is detected using the chronic duckweed test, a Toxicity Identification Evaluation (TIE) programme can be initiated to identify the cause of the observed toxicity.

Chronic Toxicity Test With the Duckweed *L.minor*	
Test type	Chronic static
Test end-point	Specific growth rate and dry weight
Test duration	7 days
Test Temperature	$25 \pm 1^{o}C$
Sample volume required	1 litre for full EC50 determination
Test availability	24hrs notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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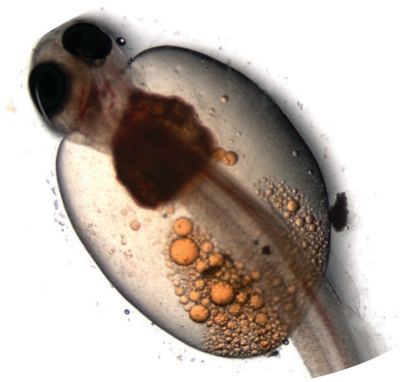

TOXICITY TEST FACT SHEET #11 – Freshwater & Marine

Acute Toxicity Test with Fish larvae

A number of species of fish have been used for toxicity assessments. The species commonly used in our laboratory are the Rainbowfish (*Melanotaenia splendida*) and the zebra fish (*Zebra danio*). The most commonly used marine species in Australia are the Barramundi (*Lates calcarifer*), the Bass (*Macquaria novemaculeata*) , the australasian snapper (*Pagrus auratus*) and the Kingfish (*Seriola lalandis lalandis*).

Fish are both ecologically and economically important. The acute toxicity test uses externally sourced and laboratory reared fish larvae and is based on USEPA test method for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms (2002).

In summary, this test involves exposing fish larvae to the test material for 96 hours. The test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. At the end of the exposure period, the number of balanced and the number of un-balanced fish larvae are recorded.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% reduction in unbalanced fish in the test population (EC50 estimate). The test data can then be used to estimate concentrations of the test material likely to cause acute toxicity in the environment.

The Acute Fish Test may be used to assess the toxicity of:
- Chemicals
- Effluents
- Leachates and groundwater
- Sediments

The Acute Fish test exposure period can be extended to 7 days.

If toxicity is detected using the Acute Fish Test, a Toxicity Identification Evaluation (TIE) programme can be initiated to identify the cause of the observed toxicity.

Acute Toxicity Test Using Fish Larvae	
Test type	Acute static
Test end-point	Imbalance
Test duration	96 hours
Test Temperature	25 ± 2°C or 20 ± 2°C
Sample quantity required	4 L
Test availability	7 days notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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TOXICITY TEST FACT SHEET #13 – Freshwater

Rainbowfish 10-d Embryonic Development and Post-Hatch Survival

This chronic toxicity test using the Eastern Rainbowfish (*Melanotaenia splendida*) has been recently developed to fulfil a need to provide chronic ecotoxicity test data for use with Species Sensitivity Distributions (SSDs) under the ANZECC and ARMCANZ Water Quality Guidelines (2000). Until recently only 96-h Fish Imbalance tests were routinely available for Australian freshwater fish, however being akin to an acute assay, these Fish Imbalance Test results were subject to an acute:chronic application factor, which at times resulted in excessively conservative estimates.

The 10-day embryo development and survival assay is based on a similar USEPA test Method 1001.0: Fathead Minnow Embyo-larval Survival and Teratogenicity test. Trials using 7 day larval growth and survival using the rainbowfish proved to be too problematic with respect to variable survival, largely due to difficulties with meeting dietary requirements once yolk sacs were exhausted 4 days post-hatch. The embryo development and post-hatch survival test method overcomes this problem, as the test covers the first 6 days of embryonic development and 4-days post hatch period, 10-day exposure period in total.

Like the 96-h Fish Imbalance Test, the test is usually undertaken on a range of concentrations of a test material, eg 100, 50, 25, 12.5 and 6.3% effluent. The number of embryos successfully emerged at around Day 6 and the number of surviving larval fish at Day 10 are recorded.

Statistical analyses are then applied to the test data to determine for example, the concentration of the test material causing 50% reduction for both embryo emergence and survival endpoints (EC50 estimates). The test data can then be used to estimate concentrations of the test material likely to cause chronic toxicity to fish in the environment and for SSD calulations without the need for an acute:chronic application factor.

The 10-d embyo development and survival test may be used to assess the toxicity of:
- Chemicals
- Effluents
- Leachates and groundwater
- Sediments

Rainbowfish 10-d Embryonic Development and Post Hatch Survival	
Test type	chronic static
Test end-point	Embryo emergence at 6-d, survival at 10-d
Test duration	10-days
Test Temperature	25 ± 2ºC
Sample quantity required	10 L
Test availability	7 days notice requested
Test turnaround time	Advice given within 72 hours of test initiation

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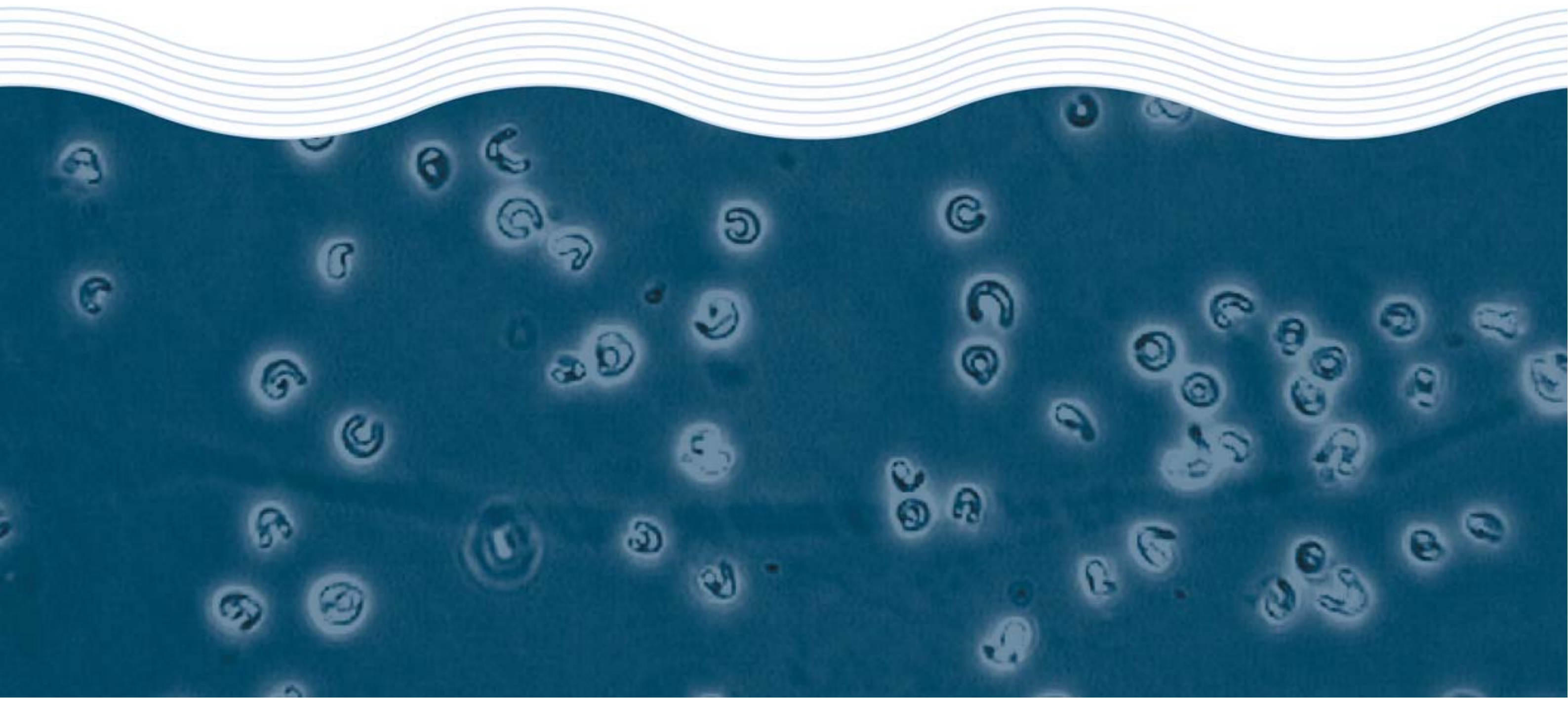
Appendix 2 Bioassay test results – Ecotox Services Pty Ltd

Toxicity Assessment of a River Water with the Addition of Boron and Fluoride

Aqua Della Vita Pty Ltd

Test Report

March 2014



Toxicity Assessment of a River Water with the Addition of Boron and Fluoride

Aqua Della Vita Pty Ltd

Test Report

April 2014

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Toxicity Test Report: TR1030/1b

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Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	Sample Name:	Sample Description:
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	48-hr acute toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia*
Test Protocol:	ESA SOP 101 (ESA 2011), based on USEPA (2002) and Bailey *et al*. (2000)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with boron or fluoride. The prepared samples were then serially diluted with sample 5887 (NAR_7102(2)_SURF_W). A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The boron and fluoride concentrations of the diluent controls are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	1 May 2013 at 1500h

Sample 5887 + Boron: *NAR_7102(2)_SURF_W + Boron*		*Sample 5887 + Fluoride: NAR_7102(2)_SURF_W + Fluoride*	
Concentration (mg/L)	**% non-immobilised (Mean ± SD)**	**Concentration (mg/L)**	**% non-immobilised (Mean ± SD)**
DMW Control	100 ± 0.0	DMW Control	100 ± 0.0
DC2[0.02]	100 ± 0.0	DC2[0.0]	100 ± 0.0
19.0	100 ± 0.0	31.0	100 ± 0.0
38.0	100 ± 0.0	61.0	100 ± 0.0
78.0	80.0 ± 16.3	120.0	100 ± 0.0
170.0	10.0 ± 11.6 *	240.0	0.0 ± 0.0
310.0	0.0 ± 0.0	480.0	0.0 ± 0.0
48-hr EC10 = 67.4 (46.7-82.2)mg/L **48-hr EC50 = 106.3 (88.4-127.9)mg/L** **NOEC = 78.0mg/L** **LOEC = 170.0mg/L**		**48-hr IC10 = 156.3mg/L**** **48-hr EC50 = 169.4 (120-240)mg/L** **NOEC = 120.0mg/L** **LOEC = 240.0mg/L**	

*Significantly lower percent immobilisation compared with DC2 (Steel's Many-One Rank Test, 1-tailed, P=0.05)
**95% confidence limits are not reliable

Toxicity Test Report: TR1030/1b

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % non-immobilised	≥90.0%	100%	Yes
Reference Toxicant within cusum chart limits	141.3-387.2mg KCl/L	261.2mg KCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

Bailey, H.C., Krassoi, R., Elphick, J.R., Mulhall, A., Hunt, P., Tedmanson, L. and Lovell, A. (2000) Application of *Ceriodaphnia cf. dubia* for whole effluent toxicity tests in the Hawkesbury-Nepean watershed, New South Wales, Australia: method development and validation. *Environmental Toxicology and Chemistry* 19:88-93.

ESA (2011) *SOP 101 – Acute toxicity test using Ceriodaphnia dubia*. Issue No. 9. Ecotox Services Australasia, Sydney, New South Wales.

USEPA (2002) *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. 4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

Toxicity Test Report: TR1030/2b

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Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	ESA Job #: Date Sampled: Date Received:	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	Sampled By:	Client
Client Ref:	Not supplied	ESA Quote #:	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	Partial life-cycle toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia*
Test Protocol:	ESA SOP 102 (ESA 2011), based on USEPA (2002) and Bailey *et al*. (2000)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with boron. The prepared sample was then serially diluted with sample 5887 (NAR_7102(2)_SURF_W). A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The boron concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	3 May 2013 at 1600h

Sample 5887 + Boron : *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	**% Survival at 7 days (Mean ± SD)**
DMW Control	90.0 ± 31.6
DC2 [0.02]	100 ± 0.0
5.8	100 ± 0.0
12.0	90.0 ± 0.0
24.0	100 ± 0.0
44.0	100 ± 0.0
94.0	0.0 ± 0.0

7 day IC10 (survival) = 47.2 (44.0-58.8)mg/L
7 day EC50 (survival) = 60.1 (52.5-68.7)mg/L
NOEC = 44.0mg/L
LOEC = 94.0mg/L

Sample 5887 + Boron : *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	**Number of Young (Mean ± SD)**	
DMW Control	17.6 ± 7.1	
DC2 [0.02]	22.6 ± 7.0	
5.8	25.5 ± 5.3	
12.0	19.0 ± 8.6	
24.0	16.6 ± 4.4	*
44.0	0.0 ± 0.0	
94.0	0.0 ± 0.0	

7 day IC10 (reproduction) = 8.8 (6.3-16.6)mg/L
7 day IC50 (reproduction) = 29.5 (25.4-32.0)mg/L
NOEC = 12.0mg/L
LOEC = 24.0mg/L

*Significantly lower number of young compared with DC2 (Steel's Many-One Rank Test, 1-tailed, p=0.05)

Toxicity Test Report: TR1030/2b

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % survival	≥80.0%	90.0%	Yes
Control mean number of young	≥15.0	19.6	Yes
Reference Toxicant within cusum chart limits	166.8-302.1mgKCl/L	210.9mgKCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

Bailey, H.C., Krassoi, R., Elphick, J.R., Mulhall, A., Hunt, P., Tedmanson, L. and Lovell, A. (2000) Application of *Ceriodaphnia cf. dubia* for whole effluent toxicity tests in the Hawkesbury-Nepean watershed, New South Wales, Australia: method development and validation. *Environmental Toxicology and Chemistry* 19:88-93.

ESA (2011) ESA SOP 102 – *Acute Toxicity Test Using Ceriodaphnia dubia.* Issue No 8. Ecotox Services Australasia, Sydney, NSW.

USEPA (2002) *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

Toxicity Test Report: TR1030/2c

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Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	ESA Job #: Date Sampled: Date Received:	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	Sampled By:	Client
Client Ref:	Not supplied	ESA Quote #:	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	Partial life-cycle toxicity test using the freshwater cladoceran *Ceriodaphnia cf dubia*
Test Protocol:	ESA SOP 102 (ESA 2011), based on USEPA (2002) and Bailey *et al*. (2000)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with fluoride. The prepared sample was then serially diluted with sample 5887 'NAR_7102(2)_SURF_W'. A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the sample. The results are expressed as measured concentrations. The fluoride concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	17 May 2013 at 1500h

Sample 5887 + fluoride: *NAR_7102(2)_SURF_W + fluoride*

Concentration (mg/L)	**% Survival at 7 days (Mean ± SD)**
DMW Control	100 ± 0.0
DC2 [0.0]	100 ± 0.0
2.2	100 ± 0.0
3.9	100 ± 0.0
8.5	100 ± 0.0
17.0	90.0 ± 31.6
33.0	100 ± 0.0

7 day EC10 (survival) = >33.0mg/L
7 day EC50 (survival) = >33.0mg/L
NOEC = 33.0mg/L
LOEC = >33.0mg/L

Sample 5887 + fluoride: *NAR_7102(2)_SURF_W + fluoride*

Concentration (mg/L)	**Number of Young (Mean ± SD)**
DMW Control	16.9 ± 5.2
DC2 [0.0]	17.9 ± 3.7
2.2	19.7 ± 2.4
3.9	17.3 ± 2.4
8.5	18.6 ± 4.2
17.0	2.6 ± 2.5 *
33.0	0.0 ± 0.0

7 day IC10 (reproduction) = 9.1 (3.5-9.5)mg/L
7 day IC50 (reproduction) = 13.2 (12.4-13.8)mg/L
NOEC = 8.5mg/L
LOEC = 17.0mg/L

*Significantly lower number of young compared with DC2 (Dunnett's Test, 1-tailed, p=0.05)

Toxicity Test Report: TR1030/2c

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % survival	≥80.0%	100%	Yes
Control mean number of young	≥15.0	16.9	Yes
Reference Toxicant within cusum chart limits	166.3-302.3mgKCl/L	211.7mgKCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

Bailey, H.C., Krassoi, R., Elphick, J.R., Mulhall, A., Hunt, P., Tedmanson, L. and Lovell, A. (2000) Application of *Ceriodaphnia cf. dubia* for whole effluent toxicity tests in the Hawkesbury-Nepean watershed, New South Wales, Australia: method development and validation. *Environmental Toxicology and Chemistry* 19:88-93.

ESA (2011) ESA SOP 102 – *Acute Toxicity Test Using Ceriodaphnia dubia.* Issue No 8. Ecotox Services Australasia, Sydney, NSW.

USEPA (2002) *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

Toxicity Test Report: TR1030/3c

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Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum*
Test Protocol:	ESA SOP 103 (ESA 2011), based on USEPA (2002)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	The samples were filtered to 0.45µm prior to testing. Sample 5887 'NAR_7102(2)_SURF_W' was spiked with boron. The prepared sample was then serially diluted with sample 5887 'NAR_7102(2)_SURF_W'. A USEPA control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the sample. The results are expressed as measured concentrations. The boron concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS
Test Initiated:	30 April 2013 at 1600h

Sample 5887 + Boron : *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	**Cell Yield $x10^4$ cells/mL (Mean ± SD)**
USEPA Control	125.7 ± 16.3
DC2 [0.06]	184.0 ± 11.5
3.8	193.8 ± 24.7
7.2	168.8 ± 12.9
14.0	162.4 ± 130
28.0	57.5 ± 3.0 *
54.0	6.6 ± 1.0 *

72-hr IC10 = 7.0 (4.6-19.5)mg/L
72-hr IC50 =23.1 (21.3-24.4)mg/L
NOEC = 14.0mg/L
LOEC = 28.0mg/L

Vacant

*Significantly lower cell yield compared with DC2 (Steel's Many One Rank Test Test, 1-tailed, P=0.05)

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Toxicity Test Report: TR1030/3c

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean cell density	≥16.0x10^4 cells/mL	126.7x10^4 cells/mL	Yes
Control coefficient of variation	<20%	13.0%	Yes
Reference Toxicant within cusum chart limits	1.7-4.7g KCl/L	3.1g KCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

Citations:

ESA (2011) *ESA SOP 103 – Green Alga, Selenastrum capricornutum, Growth Test*. Issue No 9. Ecotox Services Australasia, Sydney, NSW.

USEPA (2002) *Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms*. Fourth Edition. EPA-821-R-02-013. United States Environmental Protection Agency, Office of Research and Development, Washington DC, USA,

Toxicity Test Report: TR1030/3d

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Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	72-hr microalgal growth inhibition test using the green alga *Selenastrum capricornutum*
Test Protocol:	ESA SOP 103 (ESA 2011), based on USEPA (2002)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	The samples were filtered to 0.45µm prior to testing. Sample 5887 'NAR_7102(2)_SURF_W' was spiked with fluoride. The prepared sample was then serially diluted with sample 5887 'NAR_7102(2)_SURF_W'. A USEPA control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the sample. The results are expressed as measured concentrations. The fluoride concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture, originally sourced from CSIRO Microalgal Supply Service, TAS
Test Initiated:	10 May 2013 at 1330h

Sample 5887 + Fluoride : *NAR_7102(2)_SURF_W + Fluoride*

Concentration (mg/L)	Cell Yield $x10^4$ cells/mL (Mean ± SD)
USEPA Control	106.8 ± 18.0
DC2 [<0.1]	145.0 ± 17.4
96.0	118.1 ± 20.5
190.0	111.5 ± 15.4
400.0	72.8 ± 2.7 *
800.0	9.1 ± 0.7 *
1583.0	0.4 ± 0.4 *

72-hr IC10 = <96.0mg/L
72-hr IC50 = 402.0 (334.8-488.2mg/L
NOEC = 190.0mg/L
LOEC = 400.0mg/L

Vacant

*Significantly lower cell yield compared with DC2 (Steel's Many One Rank Test Test, 1-tailed, P=0.05)

Toxicity Test Report: TR1030/3d

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean cell density	≥16.0x10^4 cells/mL	107.8x10^4 cells/mL	Yes
Control coefficient of variation	<20%	16.9%	Yes
Reference Toxicant within cusum chart limits	1.6-4.5g KCl/L	2.1g KCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

ESA (2011) *ESA SOP 103 – Green Alga, Selenastrum capricornutum, Growth Test*. Issue No 9. Ecotox Services Australasia, Sydney, NSW.

USEPA (2002) *Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms*. Fourth Edition. EPA-821-R-02-013. United States Environmental Protection Agency, Office of Research and Development, Washington DC, USA,

Toxicity Test Report: TR1030/4c

This document is issued in accordance with NATA's accreditation requirements

Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	Sample Name:	Sample Description:
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	7-day Growth inhibition of the freshwater aquatic duckweed *Lemna disperma*
Test Protocol:	ESA SOP 112 (ESA 2011), based on OECD method 221 (2006)
Test Temperature:	The test was performed at 25±2°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7108(2)_SURF_W' was spiked with boron or fluoride. The prepared samples were then serially diluted with sample 5887 'NAR_7102(2)_SURF_W'. A Swedish standard medium (SIS) control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The boron and fluoride concentrations of the diluent controls are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	2 May 2013 at 1400h

Sample 5887 + Boron: *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	Specific Growth Rate (Mean ± SD)
SIS Control	0.32 ± 0.08
DC2[0.15]	0.30 ± 0.06
2.7	0.34 ± 0.10
4.9	0.21 ± 0.13
9.6	0.12 ± 0.17
18.0	0.00 ± 0.00
35.0	0.00 ± 0.00

7 day IC10 = 3.3mg/L*
7 day IC50 = 7.3 (2.8-15.2)mg/L
NOEC = 9.6mg/L
LOEC = 18.0mg/L

Sample 5887 + Fluoride: NAR_7102(2)_SURF_W + Fluoride

Concentration (mg/L)	Specific Growth Rate (Mean ± SD)
SIS Control	0.32 ± 0.08
DC2[0.11]	0.30 ± 0.06
6.6	0.37 ± 0.03
13.0	0.34 ± 0.05
26.0	0.45 ± 0.05
56.0	0.31 ± 0.06
110.0	0.25 ± 0.08

7 day IC10 = 45.3 (31.8-88.4)mg/L
7 day IC50 = >110.0mg/L
NOEC = 110.0mg/L
LOEC = >110.0mg/L

*95% confidence limits are not reliable

Toxicity Test Report: TR1030/4c

QA/QC Parameter	Criterion	This Test	Criterion met?
Control frond doubling time	<2.5 days	2.3days	Yes
Reference Toxicant within cusum chart limits	2.3-7.8g KCl/L	3.6g KCl/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

ESA (2011) *SOP 112 – Duckweed Growth Inhibition Test.* Issue No. 3. Ecotox Services Australasia, Sydney NSW

OECD (2006) *Lemna sp*. Growth Inhibition Test. Method 221. OECD Guideline for the Testing of Chemicals. Organisation for Economic Cooperation and Development, Paris

ecotox SERVICES AUSTRALASIA

Toxicity Test Report: TR1030/5b

Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L. Sample received at 15ºC in apparent good condition.

Test Performed:	48-hr acute (survival) toxicity test using the freshwater chironomid *Chironomus tepperi*
Test Protocol:	ESA SOP 121 (ESA 2012), based on OECD (2011) USEPA (2002) and Bailey *et al*. (2000)
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with boron or fluoride. The prepared sample was then serially diluted with sample 5887 (NAR_7102(2)_SURF_W). A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The boron and fluoride concentrations of the diluent controls are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Age of Test Organisms:	7 days old
Test Initiated:	1 May 2013 at 1600h

Sample 5887 + Boron: *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	**% Survival (Mean ± SD)**
DMW Control	100 ± 0.0
DC2 [0.02]	100 ± 0.0
78.0	75.0 ± 30.0
170.0	80.0 ± 16.3
310.0	0.0 ± 0.0
620.0	5.0 ± 10.0 *
1300.0	0.0 ± 0.0

48-hr EC10 = 67.4mg/L***
48-hr EC50 = 166.6mg/L ***
NOEC = 170.0mg/L
LOEC = 310.0mg/L

Sample 5887 + Fluoride: *NAR_7102(2)_SURF_W + Fluoride*

Concentration (mg/L)	**% Survival (Mean ± SD)**
DMW Control	100 ± 0.0
DC2[0.0]	100 ± 0.0
61.0	55.0 ± 30.0 **
120.0	0.0 ± 0.0
240.0	0.0 ± 0.0
480.0	0.0 ± 0.0
930.0	0.0 ± 0.0

48-hr EC10 = 23.8 (12.5-48.8)mg/L
48-hr EC50 =64.9(50.6-83.2)mg/L
NOEC = <61.0mg/L
LOEC = 61.0mg/L

* Significantly lower percent survival compared with DC2 (Steel's Many-One Rank Test, 1-tailed, P=0.05)
**Significantly lower percent survival compared with DC2 (Heteroscedastic t Test, 1-tailed, P=0.05)
***95% confidence limits are not available

ECOTOX Services Australasia Pty Ltd ABN>45 094 714 904
unit 27/2 chaplin drive lane cove nsw 2066 T>61 2 9420 9481 F>61 2 9420 9484 W>www.ecotox.com.au

Toxicity Test Report: TR1030/5b

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % survival	≥85.0%	100%	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA. This document shall not be reproduced except in full.

Citations:

Bailey, H.C., Krassoi, R., Elphick, J.R., Mulhall, A., Hunt, P., Tedmanson, L. and Lovell, A. (2000) Application of *Ceriodaphnia cf. dubia* for whole effluent toxicity tests in the Hawkesbury-Nepean watershed, New South Wales, Australia: method development and validation. *Environmental Toxicology and Chemistry* 19:88-93.

ESA (2012) *SOP 121 – Acute toxicity test using Chironomus tepperi*. Issue No. 1. Ecotox Services Australasia, Sydney, New South Wales.

OECD (2011) OECD Guideline for the Testing of Chemicals. Test Guideline 235: *Chironomus sp*, Acute Immobilisation Test.

USEPA (2002) *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. 4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

Toxicity Test Report: TR1030/6c

Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1030_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	96-hr acute survival test using the freshwater shrimp *Paratya australiensis*
Test Protocol:	ESA SOP 123 (ESA 2012), based on USEPA (1996)
Test Temperature:	The test was performed at 20±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' were spiked with boron. The prepared sample was then serially diluted with sample 5887 (NAR_7102(2)_SURF_W). A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The boron concentrations of the diluent controls are shown in brackets.
Source of Test Organisms:	Hatchery reared, QLD
Test Initiated:	2 May 2013 at 1630h

Sample 5887 + Boron: *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	**% Un-affected (Mean ± SD)**
DMW Control	90.0 ± 11.6
DC2 [0.02]	95.0 ± 10.0
59.0	90.0 ± 11.6
110.0	80.0 ± 16.3
220.0	90.0 ± 11.6
430.0	60.0 ± 40.0
940.0	0.0 ± 0.0

96-hr IC10 = 101.3mg/L*
96-hr EC50 = 445.3 (353.9-560.2)mg/L
NOEC =430.0mg/L
LOEC = 940.0mg/L

Vacant

*95% confidence limits are not reliable

Toxicity Test Report: TR1030/6c

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % un-affected	≥90.0%	90.0%	Yes
Reference Toxicant within cusum chart limits	24.3-902.3µg Cu/L	134.1µg Cu/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

Citations:

ESA (2012) SOP 123 –*Acute Toxicity Test Using Freshwater Shrimp.* Issue No 2. Ecotox Services Australasia, Sydney, NSW

USEPA (1996) Ecological Effects Test Guidelines: OPPTS 850.1035 Mysid Acute Toxicity Test. Public Draft. United States Environmental Protection Agency, Washington DC, USA.

Toxicity Test Report: TR1030/6d

Client:	Acqua Della Vita Pty Ltd PO Box 194 Browns Plains, Qld, 4118	ESA Job #: Date Sampled: Date Received:	PR1030 13 March 2013 14 March 2013
Attention:	Heather Chapman	Sampled By:	Client
Client Ref:	Not supplied	ESA Quote #:	PL1030_q01

Lab ID No.:	Sample Name:	Sample Description:
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	96-hr acute survival test using the freshwater shrimp *Paratya australiensis*
Test Protocol:	ESA SOP 123 (ESA 2012), based on USEPA (1996)
Test Temperature:	The test was performed at 20±1°C.
Deviations from Protocol:	Nil
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with fluoride. The prepared sample was then serially diluted with sample 5887 (NAR_7102(2)_SURF_W). A DMW control and a DC2 (NAR_7102(2)_SURF_W) were tested concurrently with the samples. The results are expressed as measured concentrations. The fluoride concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	Hatchery reared, QLD
Test Initiated:	16 May 2013 at 1630h

Sample 5887 + fluoride : *NAR_7102(2)_SURF_W + fluoride*

Concentration (mg/L)	% Un-affected (Mean ± SD)		Vacant
DMW Control	100 ± 0.0		
DC2 [0.0]	100 ± 0.0		
1.2	95.0 ± 10.0		
2.4	100 ± 0.0		
5.3	95.0 ± 10.0		
10.0	85.0 ± 19.2		
21.0	15.0 ± 19.2	*	

96-hr IC10 = 7.9 (2.3-15.2)mg/L
96-hr EC50 = 14.5 (12.9-16.3)mg/L
NOEC =10.0mg/L
LOEC = 21.0mg/L

*Significantly lower percent un-affected compared with DC2 (Steel's Many One Rank Test, 1-tailed, P=0.05)

Toxicity Test Report: TR1030/6d

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % un-affected	≥90.0%	100%	Yes
Reference Toxicant within cusum chart limits	24.0-1011.8µg Cu/L	138.4µg Cu/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 1 April 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

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Citations:

ESA (2012) SOP 123 –*Acute Toxicity Test Using Freshwater Shrimp.* Issue No 2. Ecotox Services Australasia, Sydney, NSW

USEPA (1996) Ecological Effects Test Guidelines: OPPTS 850.1035 Mysid Acute Toxicity Test. Public Draft. United States Environmental Protection Agency, Washington DC, USA.

Chain-of-Custody Documentation

Datasheet ID: 601.2
Last Revised: 30 April 2009

Sample Receipt Notification

Attention : Heather Chapman

Client : Acqua Della Vita Pty Ltd
PO Box 194,
Browns Plains, Queensland 4118

Email : acquadellavita@gmail.com
Telephone : 0400 096 359
Facsimile :

Date : 15/03/2013

Re : Receipt of samples **Pages : 3**

ESA Project : PR1030 ☑ For Review ☐ Additional Documentation Required - Please Respond

Sample Delivery Details

Completed Chain of Custody accompanied samples: **YES**
Samples received in apparent good condition and correctly bottled: **YES**
Security seals on sample bottles and esky intact: **YES**

Date samples received : 14/03/2013
Time samples received : 11:00
No. of samples received : 2
Sample matrix : aqueous
Sample temperature : 11-15°C

Comments : Includes 30 x 5L NAR7108(1)_SURF_W (ESA ID# 5886) and 30 x 5L NAR7102(2)_SURF_W (ESA ID# 5887)

Contact Details

Customer Services Officer : Tina Micevska
Telephone : 61 2 9420 9481
Facsimile : 61 2 9420 9484
Email : tmicevska@ecotox.com.au

Please contact customer services officer for all queries or issues regarding samples

Note that the chain-of-custody provides definitive information on the tests to be performed

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SERVICES AUSTRALASIA

Chain-of-Custody / Service Request Form

Datasheet ID: 601.1
Last Revised: 22 January 2013

Customer: CH2M HILL
Contact Name: Re MARK FARUETTA
Phone: 612 92509909 Email: Mark.FAVETTA@CH2M.COM
Sampled by: Ryan Loveridge

Ship To: ECOTOX SERVICES AUSTRALASIA
Attention: RICK KRASROIL
(please provide an email address for sample receipt notification)
Consinement NO: 9800 2672 8614 TNT

Sample Date (day/month/year)	Sample Time	Sample Name (exactly as written on the sample vessel)	Sample Method (eg. Grab, composite etc.)	Number and Volume of Containers (eg 2 x 1L)	Tests Requested (See reverse for guidance)	Comments / Instructions
13/03/13	08:30	NAR-7108(1)_SURF_W	GRAB	30 x 5L	refer to Heather Chapman	

Comments / Instructions:

Note that testing will be delayed if an incomplete chain of custody is received

- Additional treatment of samples (i.e. spiking)
- Sub-contracted services (i.e. chemical analyses)
- Dilutions required (if different than 100% down to 6.25%)
- Sample holding time restriction (if applicable)
- Sample used for litigation (if applicable)

Note: An MSDS must be attached if Available

ESA Project Number: PR 030

5880
~15°C

1) Released By:	Date:	2) Received By: NR	Date: 14/3/13	3) Released By:	Date:	4) Received By:	Date:
Of:	Time:	Of: ESA	Time: 11:00	Of:	Time:	Of:	Time:

Note that the chain-of-custody documentation will provide definitive information on the tests to be performed.

Ecotox Services Australasia . Unit 27, 2 Chaplin Drive, Lane Cove NSW 2066 AUSTRALIA
Phone: 61 2 9420-9481 Fax 61 2 9420-9484 info@ecotox.com.au

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SERVICES AUSTRALASIA

Chain-of-Custody / Service Request Form

Datasheet ID: 601.1
Last Revised: 22 January 2013

Customer: CH2M HILL

Contact Name: ~~Rick Krassoi~~ RK Mark Farctta

Phone: 61 2 9250-9909 Email: Mark.Favetta@ch2m.com (please provide an email address for sample receipt notification)

Sampled by: Ryan Loveidge

Ship To: Ecotox Services ~~Austral~~ RK Australasia

Attention: Rick Krassoi

consignment no: 102351631 TNT Express

Sample Date (day/month /year)	Sample Time	Sample Name (exactly as written on the sample vessel)	Sample Method (eg. Grab, composite etc.)	Number and Volume of Containers (eg 2 x 1L)	Tests Requested (See reverse for guidance)						Comments / Instructions
											Note that testing will be delayed if an incomplete chain of custody is received • Additional treatment of samples (i.e. spiking) • Sub-contracted services (i.e. chemical analyses) • Dilutions required (if different than 100% down to 6.25%) • Sample holding time restriction (if applicable) • Sample used for litigation (if applicable) *Note: An MSDS must be attached if Available* **ESA Project Number: PR** 1030
12/03/13	0745	NAR-7102(2)-SURF-W	Grab	30 x 5L	refer to						[illegible] (see reverse)

5887
15°C

1) Released By: Ryan Loveidge	Date: 12-3-13	2) Received By: MR	Date: 14/3/13	3) Released By:	Date:	4) Received By:	Date:
Of: CH2M HILL	Time: 1530	Of: ESA	Time: 11:00	Of:	Time:	Of:	Time:

Note that the chain-of-custody documentation will provide definitive information on the tests to be performed.

Ecotox Services Australasia . Unit 27, 2 Chaplin Drive, Lane Cove NSW 2066 AUSTRALIA
Phone: 61 2 9420-9481 Fax 61 2 9420-9484 info@ecotox.com.au

Statistical Printouts for the Acute Test with *Ceriodaphnia dubia*

Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/1	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2[0.02]	1.0000	1.0000	1.0000	1.0000
19	1.0000	1.0000	1.0000	1.0000
38	1.0000	1.0000	1.0000	1.0000
78	1.0000	0.6000	0.8000	0.8000
170	0.2000	0.2000	0.0000	0.0000
310	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2[0.02]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		0	20
19	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
38	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
78	0.8000	0.8000	1.1114	0.8861	1.3453	16.874	4	12.00	10.00	4	20
*170	0.1000	0.1000	0.3446	0.2255	0.4636	39.900	4	10.00	10.00	18	20
310	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20

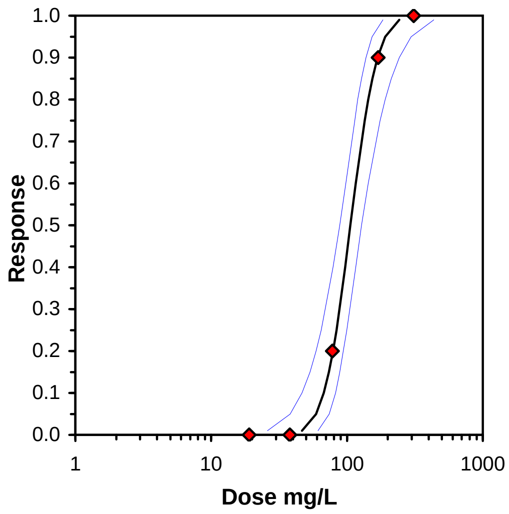
Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.783666	0.905	0.10002	2.77747
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	78	170	115.1521	
Treatments vs DC2[0.02]				

Maximum Likelihood-Probit

Parameter	Value	SE	95% Fiducial Limits		Control	Chi-Sq	Critical	P-value	Mu	Sigma	Iter
Slope	6.480827	1.30742	3.918284	9.043369	0	0.083648	7.814728	0.99	2.026684	0.154301	3
Intercept	-8.13459	2.661419	-13.351	-2.91821							
TSCR											

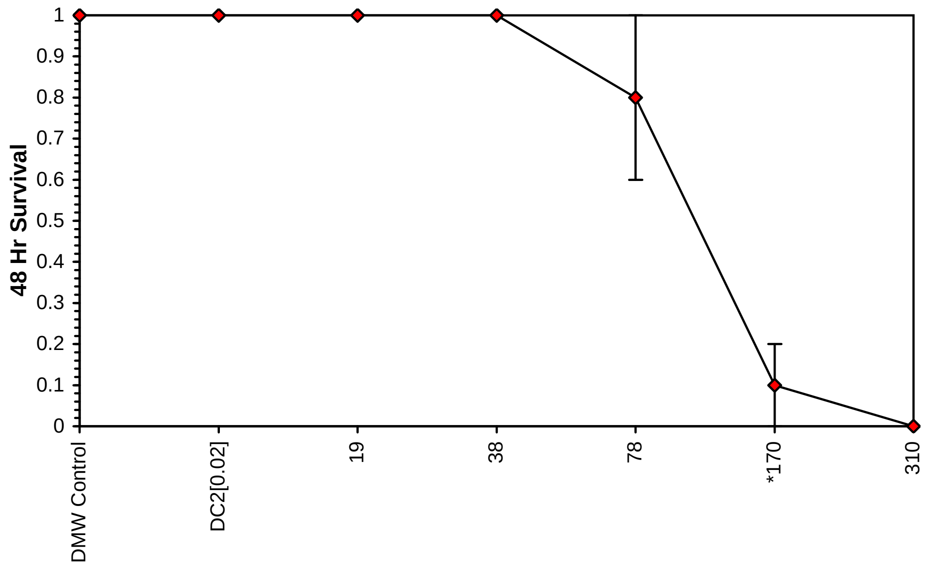
Point	Probits	mg/L	95% Fiducial Limits	
EC01	2.674	46.52921	25.97663	61.33081
EC05	3.355	59.2763	38.20754	74.02828
EC10	3.718	67.44334	46.72068	82.21112
EC15	3.964	73.58023	53.35102	88.50325
EC20	4.158	78.85349	59.13967	94.07707
EC25	4.326	83.67766	64.45748	99.36301
EC40	4.747	97.18347	79.05963	115.5032
EC50	5.000	106.3369	88.38901	127.8859
EC60	5.253	116.3526	97.88364	142.9497
EC75	5.674	135.1322	113.8125	175.2888
EC80	5.842	143.3994	120.2161	191.0367
EC85	6.036	153.6764	127.7957	211.7502
EC90	6.282	167.6599	137.5853	241.7854
EC95	6.645	190.76	152.8032	295.6398
EC99	7.326	243.0204	184.45	434.8123



Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/1	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/1	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2[0.02]		100.00	100.00	100.00	0.00	0.00	4
19		100.00	100.00	100.00	0.00	0.00	4
38		100.00	100.00	100.00	0.00	0.00	4
78		80.00	60.00	100.00	16.33	5.05	4
170		10.00	0.00	20.00	11.55	33.98	4
310		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2[0.02]		7.10	7.10	7.10	0.00	0.00	1
19		6.90	6.90	6.90	0.00	0.00	1
38		6.70	6.70	6.70	0.00	0.00	1
78		6.60	6.60	6.60	0.00	0.00	1
170		6.50	6.50	6.50	0.00	0.00	1
310		6.50	6.50	6.50	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2[0.02]		94.20	94.20	94.20	0.00	0.00	1
19		96.90	96.90	96.90	0.00	0.00	1
38		97.00	97.00	97.00	0.00	0.00	1
78		95.10	95.10	95.10	0.00	0.00	1
170		95.40	95.40	95.40	0.00	0.00	1
310		95.40	95.40	95.40	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2[0.02]		76.30	76.30	76.30	0.00	0.00	1
19		76.20	76.20	76.20	0.00	0.00	1
38		76.00	76.00	76.00	0.00	0.00	1
78		76.20	76.20	76.20	0.00	0.00	1
170		75.70	75.70	75.70	0.00	0.00	1
310		75.30	75.30	75.30	0.00	0.00	1

Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2[0.0]	1.0000	1.0000	1.0000	1.0000
31	1.0000	1.0000	1.0000	1.0000
61	1.0000	1.0000	1.0000	1.0000
120	1.0000	1.0000	1.0000	1.0000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000

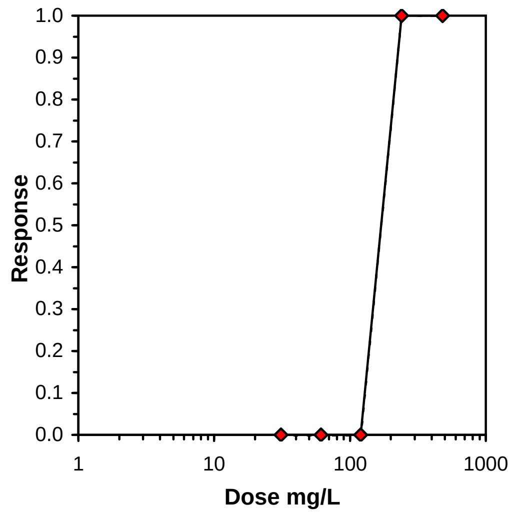
			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2[0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		0	20
31	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
61	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
120	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	1	0.887		
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	120	240	169.7056	
Treatments vs DC2[0.0]				

Graphical Method

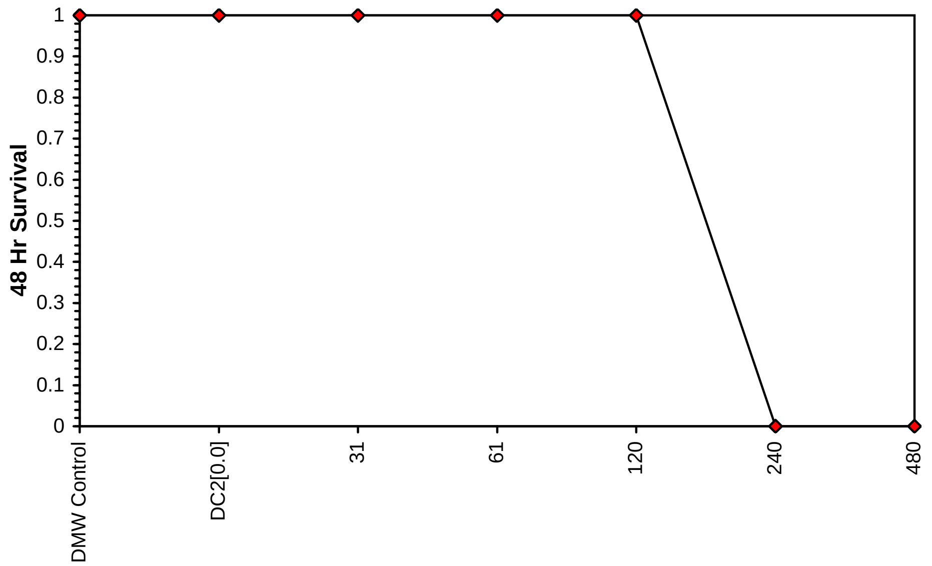
Trim Level	EC50
0.0%	169.71
	169.71



Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2[0.0]		100.00	100.00	100.00	0.00	0.00	4
31		100.00	100.00	100.00	0.00	0.00	4
61		100.00	100.00	100.00	0.00	0.00	4
120		100.00	100.00	100.00	0.00	0.00	4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2[0.0]		7.10	7.10	7.10	0.00	0.00	1
31		7.00	7.00	7.00	0.00	0.00	1
61		7.10	7.10	7.10	0.00	0.00	1
120		7.10	7.10	7.10	0.00	0.00	1
240		7.10	7.10	7.10	0.00	0.00	1
480		6.70	6.70	6.70	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2[0.0]		94.20	94.20	94.20	0.00	0.00	1
31		97.30	97.30	97.30	0.00	0.00	1
61		95.50	95.50	95.50	0.00	0.00	1
120		95.00	95.00	95.00	0.00	0.00	1
240		93.70	93.70	93.70	0.00	0.00	1
480		92.10	92.10	92.10	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2[0.0]		76.30	76.30	76.30	0.00	0.00	1
31		248.00	248.00	248.00	0.00	0.00	1
61		427.00	427.00	427.00	0.00	0.00	1
120		727.00	727.00	727.00	0.00	0.00	1
240		1347.00	1347.00	1347.00	0.00	0.00	1
480		2500.00	2500.00	2500.00	0.00	0.00	1

Ceriodaphnia Acute Toxicity Test-48 Hr Survival					
Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + Fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2[0.0]	1.0000	1.0000	1.0000	1.0000
31	1.0000	1.0000	1.0000	1.0000
61	1.0000	1.0000	1.0000	1.0000
120	1.0000	1.0000	1.0000	1.0000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000

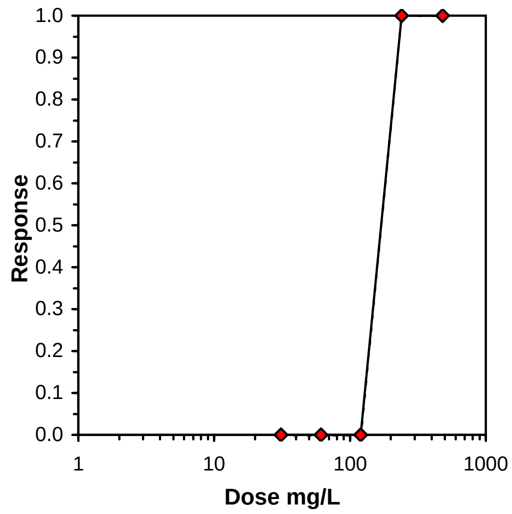
			Transform: Arcsin Square Root					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2[0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		1.0000	1.0000
31	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	1.0000	1.0000
61	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	1.0000	1.0000
120	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	1.0000	1.0000
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	1	0.887		
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	120	240	169.7056	
Treatments vs DC2[0.0]				

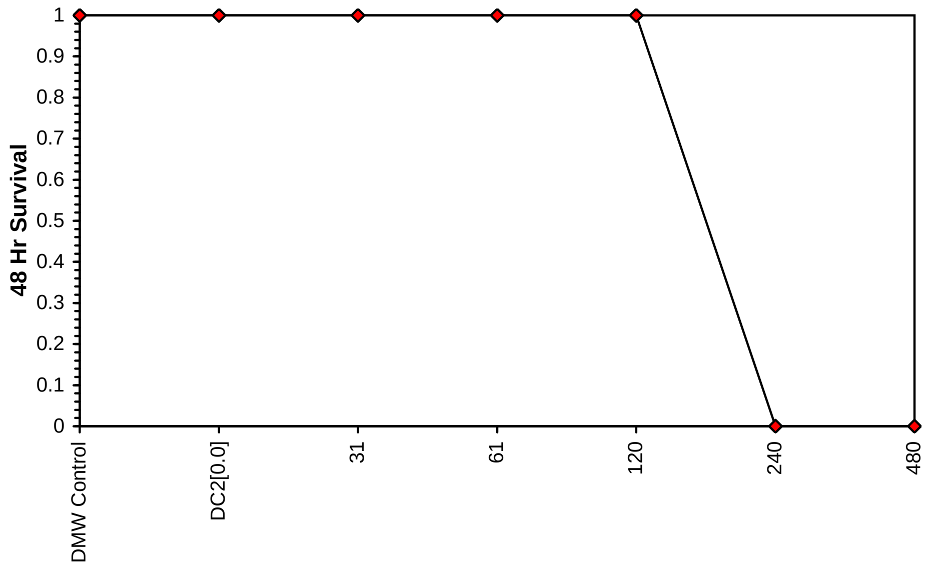
Log-Logit Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05	151.96	0.00	151.96	151.96	1.0076
IC10	156.29	0.00	156.29	156.29	-1.0076
IC15	159.04	0.00	159.04	159.04	#DIV/0!
IC20	161.14	0.00	161.14	161.14	1.0076
IC25	162.89	0.00	162.89	162.89	-1.0076
IC40	167.20	0.00	167.20	167.20	-1.0076
IC50	169.77	0.00	169.77	169.77	-1.0076



Ceriodaphnia Acute Toxicity Test-48 Hr Survival					
Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + Fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



Ceriodaphnia Acute Toxicity Test-48 Hr Survival

Start Date:	1/05/2013 15:00	Test ID:	PR1030/2	Sample ID:	NAR_7102(2)_SURF_W + Fluoride
End Date:	3/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 101	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2[0.0]		100.00	100.00	100.00	0.00	0.00	4
31		100.00	100.00	100.00	0.00	0.00	4
61		100.00	100.00	100.00	0.00	0.00	4
120		100.00	100.00	100.00	0.00	0.00	4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2[0.0]		7.10	7.10	7.10	0.00	0.00	1
31		7.00	7.00	7.00	0.00	0.00	1
61		7.10	7.10	7.10	0.00	0.00	1
120		7.10	7.10	7.10	0.00	0.00	1
240		7.10	7.10	7.10	0.00	0.00	1
480		6.70	6.70	6.70	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2[0.0]		94.20	94.20	94.20	0.00	0.00	1
31		97.30	97.30	97.30	0.00	0.00	1
61		95.50	95.50	95.50	0.00	0.00	1
120		95.00	95.00	95.00	0.00	0.00	1
240		93.70	93.70	93.70	0.00	0.00	1
480		92.10	92.10	92.10	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2[0.0]		76.30	76.30	76.30	0.00	0.00	1
31		248.00	248.00	248.00	0.00	0.00	1
61		427.00	427.00	427.00	0.00	0.00	1
120		727.00	727.00	727.00	0.00	0.00	1
240		1347.00	1347.00	1347.00	0.00	0.00	1
480		2500.00	2500.00	2500.00	0.00	0.00	1

Statistical Printouts for the 7-d Chronic Test with *Ceriodaphnia dubia*

Ceriodaphnia Partial Life-Cycle Test-7 Day Survival

Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

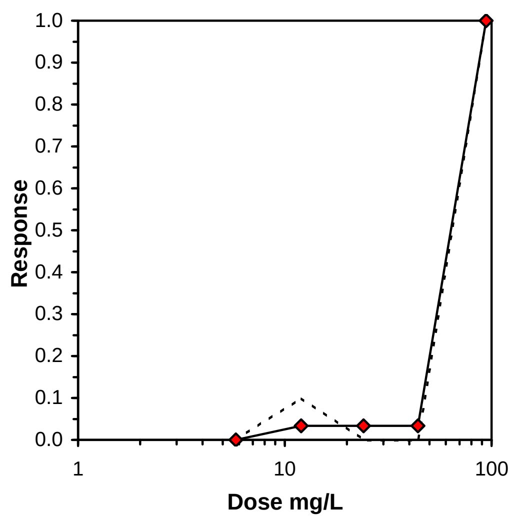
Conc-mg/L	1	2	3	4	5	6	7	8	9	10
DMW Control	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DC2 [0.021]	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5.8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
44	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
94	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

				Not			Fisher's	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Resp	Resp	Total	N	Exact P	Critical	Mean	N-Mean
DMW Control	0.9000	0.9000	1	9	10	10	0.5619			
DC2 [0.021]	1.0000	1.0000	0	10	10	10	*		1.0000	1.0000
5.8	1.0000	1.0000	0	10	10	10	1.0000	0.0500	1.0000	1.0000
12	0.9000	0.9000	1	9	10	10	0.5000	0.0500	0.9667	0.9667
24	1.0000	1.0000	0	10	10	10	1.0000	0.0500	0.9667	0.9667
44	1.0000	1.0000	0	10	10	10	1.0000	0.0500	0.9667	0.9667
94	0.0000	0.0000	10	0	10	10			0.0000	0.0000

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Fisher's Exact Test	44	94	64.31174	
Treatments vs DC2 [0.021]				

Log-Logit Interpolation (200 Resamples)

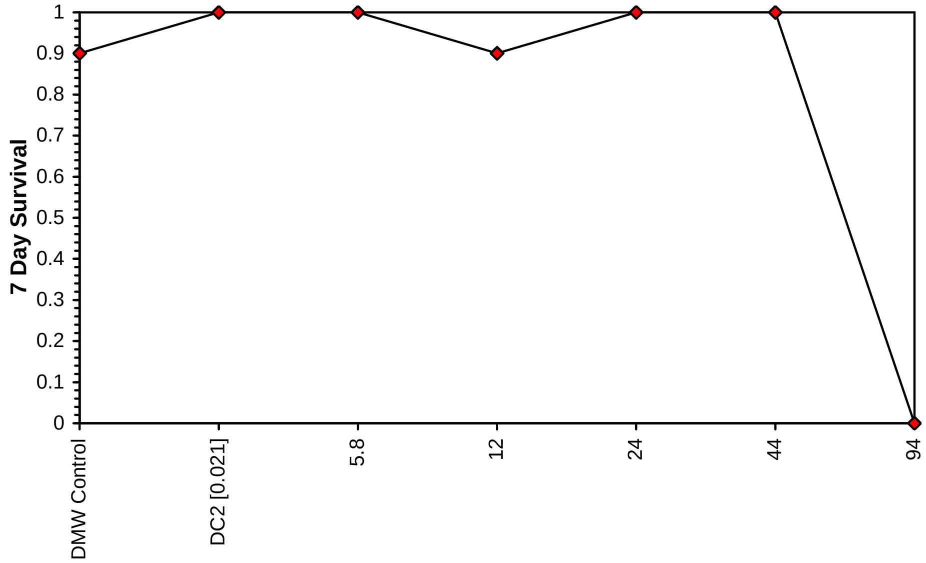
Point	mg/L	SD	95% CL		Skew
IC05	45.145	17.719	11.133	57.022	-0.8747
IC10	47.239	6.583	44.000	58.808	-0.5238
IC15	48.584	5.895	45.385	59.941	0.5896
IC20	49.620	5.810	46.455	60.808	0.5889
IC25	50.493	5.735	47.358	61.534	0.5883
IC40	52.657	5.542	49.604	63.317	0.5869
IC50	53.966	5.419	50.966	64.383	0.5860



Ceriodaphnia Partial Life-Cycle Test-7 Day Survival

Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



Ceriodaphnia Partial Life-Cycle Test-7 Day Survival					
Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	No of Young	17.60	4.00	27.00	7.07	15.11	10
DC2 [0.021]		22.60	7.00	31.00	7.00	11.70	10
5.8		25.50	13.00	33.00	5.25	8.99	10
12		19.00	0.00	28.00	8.55	15.39	10
24		16.60	9.00	24.00	4.43	12.68	10
44		0.00	0.00	0.00	0.00		10
94		0.00	0.00	0.00	0.00		10
DMW Control	% survival	90.00	0.00	100.00	31.62	6.25	10
DC2 [0.021]		100.00	100.00	100.00	0.00	0.00	10
5.8		100.00	100.00	100.00	0.00	0.00	10
12		90.00	0.00	100.00	31.62	6.25	10
24		100.00	100.00	100.00	0.00	0.00	10
44		100.00	100.00	100.00	0.00	0.00	10
94		0.00	0.00	0.00	0.00		10
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.021]		7.10	7.10	7.10	0.00	0.00	1
5.8		6.90	6.90	6.90	0.00	0.00	1
12		6.70	6.70	6.70	0.00	0.00	1
24		6.70	6.70	6.70	0.00	0.00	1
44		6.70	6.70	6.70	0.00	0.00	1
94		6.70	6.70	6.70	0.00	0.00	1
DMW Control	DO %	102.90	102.90	102.90	0.00	0.00	1
DC2 [0.021]		105.30	105.30	105.30	0.00	0.00	1
5.8		109.30	109.30	109.30	0.00	0.00	1
12		107.00	107.00	107.00	0.00	0.00	1
24		104.10	104.10	104.10	0.00	0.00	1
44		104.40	104.40	104.40	0.00	0.00	1
94		104.60	104.60	104.60	0.00	0.00	1
DMW Control	Cond uS/cm	180.00	180.00	180.00	0.00	0.00	1
DC2 [0.021]		85.70	85.70	85.70	0.00	0.00	1
5.8		85.50	85.50	85.50	0.00	0.00	1
12		85.30	85.30	85.30	0.00	0.00	1
24		86.00	86.00	86.00	0.00	0.00	1
44		86.30	86.30	86.30	0.00	0.00	1
94		86.30	86.30	86.30	0.00	0.00	1

Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Conc-mg/L	1	2	3	4	5	6	7	8	9	10
DMW Control	27.000	14.000	4.000	24.000	17.000	25.000	22.000	16.000	16.000	11.000
DC2 [0.021]	29.000	23.000	26.000	25.000	31.000	25.000	25.000	7.000	16.000	19.000
5.8	25.000	33.000	24.000	29.000	24.000	24.000	29.000	27.000	27.000	13.000
12	19.000	21.000	0.000	24.000	27.000	24.000	28.000	22.000	11.000	14.000
24	24.000	19.000	19.000	19.000	16.000	12.000	18.000	18.000	12.000	9.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
94	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

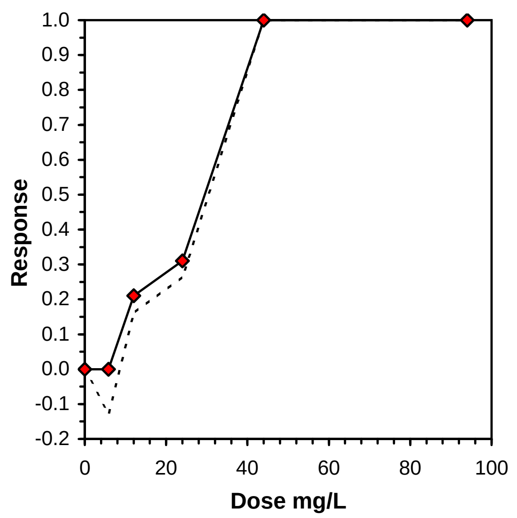
			Transform: Untransformed					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	17.600	0.7788	17.600	4.000	27.000	40.194	10				
DC2 [0.021]	22.600	1.0000	22.600	7.000	31.000	30.952	10	*		24.050	1.0000
5.8	25.500	1.1283	25.500	13.000	33.000	20.606	10	116.50	77.00	24.050	1.0000
12	19.000	0.8407	19.000	0.000	28.000	45.003	10	89.50	77.00	19.000	0.7900
*24	16.600	0.7345	16.600	9.000	24.000	26.670	10	75.00	77.00	16.600	0.6902
44	0.000	0.0000	0.000	0.000	0.000	0.000	10			0.000	0.0000
94	0.000	0.0000	0.000	0.000	0.000	0.000	10			0.000	0.0000

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.90639	0.94	-1.19365	1.664854
Bartlett's Test indicates equal variances (p = 0.23)	4.337653	11.34487		
The control means are not significantly different (p = 0.13)	1.589283	2.100922		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	12	24	16.97056	
Treatments vs DC2 [0.021]				

Linear Interpolation (200 Resamples)

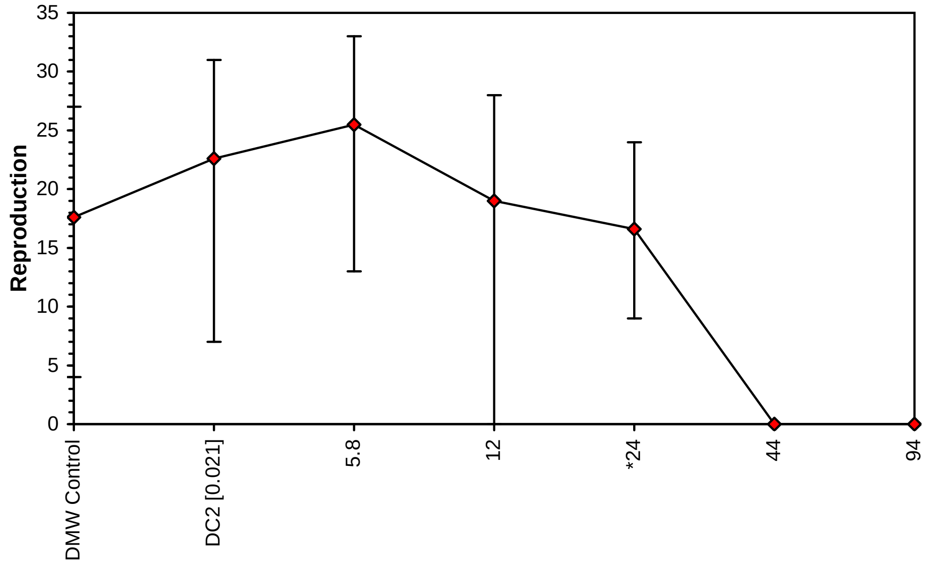
Point	mg/L	SD	95% CL		Skew
IC05	7.276	2.235	3.539	13.522	1.2031
IC10	8.753	2.858	6.318	16.607	1.4623
IC15	10.229	3.613	7.839	20.290	1.3409
IC20	11.705	4.634	8.797	24.785	0.8331
IC25	16.813	5.485	9.606	25.985	0.1445
IC40	26.614	3.245	11.889	29.588	-2.6525
IC50	29.512	2.006	25.428	31.990	-3.3393



Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	3/05/2013 16:00	Test ID:	PR1030/12	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	10/05/2013 11:45	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	No of Young	17.60	4.00	27.00	7.07	15.11	10
DC2 [0.021]		22.60	7.00	31.00	7.00	11.70	10
5.8		25.50	13.00	33.00	5.25	8.99	10
12		19.00	0.00	28.00	8.55	15.39	10
24		16.60	9.00	24.00	4.43	12.68	10
44		0.00	0.00	0.00	0.00		10
94		0.00	0.00	0.00	0.00		10
DMW Control	% survival	90.00	0.00	100.00	31.62	6.25	10
DC2 [0.021]		100.00	100.00	100.00	0.00	0.00	10
5.8		100.00	100.00	100.00	0.00	0.00	10
12		90.00	0.00	100.00	31.62	6.25	10
24		100.00	100.00	100.00	0.00	0.00	10
44		100.00	100.00	100.00	0.00	0.00	10
94		0.00	0.00	0.00	0.00		10
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.021]		7.10	7.10	7.10	0.00	0.00	1
5.8		6.90	6.90	6.90	0.00	0.00	1
12		6.70	6.70	6.70	0.00	0.00	1
24		6.70	6.70	6.70	0.00	0.00	1
44		6.70	6.70	6.70	0.00	0.00	1
94		6.70	6.70	6.70	0.00	0.00	1
DMW Control	DO %	102.90	102.90	102.90	0.00	0.00	1
DC2 [0.021]		105.30	105.30	105.30	0.00	0.00	1
5.8		109.30	109.30	109.30	0.00	0.00	1
12		107.00	107.00	107.00	0.00	0.00	1
24		104.10	104.10	104.10	0.00	0.00	1
44		104.40	104.40	104.40	0.00	0.00	1
94		104.60	104.60	104.60	0.00	0.00	1
DMW Control	Cond uS/cm	180.00	180.00	180.00	0.00	0.00	1
DC2 [0.021]		85.70	85.70	85.70	0.00	0.00	1
5.8		85.50	85.50	85.50	0.00	0.00	1
12		85.30	85.30	85.30	0.00	0.00	1
24		86.00	86.00	86.00	0.00	0.00	1
44		86.30	86.30	86.30	0.00	0.00	1
94		86.30	86.30	86.30	0.00	0.00	1

Ceriodaphnia Partial Life-Cycle Test-7 Day Survival

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

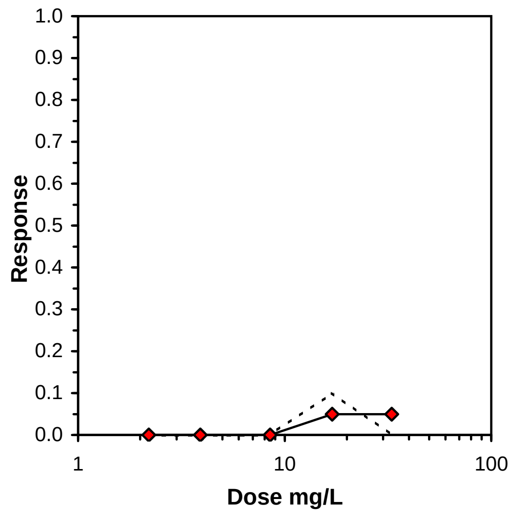
Conc-mg/L	1	2	3	4	5	6	7	8	9	10
DMW Control	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
DC2 [0.0]	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2.2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
8.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Conc-mg/L	Mean	N-Mean	Resp	Not Resp	Total	N	Fisher's Exact P	1-Tailed Critical	Isotonic Mean	Isotonic N-Mean
DMW Control	1.0000	1.0000	0	10	10	10	0.6238			
DC2 [0.0]	1.0000	1.0000	0	10	10	10	*		1.0000	1.0000
2.2	1.0000	1.0000	0	10	10	10	1.0000	0.0500	1.0000	1.0000
3.9	1.0000	1.0000	0	10	10	10	1.0000	0.0500	1.0000	1.0000
8.5	1.0000	1.0000	0	10	10	10	1.0000	0.0500	1.0000	1.0000
17	0.9000	0.9000	1	9	10	10	0.5000	0.0500	0.9500	0.9500
33	1.0000	1.0000	0	10	10	10	1.0000	0.0500	0.9500	0.9500

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Fisher's Exact Test	33	>33		
Treatments vs DC2 [0.0]				

Log-Logit Interpolation (200 Resamples)

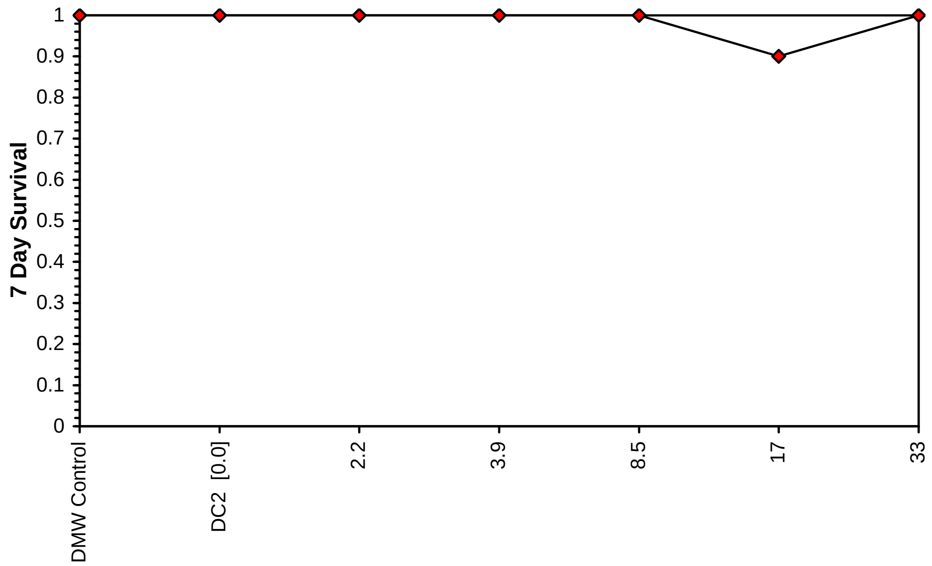
Point	mg/L	SD	95% CL	Skew
IC05	>33			
IC10	>33			
IC15	>33			
IC20	>33			
IC25	>33			
IC40	>33			
IC50	>33			



Ceriodaphnia Partial Life-Cycle Test-7 Day Survival

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



ToxCalc v5.0.23

Reviewed by:_____

Ceriodaphnia Partial Life-Cycle Test-7 Day Survival

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	No of Young	16.90	4.00	22.00	5.20	13.49	10
DC2 [0.0]		17.90	10.00	22.00	3.67	10.70	10
2.2		19.70	15.00	24.00	2.41	7.87	10
3.9		17.30	12.00	20.00	2.36	8.88	10
8.5		18.60	11.00	25.00	4.20	11.01	10
17		2.30	0.00	6.00	2.50	68.70	10
33		0.00	0.00	0.00	0.00		10
DMW Control	% survival	100.00	100.00	100.00	0.00	0.00	10
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	10
2.2		100.00	100.00	100.00	0.00	0.00	10
3.9		100.00	100.00	100.00	0.00	0.00	10
8.5		100.00	100.00	100.00	0.00	0.00	10
17		90.00	0.00	100.00	31.62	6.25	10
33		100.00	100.00	100.00	0.00	0.00	10
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.0]		7.40	7.40	7.40	0.00	0.00	1
2.2		7.30	7.30	7.30	0.00	0.00	1
3.9		7.20	7.20	7.20	0.00	0.00	1
8.5		7.20	7.20	7.20	0.00	0.00	1
17		7.30	7.30	7.30	0.00	0.00	1
33		7.80	7.80	7.80	0.00	0.00	1
DMW Control	DO %	116.00	116.00	116.00	0.00	0.00	1
DC2 [0.0]		110.50	110.50	110.50	0.00	0.00	1
2.2		110.30	110.30	110.30	0.00	0.00	1
3.9		107.50	107.50	107.50	0.00	0.00	1
8.5		107.20	107.20	107.20	0.00	0.00	1
17		107.60	107.60	107.60	0.00	0.00	1
33		116.70	116.70	116.70	0.00	0.00	1
DMW Control	Cond uS/cm	180.30	180.30	180.30	0.00	0.00	1
DC2 [0.0]		90.00	90.00	90.00	0.00	0.00	1
2.2		95.90	95.90	95.90	0.00	0.00	1
3.9		106.80	106.80	106.80	0.00	0.00	1
8.5		127.40	127.40	127.40	0.00	0.00	1
17		166.50	166.50	166.50	0.00	0.00	1
33		246.00	246.00	246.00	0.00	0.00	1

Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Conc-mg/L	1	2	3	4	5	6	7	8	9	10
DMW Control	19.000	20.000	16.000	17.000	17.000	4.000	22.000	22.000	14.000	18.000
DC2 [0.0]	18.000	19.000	20.000	19.000	22.000	19.000	13.000	10.000	21.000	18.000
2.2	19.000	24.000	15.000	20.000	17.000	21.000	20.000	20.000	20.000	21.000
3.9	18.000	17.000	20.000	17.000	16.000	19.000	12.000	16.000	18.000	20.000
8.5	24.000	11.000	17.000	25.000	18.000	20.000	15.000	19.000	16.000	21.000
17	4.000	0.000	1.000	2.000	6.000	0.000	0.000	6.000	4.000	
33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

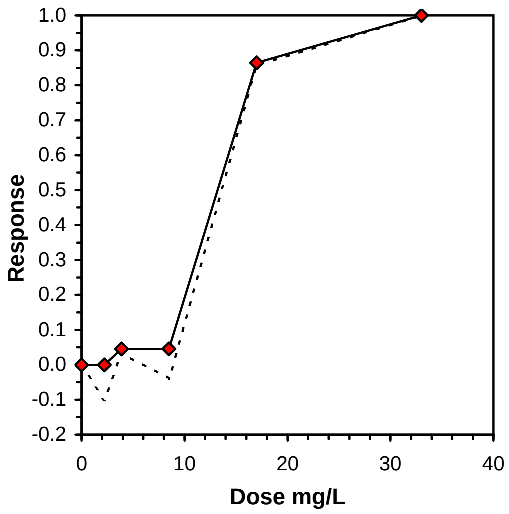
			Transform: Untransformed						1-Tailed		Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Mean	N-Mean
DMW Control	16.900	0.9441	16.900	4.000	22.000	30.740	10					
DC2 [0.0]	17.900	1.0000	17.900	10.000	22.000	20.476	10	*			18.800	1.0000
2.2	19.700	1.1006	19.700	15.000	24.000	12.213	10	-1.285	2.321	3.251	18.800	1.0000
3.9	17.300	0.9665	17.300	12.000	20.000	13.638	10	0.428	2.321	3.251	17.950	0.9548
8.5	18.600	1.0391	18.600	11.000	25.000	22.555	10	-0.500	2.321	3.251	17.950	0.9548
*17	2.556	0.1428	2.556	0.000	6.000	98.043	9	10.662	2.321	3.340	2.556	0.1359
33	0.000	0.0000	0.000	0.000	0.000	0.000	10				0.000	0.0000

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.96783	0.947	-0.55113	0.659577
Bartlett's Test indicates equal variances (p = 0.28)	5.104039	13.2767		
The control means are not significantly different (p = 0.62)	0.497382	2.100922		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU	MSDu	MSDp	MSB	MSE	F-Prob	df
Bonferroni t Test	8.5	17	12.02082		3.340046	0.186595	467.6205	9.811869	1.9E-15	4, 44
Treatments vs DC2 [0.0]										

Linear Interpolation (200 Resamples)

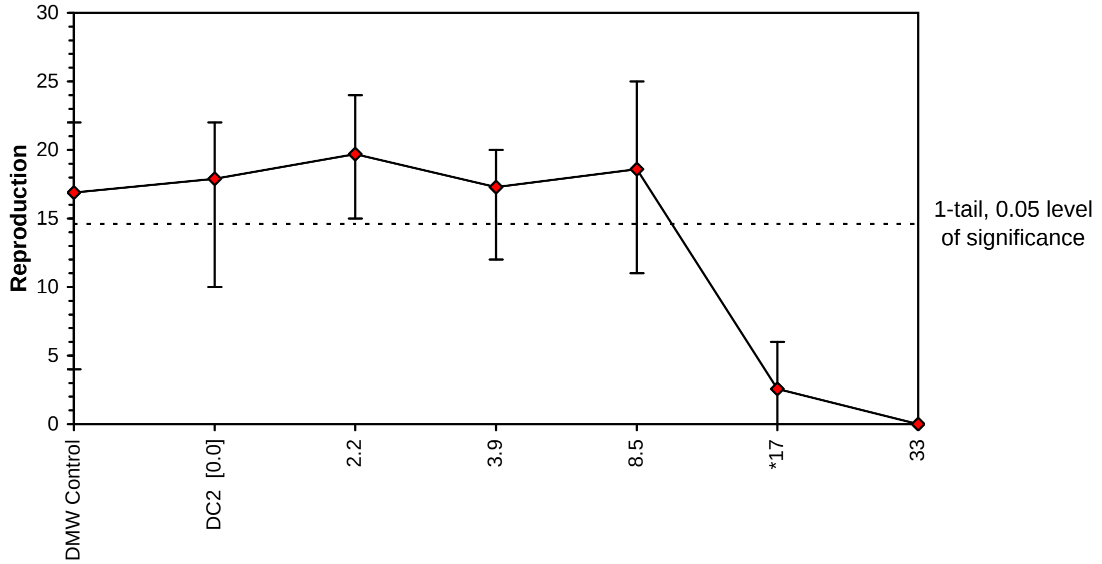
Point	mg/L	SD	95% CL		Skew
IC05	8.550	2.772	2.397	9.014	0.0211
IC10	9.069	1.772	3.542	9.528	-2.1563
IC15	9.588	0.801	8.509	10.044	-4.8951
IC20	10.107	0.627	9.093	10.559	-5.4531
IC25	10.626	0.412	9.673	11.080	-1.0771
IC40	12.183	0.372	11.350	12.682	-0.9596
IC50	13.221	0.361	12.432	13.754	-0.7578



Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

Dose-Response Plot



 ToxCalc v5.0.23 Reviewed by:_____

Ceriodaphnia Partial Life-Cycle Test-Reproduction

Start Date:	17/05/2013 15:00	Test ID:	PR1030/31	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	24/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 102	Test Species:	CD-Ceriodaphnia dubia
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	No of Young	16.90	4.00	22.00	5.20	13.49	10
DC2 [0.0]		17.90	10.00	22.00	3.67	10.70	10
2.2		19.70	15.00	24.00	2.41	7.87	10
3.9		17.30	12.00	20.00	2.36	8.88	10
8.5		18.60	11.00	25.00	4.20	11.01	10
17		2.56	0.00	6.00	2.51	61.94	9
33		0.00	0.00	0.00	0.00		10
DMW Control	% survival	100.00	100.00	100.00	0.00	0.00	10
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	10
2.2		100.00	100.00	100.00	0.00	0.00	10
3.9		100.00	100.00	100.00	0.00	0.00	10
8.5		100.00	100.00	100.00	0.00	0.00	10
17		90.00	0.00	100.00	31.62	6.25	10
33		100.00	100.00	100.00	0.00	0.00	10
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.0]		7.40	7.40	7.40	0.00	0.00	1
2.2		7.30	7.30	7.30	0.00	0.00	1
3.9		7.20	7.20	7.20	0.00	0.00	1
8.5		7.20	7.20	7.20	0.00	0.00	1
17		7.30	7.30	7.30	0.00	0.00	1
33		7.80	7.80	7.80	0.00	0.00	1
DMW Control	DO %	116.00	116.00	116.00	0.00	0.00	1
DC2 [0.0]		110.50	110.50	110.50	0.00	0.00	1
2.2		110.30	110.30	110.30	0.00	0.00	1
3.9		107.50	107.50	107.50	0.00	0.00	1
8.5		107.20	107.20	107.20	0.00	0.00	1
17		107.60	107.60	107.60	0.00	0.00	1
33		116.70	116.70	116.70	0.00	0.00	1
DMW Control	Cond uS/cm	180.30	180.30	180.30	0.00	0.00	1
DC2 [0.0]		90.00	90.00	90.00	0.00	0.00	1
2.2		95.90	95.90	95.90	0.00	0.00	1
3.9		106.80	106.80	106.80	0.00	0.00	1
8.5		127.40	127.40	127.40	0.00	0.00	1
17		166.50	166.50	166.50	0.00	0.00	1
33		246.00	246.00	246.00	0.00	0.00	1

Statistical Printouts for the *Selenastrum* Growth Inhibition Tests

Microalgal Growth inhibition Test-Cell Yield

Start Date:	30/04/2013 16:00	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	143.20	119.60	106.00	134.00
DC2[0.055]	186.40	176.80	199.20	173.60
3.8	164.00	189.60	224.00	197.60
7.2	160.40	168.40	159.20	187.20
14	177.60	148.80	168.40	154.80
28	53.60	58.40	57.20	60.80
54	6.80	6.80	7.60	5.20

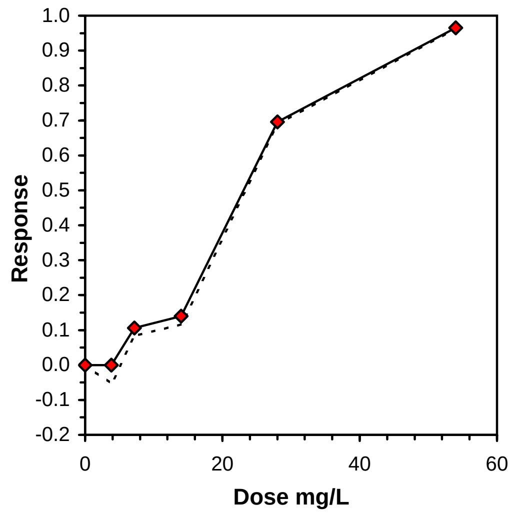
			Transform: Untransformed					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	125.70	0.6832	125.70	106.00	143.20	12.995	4				
DC2[0.055]	184.00	1.0000	184.00	173.60	199.20	6.250	4	*		188.90	1.0000
3.8	193.80	1.0533	193.80	164.00	224.00	12.752	4	20.00	10.00	188.90	1.0000
7.2	168.80	0.9174	168.80	159.20	187.20	7.659	4	13.00	10.00	168.80	0.8936
14	162.40	0.8826	162.40	148.80	177.60	8.027	4	12.00	10.00	162.40	0.8597
*28	57.50	0.3125	57.50	53.60	60.80	5.217	4	10.00	10.00	57.50	0.3044
*54	6.60	0.0359	6.60	5.20	7.60	15.255	4	10.00	10.00	6.60	0.0349

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.943389	0.916	0.240297	1.898168
Bartlett's Test indicates unequal variances (p = 1.37E-03)	19.78333	15.08627		
The control means are significantly different (p = 1.11E-03)	5.836716	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	14	28	19.79899	
Treatments vs DC2[0.055]				

Linear Interpolation (200 Resamples)

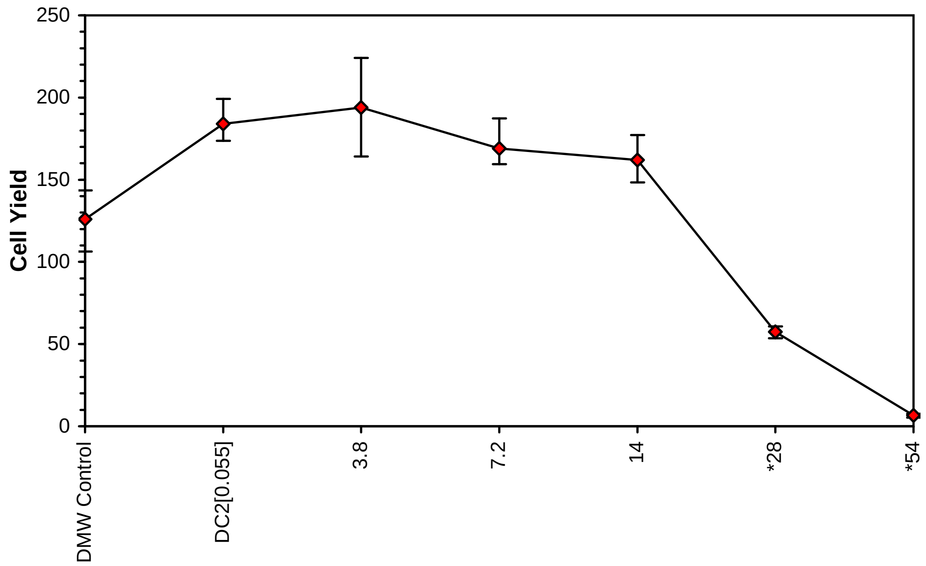
Point	mg/L	SD	95% CL(Exp)		Skew
IC05	5.398	1.378	1.781	12.492	1.9121
IC10	6.995	2.923	4.626	19.519	1.1420
IC15	14.245	3.006	1.959	16.999	-0.8871
IC20	15.505	1.471	7.825	18.072	-2.3350
IC25	16.766	0.881	13.329	19.143	-0.4017
IC40	20.548	0.652	18.093	22.314	-0.3327
IC50	23.069	0.510	21.319	24.435	-0.2546



Microalgal Growth inhibition Test-Cell Yield

Start Date:	30/04/2013 16:00	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

Dose-Response Plot



Microalgal Growth inhibition Test-Cell Yield

Start Date:	30/04/2013 16:00	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	Cell Yield	125.70	106.00	143.20	16.33	3.22	4
DC2[0.055]		184.00	173.60	199.20	11.50	1.84	4
3.8		193.80	164.00	224.00	24.71	2.57	4
7.2		168.80	159.20	187.20	12.93	2.13	4
14		162.40	148.80	177.60	13.04	2.22	4
28		57.50	53.60	60.80	3.00	3.01	4
54		6.60	5.20	7.60	1.01	15.20	4
DMW Control	pH	7.50	7.50	7.50	0.00	0.00	1
DC2[0.055]		7.80	7.80	7.80	0.00	0.00	1
3.8		7.60	7.60	7.60	0.00	0.00	1
7.2		7.50	7.50	7.50	0.00	0.00	1
14		7.30	7.30	7.30	0.00	0.00	1
28		7.20	7.20	7.20	0.00	0.00	1
54		7.10	7.10	7.10	0.00	0.00	1
DMW Control	Conductivity uS/cm	99.80	99.80	99.80	0.00	0.00	1
DC2[0.055]		165.40	165.40	165.40	0.00	0.00	1
3.8		163.40	163.40	163.40	0.00	0.00	1
7.2		162.80	162.80	162.80	0.00	0.00	1
14		162.70	162.70	162.70	0.00	0.00	1
28		162.30	162.30	162.30	0.00	0.00	1
54		161.10	161.10	161.10	0.00	0.00	1

Microalgal Growth inhibition Test-Growth-Cell Yield

Start Date:	10/05/2013 13:30	Test ID:	PR1030/41	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	13/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

Conc-mg/L	1	2	3	4
USEPA Control	817977	1210977	1054977	1186977
DC2 [<0.1]	1546977	1459977	1588977	1201977
96	1072977	1186977	1465977	997977
190	982977	1138977	1015977	1321977
400	730977	712977	763977	703977
800	85977	88977	88977	100977
1583	1977	4977	0	7977

			Transform: Untransformed					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
USEPA Control	1067727	0.7366	1067727	817977	1210977	16.865	4				
DC2 [<0.1]	1449477	1.0000	1449477	1201977	1588977	11.972	4	*		1449477	1.0000
96	1180977	0.8148	1180977	997977	1465977	17.382	4	12.00	10.00	1180977	0.8148
190	1114977	0.7692	1114977	982977	1321977	13.764	4	11.00	10.00	1114977	0.7692
*400	727977	0.5022	727977	703977	763977	3.640	4	10.00	10.00	727977	0.5022
*800	91227	0.0629	91227	85977	100977	7.292	4	10.00	10.00	91227	0.0629
*1583	3732.75	0.0026	3732.75	0	7977	93.545	4	10.00	10.00	3732.75	0.0026

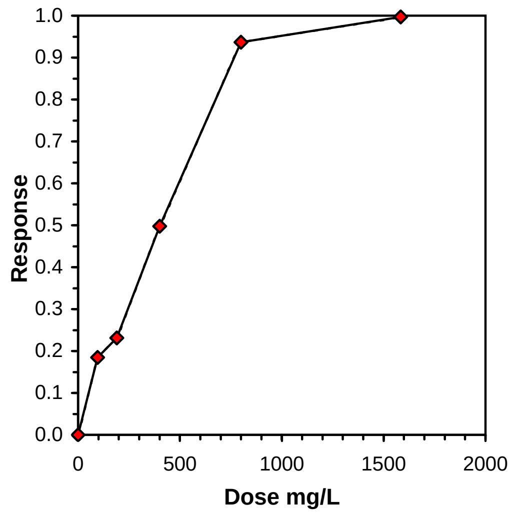
Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.90183	0.916	0.331768	1.660607
Bartlett's Test indicates unequal variances (p = 4.09E-07)	37.8282	15.08627		
The control means are significantly different (p = 0.02)	3.05309	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	190	400	275.681	
Treatments vs DC2 [<0.1]				

Linear Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05*	25.91	25.04	10.25	169.21	2.4467
IC10*	51.82	33.35	20.51	241.67	1.9816
IC15*	77.74	42.54	30.76	296.42	1.4264
IC20	126.47	54.32	27.32	315.41	0.5103
IC25	205.12	55.64	5.93	319.81	-0.3903
IC40	323.10	29.52	223.54	407.40	-0.0114
IC50	402.03	23.07	334.81	488.19	0.5484

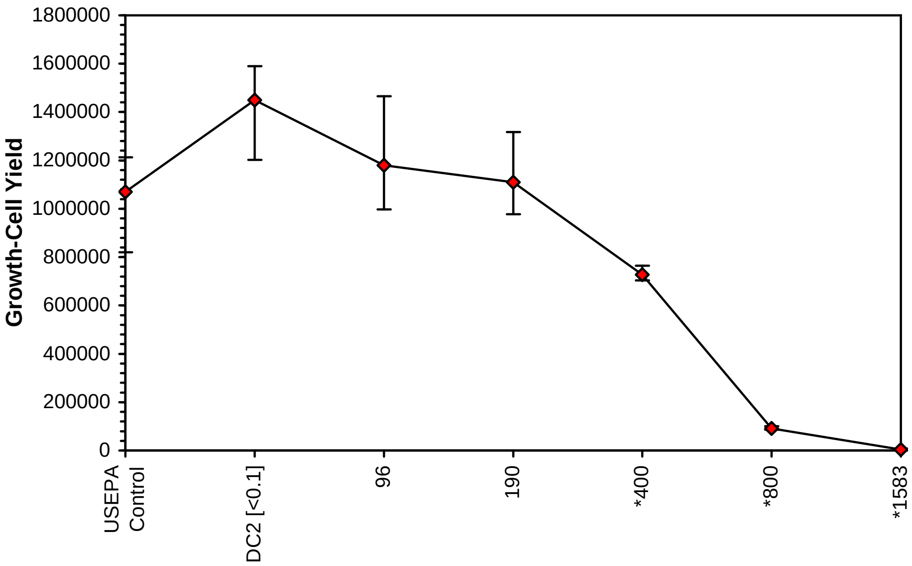
* indicates IC estimate less than the lowest concentration



Microalgal Growth inhibition Test-Growth-Cell Yield

Start Date:	10/05/2013 13:30	Test ID:	PR1030/41	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	13/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

Dose-Response Plot



 ToxCalc v5.0.23 Reviewed by:_____

Microalgal Growth inhibition Test-Growth-Cell Yield

Start Date:	10/05/2013 13:30	Test ID:	PR1030/41	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	13/05/2013 13:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 103	Test Species:	SC-Selenastrum capricornutum
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
USEPA Control	Cell Yield	106.77	81.80	121.10	18.01	3.97	4
DC2 [<0.1]		144.95	120.20	158.90	17.35	2.87	4
96		118.10	99.80	146.60	20.53	3.84	4
190		111.50	98.30	132.20	15.35	3.51	4
400		72.80	70.40	76.40	2.65	2.24	4
800		9.12	8.60	10.10	0.67	8.94	4
1583		0.37	0.00	0.80	0.35	158.31	4
USEPA Control	pH	7.60	7.60	7.60	0.00	0.00	1
DC2 [<0.1]		8.20	8.20	8.20	0.00	0.00	1
96		7.50	7.50	7.50	0.00	0.00	1
190		7.60	7.60	7.60	0.00	0.00	1
400		7.70	7.70	7.70	0.00	0.00	1
800		7.60	7.60	7.60	0.00	0.00	1
1583		6.40	6.40	6.40	0.00	0.00	1
USEPA Control	Conductivity uS/cm	91.60	91.60	91.60	0.00	0.00	1
DC2 [<0.1]		160.10	160.10	160.10	0.00	0.00	1
96		635.00	635.00	635.00	0.00	0.00	1
190		1113.00	1113.00	1113.00	0.00	0.00	1
400		2050.00	2050.00	2050.00	0.00	0.00	1
800		3860.00	3860.00	3860.00	0.00	0.00	1
1583		7230.00	7230.00	7230.00	0.00	0.00	1

Statistical Printouts for the Duckweed Growth Inhibition Tests

Duckweed Growth Inhibtion Test-Specific Growth Rate

Start Date:	2/05/2013 14:00	Test ID:	PR1030/11	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	9/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

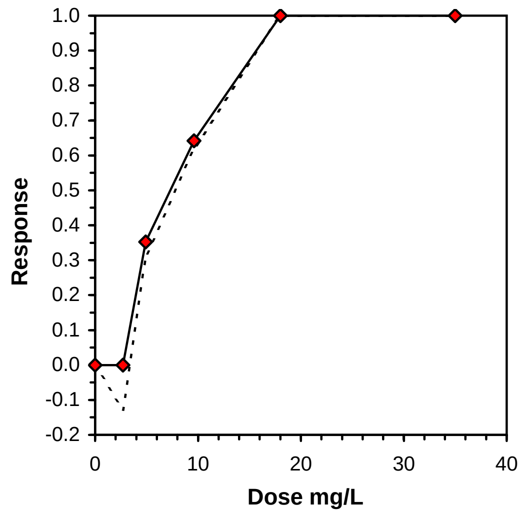
Conc-mg/L	1	2	3	4
SIS Control	0.3869	0.2369	0.3795	0.2728
DC2 [0.15]	0.3216	0.2674	0.3795	0.2435
2.7	0.2067	0.4005	0.4315	0.3289
4.9	0.3845	0.2149	0.1790	0.0579
9.6	0.0579	0.3718	0.0319	0.0000
18	0.0000	0.0000	0.0000	0.0000
35	0.0000	0.0000	0.0000	0.0000

			Transform: Untransformed						1-Tailed		Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Mean	N-Mean
SIS Control	0.3190	1.0528	0.3190	0.2369	0.3869	23.699	4					
DC2 [0.15]	0.3030	1.0000	0.3030	0.2435	0.3795	19.990	4	*			0.3225	1.0000
2.7	0.3419	1.1283	0.3419	0.2067	0.4315	29.201	4	-0.443	2.290	0.2009	0.3225	1.0000
4.9	0.2091	0.6899	0.2091	0.0579	0.3845	64.501	4	1.071	2.290	0.2009	0.2091	0.6483
9.6	0.1154	0.3808	0.1154	0.0000	0.3718	149.539	4	2.138	2.290	0.2009	0.1154	0.3579
18	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	4				0.0000	0.0000
35	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	4				0.0000	0.0000

Auxiliary Tests					Statistic		Critical		Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)					0.947603		0.887		0.841925	0.549594
Bartlett's Test indicates equal variances (p = 0.43)					2.749624		11.34487			
The control means are not significantly different (p = 0.75)					0.330301		2.446912			
Hypothesis Test (1-tail, 0.05)	**NOEC**	**LOEC**	**ChV**	**TU**	**MSDu**	**MSDp**	**MSB**	**MSE**	**F-Prob**	**df**
Dunnett's Test	9.6	18	13.14534		0.200949	0.663151	0.041088	0.0154	0.094997	3, 12
Treatments vs DC2 [0.15]										

Linear Interpolation (200 Resamples)

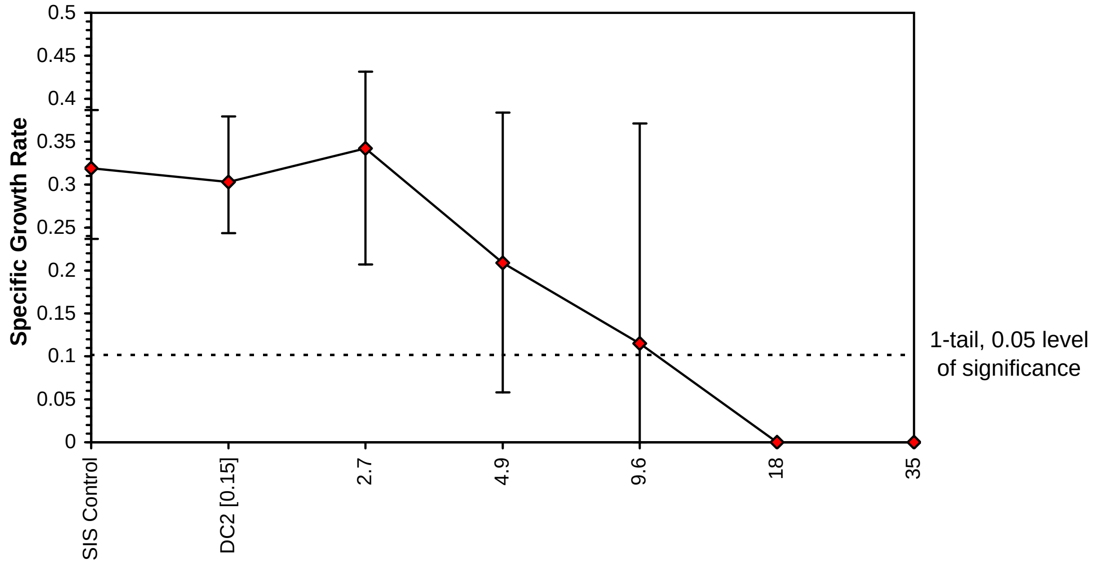
Point	mg/L	SD	95% CL(Exp)		Skew
IC05	3.0128	0.9330	0.0000	6.4035	0.3636
IC10	3.3255	1.0873	0.4262	6.8999	2.4990
IC15	3.6383	1.1206	1.4493	7.3125	2.6601
IC20	3.9511	1.1637	2.6789	7.9013	2.5576
IC25	4.2639	1.2966	3.0634	9.4101	2.2903
IC40	5.6818	2.0415	3.1892	14.2696	1.0623
IC50	7.3001	2.2452	2.7878	15.1522	0.6732



Duckweed Growth Inhibtion Test-Specific Growth Rate

Start Date:	2/05/2013 14:00	Test ID:	PR1030/11	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	9/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

Dose-Response Plot



 ToxCalc v5.0.23 Reviewed by:_____

Duckweed Growth Inhibtion Test-Specific Growth Rate

Start Date:	2/05/2013 14:00	Test ID:	PR1030/11	Sample ID:	NAR_7102(2)_SURF_W + Boron
End Date:	9/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
SIS Control	Specific Growth Rate	0.32	0.24	0.39	0.08	86.19	4
DC2 [0.15]		0.30	0.24	0.38	0.06	81.22	4
2.7		0.34	0.21	0.43	0.10	92.42	4
4.9		0.21	0.06	0.38	0.13	175.65	4
9.6		0.12	0.00	0.37	0.17	359.97	4
18		0.00	0.00	0.00	0.00		4
35		0.00	0.00	0.00	0.00		4
SIS Control	pH	6.50	6.50	6.50	0.00	0.00	1
DC2 [0.15]		6.50	6.50	6.50	0.00	0.00	1
2.7		6.60	6.60	6.60	0.00	0.00	1
4.9		6.60	6.60	6.60	0.00	0.00	1
9.6		6.60	6.60	6.60	0.00	0.00	1
18		6.60	6.60	6.60	0.00	0.00	1
35		6.50	6.50	6.50	0.00	0.00	1
SIS Control	Cond uS/cm	294.00	294.00	294.00	0.00	0.00	1
DC2 [0.15]		339.00	339.00	339.00	0.00	0.00	1
2.7		342.00	342.00	342.00	0.00	0.00	1
4.9		345.00	345.00	345.00	0.00	0.00	1
9.6		347.00	347.00	347.00	0.00	0.00	1
18		350.00	350.00	350.00	0.00	0.00	1
35		355.00	355.00	355.00	0.00	0.00	1

Duckweed Growth Inhibtion Test-Specific Growth Rate

Start Date:	2/05/2013 14:00	Test ID:	PR1030/33	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	9/05/2013 14:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

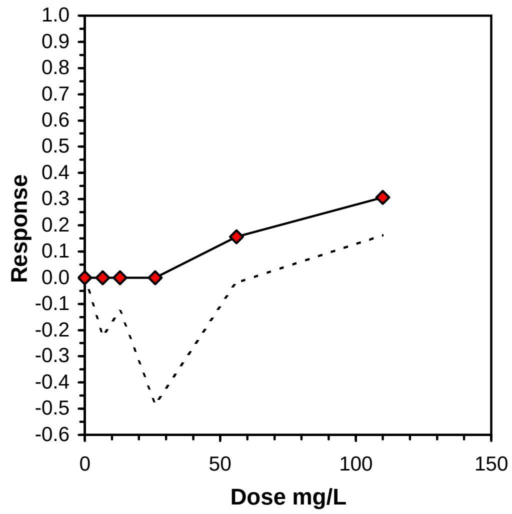
Conc-mg/L	1	2	3	4
DMW Control	0.3869	0.2369	0.3795	0.2728
DC2 [0.11]	0.3216	0.2674	0.3795	0.2435
6.6	0.3983	0.3520	0.3325	0.3961
13	0.2878	0.3178	0.3983	0.3636
26	0.5089	0.4383	0.3938	0.4540
56	0.2369	0.3718	0.3015	0.3253
110	0.3015	0.3458	0.1888	0.1790

			Transform: Untransformed						1-Tailed		Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Mean	N-Mean
DMW Control	0.3190	1.0528	0.3190	0.2369	0.3869	23.699	4					
DC2 [0.11]	0.3030	1.0000	0.3030	0.2435	0.3795	19.990	4	*			0.3658	1.0000
6.6	0.3697	1.2201	0.3697	0.3325	0.3983	8.854	4	-1.659	2.410	0.0969	0.3658	1.0000
13	0.3419	1.1283	0.3419	0.2878	0.3983	14.285	4	-0.967	2.410	0.0969	0.3658	1.0000
26	0.4488	1.4810	0.4488	0.3938	0.5089	10.588	4	-3.626	2.410	0.0969	0.3658	1.0000
56	0.3089	1.0193	0.3089	0.2369	0.3718	18.189	4	-0.146	2.410	0.0969	0.3089	0.8443
110	0.2538	0.8374	0.2538	0.1790	0.3458	32.617	4	1.226	2.410	0.0969	0.2538	0.6936

Auxiliary Tests					Statistic		Critical			Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)					0.95428		0.916			0.122278	-1.12534
Bartlett's Test indicates equal variances (p = 0.79)					2.421293		15.08627				
The control means are not significantly different (p = 0.75)					0.330301		2.446912				
Hypothesis Test (1-tail, 0.05)	**NOEC**	**LOEC**	**ChV**	**TU**	**MSDu**	**MSDp**	**MSB**	**MSE**	**F-Prob**	**df**	
Dunnett's Test	110	>110			0.096878	0.319706	0.017967	0.003232	0.002872	5, 18	
Treatments vs DC2 [0.11]											

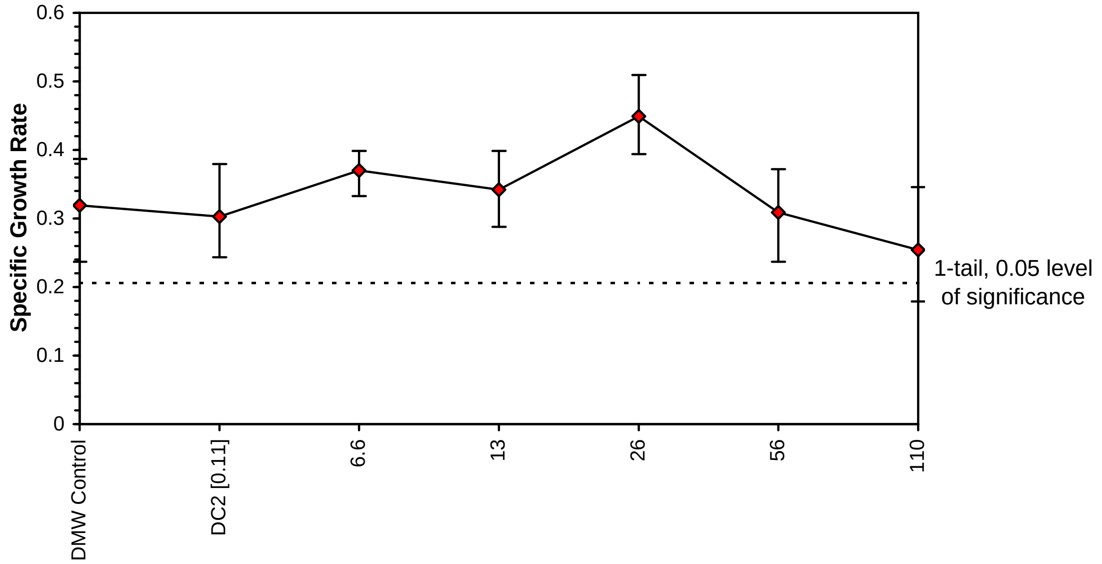
Linear Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05	35.632	8.076	28.919	78.230	1.7306
IC10	45.263	10.937	31.838	88.382	1.1124
IC15	54.895				
IC20	71.865				
IC25	89.786				
IC40	>110				
IC50	>110				



Duckweed Growth Inhibtion Test-Specific Growth Rate					
Start Date:	2/05/2013 14:00	Test ID:	PR1030/33	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	9/05/2013 14:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

Dose-Response Plot



 ToxCalc v5.0.23 Reviewed by:_____

Duckweed Growth Inhibtion Test-Specific Growth Rate

Start Date:	2/05/2013 14:00	Test ID:	PR1030/33	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	9/05/2013 14:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 112	Test Species:	LD-Lemna disperma
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	Specific Growth Rate	0.32	0.24	0.39	0.08	86.19	4
DC2 [0.11]		0.30	0.24	0.38	0.06	81.22	4
6.6		0.37	0.33	0.40	0.03	48.94	4
13		0.34	0.29	0.40	0.05	64.64	4
26		0.45	0.39	0.51	0.05	48.57	4
56		0.31	0.24	0.37	0.06	76.74	4
110		0.25	0.18	0.35	0.08	113.38	4
DMW Control	pH	6.50	6.50	6.50	0.00	0.00	1
DC2 [0.11]		6.50	6.50	6.50	0.00	0.00	1
6.6		6.60	6.60	6.60	0.00	0.00	1
13		6.60	6.60	6.60	0.00	0.00	1
26		6.60	6.60	6.60	0.00	0.00	1
56		6.60	6.60	6.60	0.00	0.00	1
110		6.50	6.50	6.50	0.00	0.00	1
DMW Control	Cond uS/cm	294.00	294.00	294.00	0.00	0.00	1
DC2 [0.11]		339.00	339.00	339.00	0.00	0.00	1
6.6		373.00	373.00	373.00	0.00	0.00	1
13		407.00	407.00	407.00	0.00	0.00	1
26		472.00	472.00	472.00	0.00	0.00	1
56		597.00	597.00	597.00	0.00	0.00	1
110		864.00	864.00	864.00	0.00	0.00	1

ecotox
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Statistical Printouts for the Acute Test with *Chironomus tepperi*

Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/4	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2 [0.02]	1.0000	1.0000	1.0000	1.0000
78	0.4000	0.6000	1.0000	1.0000
170	0.8000	1.0000	0.8000	0.6000
310	0.0000	0.0000	0.0000	0.0000
620	0.2000	0.0000	0.0000	0.0000
1300	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2 [0.02]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		0	20
78	0.7500	0.7500	1.0653	0.6847	1.3453	31.308	4	14.00	10.00	5	20
170	0.8000	0.8000	1.1114	0.8861	1.3453	16.874	4	12.00	10.00	4	20
310	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20
*620	0.0500	0.0500	0.2850	0.2255	0.4636	41.771	4	10.00	10.00	19	20
1300	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.919211	0.887	-0.14046	0.244106
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

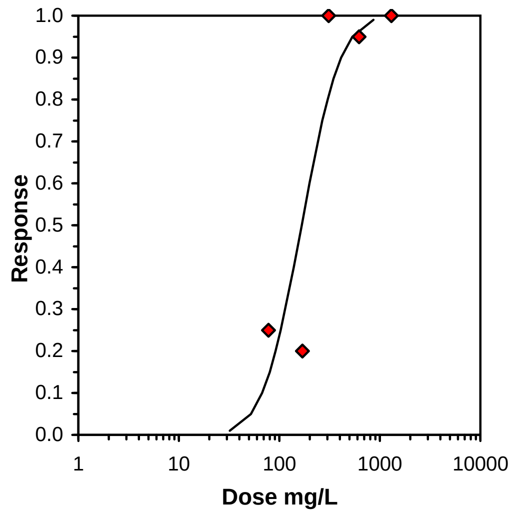
Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	170	620	324.6537	
Treatments vs DC2 [0.02]				

Maximum Likelihood-Probit

Parameter	Value	SE	95% Fiducial Limits		Control	Chi-Sq	Critical	P-value	Mu	Sigma	Iter
Slope	3.261481	1.316037	-0.92673	7.449697	0	14.65628	7.814728	2.1E-03	2.221566	0.306609	4
Intercept	-2.24559	3.030864	-11.8912	7.399967							
TSCR											

Point	Probits	mg/L	95% Fiducial Limits
EC01	2.674	32.23192	
EC05	3.355	52.14811	
EC10	3.718	67.39541	
EC15	3.964	80.12828	
EC20	4.158	91.94265	
EC25	4.326	103.4573	
EC40	4.747	139.2795	
EC50	5.000	166.5581	
EC60	5.253	199.1794	
EC75	5.674	268.1455	
EC80	5.842	301.7273	
EC85	6.036	346.215	
EC90	6.282	411.6245	
EC95	6.645	531.9772	
EC99	7.326	860.6876	

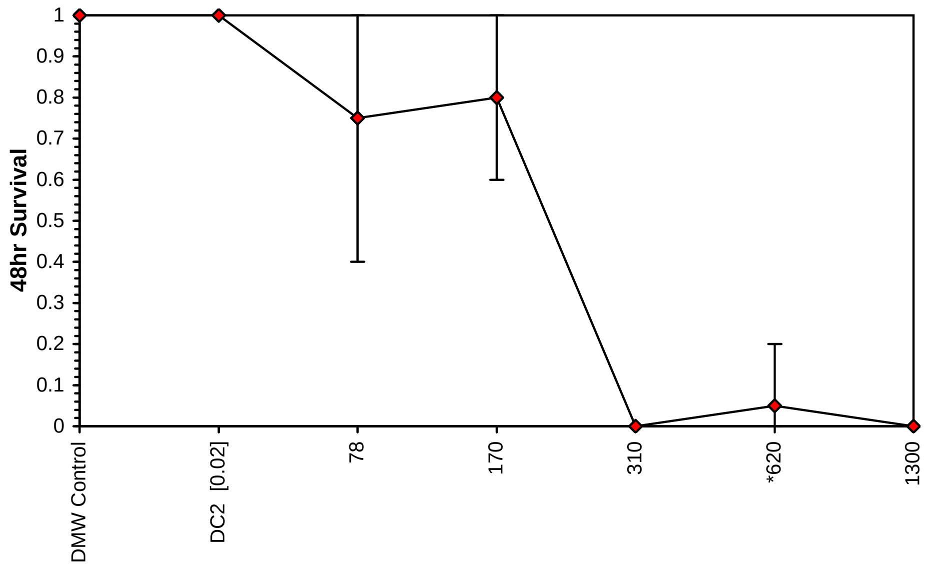
Significant heterogeneity detected (p = 2.14E-03)



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/4	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Dose-Response Plot



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/4	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Conc-mg/L	Parameter	Auxiliary Data Summary					
		Mean	Min	Max	SD	CV%	N
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2 [0.02]		100.00	100.00	100.00	0.00	0.00	4
78		75.00	40.00	100.00	30.00	7.30	4
170		80.00	60.00	100.00	16.33	5.05	4
310		0.00	0.00	0.00	0.00		4
620		5.00	0.00	20.00	10.00	63.25	4
1300		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2 [0.02]		7.10	7.10	7.10	0.00	0.00	1
78		6.60	6.60	6.60	0.00	0.00	1
170		6.50	6.50	6.50	0.00	0.00	1
310		6.50	6.50	6.50	0.00	0.00	1
620		6.40	6.40	6.40	0.00	0.00	1
1300		6.10	6.10	6.10	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2 [0.02]		76.30	76.30	76.30	0.00	0.00	1
78		76.20	76.20	76.20	0.00	0.00	1
170		75.70	75.70	75.70	0.00	0.00	1
310		75.30	75.30	75.30	0.00	0.00	1
620		74.20	74.20	74.20	0.00	0.00	1
1300		72.40	72.40	72.40	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2 [0.02]		94.20	94.20	94.20	0.00	0.00	1
78		95.10	95.10	95.10	0.00	0.00	1
170		95.40	95.40	95.40	0.00	0.00	1
310		95.40	95.40	95.40	0.00	0.00	1
620		94.60	94.60	94.60	0.00	0.00	1
1300		89.80	89.80	89.80	0.00	0.00	1

Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

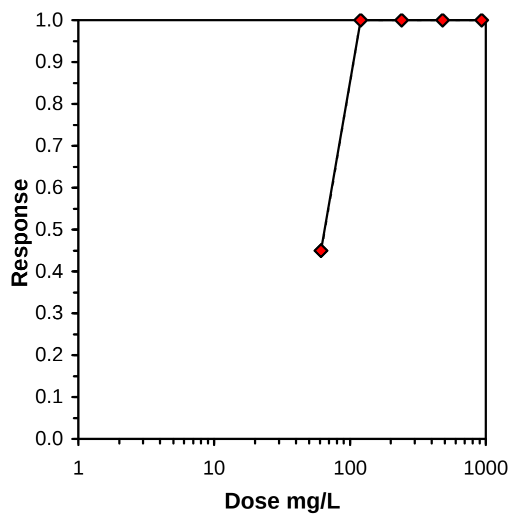
Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2 [0.0]	1.0000	1.0000	1.0000	1.0000
61	0.4000	0.8000	0.8000	0.2000
120	0.0000	0.0000	0.0000	0.0000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000
930	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root						1-Tailed		Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Resp	Number
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4					
DC2 [0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*			0	20
*61	0.5500	0.5500	0.8407	0.4636	1.1071	38.145	4	3.147	2.353	0.3773	9	20
120	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20
930	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20

Auxiliary Tests	Statistic		Critical		Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.887026		0.818		-0.40221	0.551719
Equality of variance cannot be confirmed						
The control means are not significantly different (p = 1.00)	0		2.446912			
Hypothesis Test (1-tail, 0.05)	**MSDu**	**MSDp**	**MSB**	**MSE**	**F-Prob**	**df**
Heteroscedastic t Test indicates significant differences	0.271471	0.285759	0.509276	0.051415	0.019884	1, 6
Treatments vs DC2 [0.0]						

Trimmed Spearman-Karber

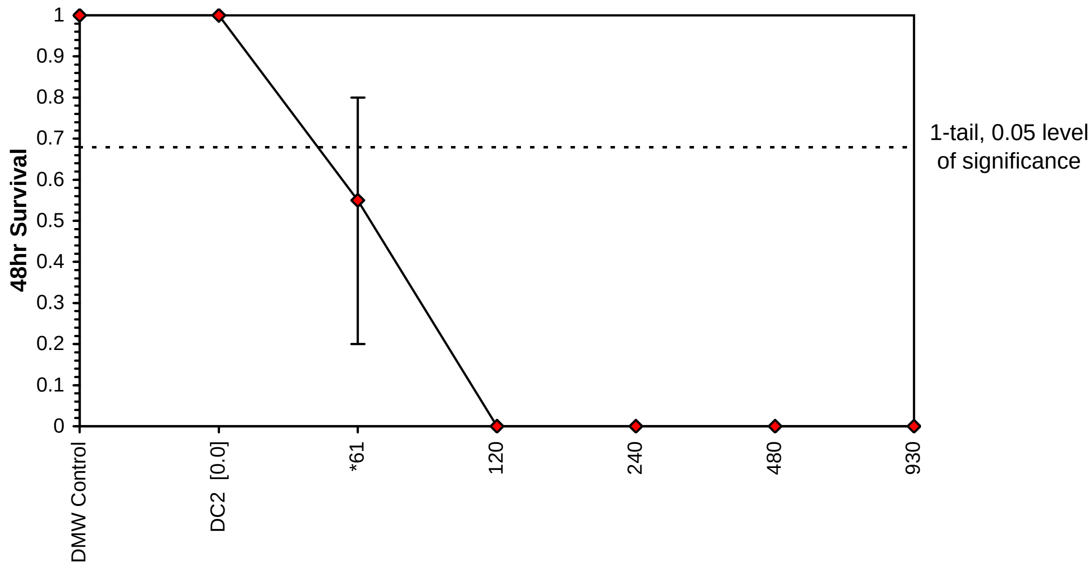
Trim Level	EC50	95% CL	
0.0%			
5.0%			
10.0%			
20.0%			
Auto-45.0%	64.870	50.580	83.197



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Dose-Response Plot



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	4
61		55.00	20.00	80.00	30.00	9.96	4
120		0.00	0.00	0.00	0.00		4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
930		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2 [0.0]		7.10	7.10	7.10	0.00	0.00	1
61		7.10	7.10	7.10	0.00	0.00	1
120		7.10	7.10	7.10	0.00	0.00	1
240		7.10	7.10	7.10	0.00	0.00	1
480		6.70	6.70	6.70	0.00	0.00	1
930		6.40	6.40	6.40	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2 [0.0]		76.30	76.30	76.30	0.00	0.00	1
61		427.00	427.00	427.00	0.00	0.00	1
120		727.00	727.00	727.00	0.00	0.00	1
240		1347.00	1347.00	1347.00	0.00	0.00	1
480		2500.00	2500.00	2500.00	0.00	0.00	1
930		4850.00	4850.00	4850.00	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2 [0.0]		94.20	94.20	94.20	0.00	0.00	1
61		95.50	95.50	95.50	0.00	0.00	1
120		95.00	95.00	95.00	0.00	0.00	1
240		93.70	93.70	93.70	0.00	0.00	1
480		92.10	92.10	92.10	0.00	0.00	1
930		86.30	86.30	86.30	0.00	0.00	1

Chironomid Acute Toxicity Test-48hr Survival					
Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2 [0.0]	1.0000	1.0000	1.0000	1.0000
61	0.4000	0.8000	0.8000	0.2000
120	0.0000	0.0000	0.0000	0.0000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000
930	0.0000	0.0000	0.0000	0.0000

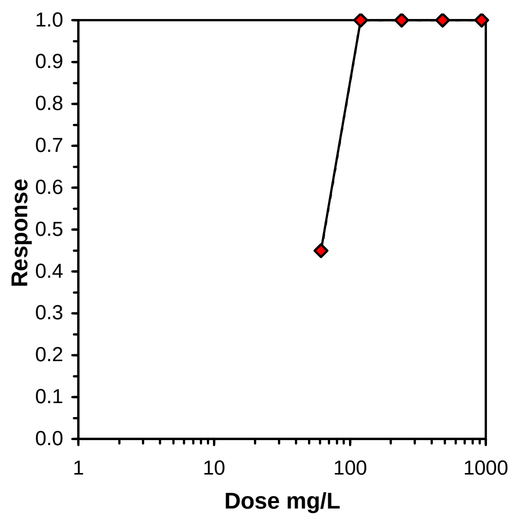
			Transform: Arcsin Square Root						1-Tailed		Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Mean	N-Mean
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4					
DC2 [0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*			1.0000	1.0000
*61	0.5500	0.5500	0.8407	0.4636	1.1071	38.145	4	3.147	2.353	0.3773	0.5500	0.5500
120	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000
930	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000

Auxiliary Tests	Statistic		Critical		Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.887026		0.818		-0.40221	0.551719
Equality of variance cannot be confirmed						
The control means are not significantly different (p = 1.00)	0		2.446912			
Hypothesis Test (1-tail, 0.05)	**MSDu**	**MSDp**	**MSB**	**MSE**	**F-Prob**	**df**
Heteroscedastic t Test indicates significant differences	0.271471	0.285759	0.509276	0.051415	0.019884	1, 6
Treatments vs DC2 [0.0]						

Log-Logit Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05*	16.642	3.697	9.345	32.022	0.8357
IC10*	23.842	5.900	12.535	48.769	0.8894
IC15*	29.706	7.835	14.962	63.126	0.9228
IC20*	35.018	9.678	17.059	76.589	0.9478
IC25*	40.092	9.946	18.985	75.362	0.4577
IC40*	55.448	9.153	24.458	70.665	-0.5052
IC50	61.890	6.831	31.332	69.534	-1.1644

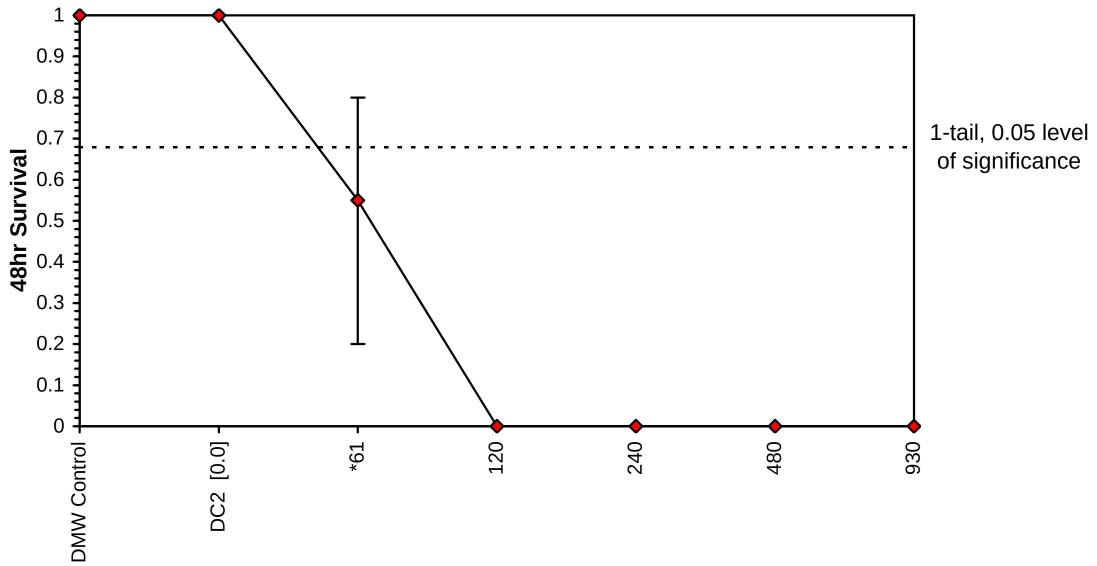
* indicates IC estimate less than the lowest concentration



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

Dose-Response Plot



Chironomid Acute Toxicity Test-48hr Survival

Start Date:	1/05/2013 15:15	Test ID:	PR1030/3	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	3/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 121	Test Species:	CT-Chironomus tepperi
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	4
61		55.00	20.00	80.00	30.00	9.96	4
120		0.00	0.00	0.00	0.00		4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
930		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.00	8.00	8.00	0.00	0.00	1
DC2 [0.0]		7.10	7.10	7.10	0.00	0.00	1
61		7.10	7.10	7.10	0.00	0.00	1
120		7.10	7.10	7.10	0.00	0.00	1
240		7.10	7.10	7.10	0.00	0.00	1
480		6.70	6.70	6.70	0.00	0.00	1
930		6.40	6.40	6.40	0.00	0.00	1
DMW Control	Cond uS/cm	178.70	178.70	178.70	0.00	0.00	1
DC2 [0.0]		76.30	76.30	76.30	0.00	0.00	1
61		427.00	427.00	427.00	0.00	0.00	1
120		727.00	727.00	727.00	0.00	0.00	1
240		1347.00	1347.00	1347.00	0.00	0.00	1
480		2500.00	2500.00	2500.00	0.00	0.00	1
930		4850.00	4850.00	4850.00	0.00	0.00	1
DMW Control	DO %	93.50	93.50	93.50	0.00	0.00	1
DC2 [0.0]		94.20	94.20	94.20	0.00	0.00	1
61		95.50	95.50	95.50	0.00	0.00	1
120		95.00	95.00	95.00	0.00	0.00	1
240		93.70	93.70	93.70	0.00	0.00	1
480		92.10	92.10	92.10	0.00	0.00	1
930		86.30	86.30	86.30	0.00	0.00	1

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Statistical Printouts for the Freshwater Shrimp Tests

Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	0.8000	1.0000	0.8000
DC2 [0.02]	1.0000	0.8000	1.0000	1.0000
59	1.0000	1.0000	0.8000	0.8000
110	0.8000	1.0000	0.8000	0.6000
220	0.8000	1.0000	1.0000	0.8000
430	0.0000	0.8000	0.8000	0.8000
940	0.0000	0.0000	0.0000	0.0000

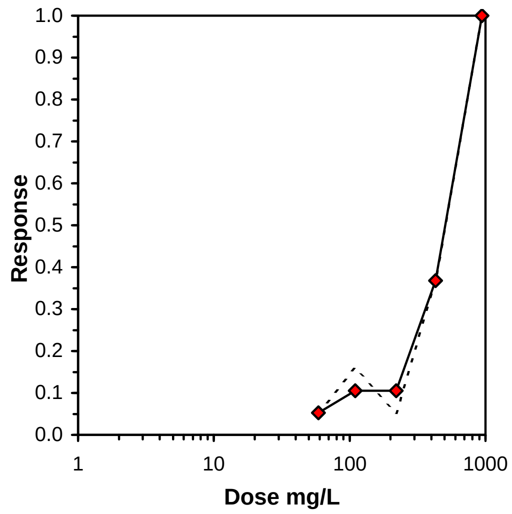
			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4				
DC2 [0.02]	0.9500	1.0000	1.2857	1.1071	1.3453	9.261	4	*		1	20
59	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4	16.00	10.00	2	20
110	0.8000	0.8421	1.1114	0.8861	1.3453	16.874	4	13.50	10.00	4	20
220	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4	16.00	10.00	2	20
430	0.6000	0.6316	0.8867	0.2255	1.1071	49.712	4	11.50	10.00	8	20
940	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.850585	0.905	-1.62716	4.012336
Bartlett's Test indicates equal variances (p = 0.12)	7.393417	13.2767		
The control means are not significantly different (p = 0.54)	0.654654	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	430	940	635.7673	
Treatments vs DC2 [0.02]				

Trimmed Spearman-Karber

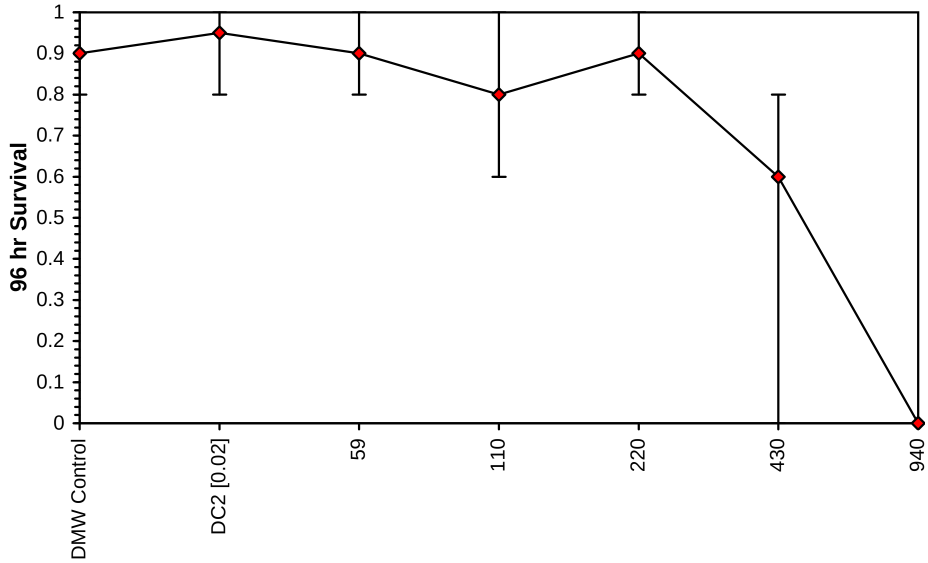
Trim Level	EC50	95% CL	
0.0%			
5.0%			
10.0%	474.89	374.95	601.47
20.0%	490.68	376.66	639.22
Auto-5.3%	445.26	353.89	560.23



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Dose-Response Plot



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	90.00	80.00	100.00	11.55	3.78	4
DC2 [0.02]		95.00	80.00	100.00	10.00	3.33	4
59		90.00	80.00	100.00	11.55	3.78	4
110		80.00	60.00	100.00	16.33	5.05	4
220		90.00	80.00	100.00	11.55	3.78	4
430		60.00	0.00	80.00	40.00	10.54	4
940		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.02]		7.50	7.50	7.50	0.00	0.00	1
59		6.70	6.70	6.70	0.00	0.00	1
110		6.60	6.60	6.60	0.00	0.00	1
220		6.50	6.50	6.50	0.00	0.00	1
430		6.50	6.50	6.50	0.00	0.00	1
940		6.30	6.30	6.30	0.00	0.00	1
DMW Control	Cond uS/cm	168.70	168.70	168.70	0.00	0.00	1
DC2 [0.02]		76.50	76.50	76.50	0.00	0.00	1
59		75.90	75.90	75.90	0.00	0.00	1
110		76.10	76.10	76.10	0.00	0.00	1
220		75.60	75.60	75.60	0.00	0.00	1
430		74.70	74.70	74.70	0.00	0.00	1
940		73.00	73.00	73.00	0.00	0.00	1
DMW Control	DO %	104.50	104.50	104.50	0.00	0.00	1
DC2 [0.02]		91.30	91.30	91.30	0.00	0.00	1
59		107.80	107.80	107.80	0.00	0.00	1
110		103.40	103.40	103.40	0.00	0.00	1
220		106.60	106.60	106.60	0.00	0.00	1
430		108.30	108.30	108.30	0.00	0.00	1
940		114.10	114.10	114.10	0.00	0.00	1

Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	0.8000	1.0000	0.8000
DC2 [0.02]	1.0000	0.8000	1.0000	1.0000
59	1.0000	1.0000	0.8000	0.8000
110	0.8000	1.0000	0.8000	0.6000
220	0.8000	1.0000	1.0000	0.8000
430	0.0000	0.8000	0.8000	0.8000
940	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4				
DC2 [0.02]	0.9500	1.0000	1.2857	1.1071	1.3453	9.261	4	*		0.9500	1.0000
59	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4	16.00	10.00	0.9000	0.9474
110	0.8000	0.8421	1.1114	0.8861	1.3453	16.874	4	13.50	10.00	0.8500	0.8947
220	0.9000	0.9474	1.2262	1.1071	1.3453	11.212	4	16.00	10.00	0.8500	0.8947
430	0.6000	0.6316	0.8867	0.2255	1.1071	49.712	4	11.50	10.00	0.6000	0.6316
940	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000

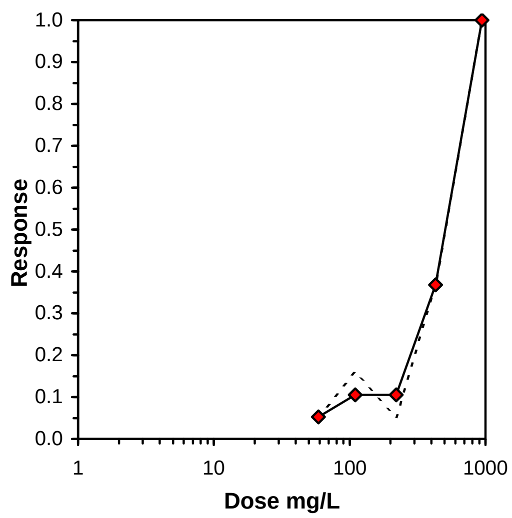
Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.850585	0.905	-1.62716	4.012336
Bartlett's Test indicates equal variances (p = 0.12)	7.393417	13.2767		
The control means are not significantly different (p = 0.54)	0.654654	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	430	940	635.7673	
Treatments vs DC2 [0.02]				

Log-Logit Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05*	50.44	70.22	0.00	402.25	2.0624
IC10	104.28	99.38	10.34	546.51	0.6351
IC15	256.06	98.92	0.00	544.91	0.0311
IC20	295.07	87.38	0.00	533.78	-0.1242
IC25	333.88	69.86	191.48	521.79	0.1906
IC40	434.35	52.00	242.50	492.59	-1.0749
IC50	448.06	41.09	277.32	504.71	-1.3834

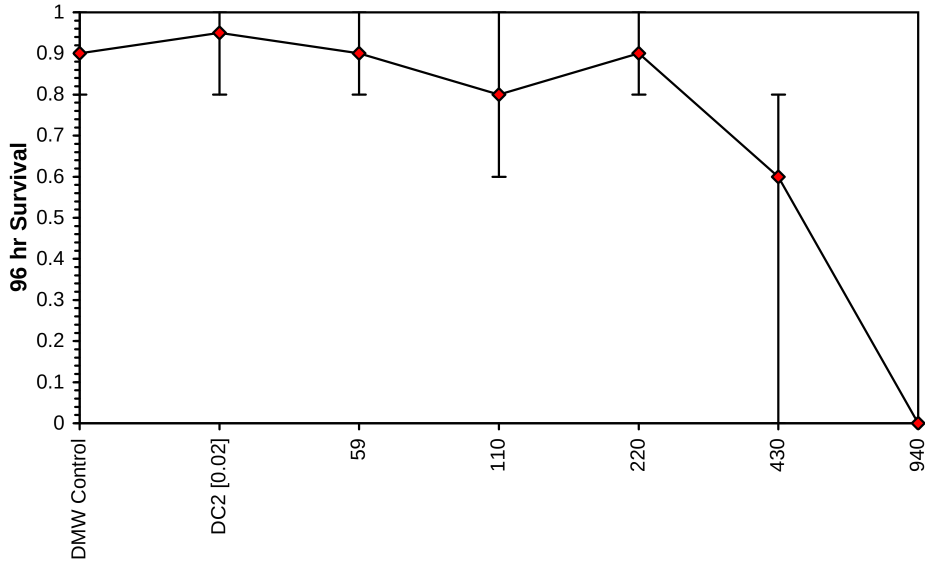
* indicates IC estimate less than the lowest concentration



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Dose-Response Plot



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	2/05/2013 16:30	Test ID:	PR1030/10	Sample ID:	NAR_7102(2)_SURF_W + boron
End Date:	6/05/2013 15:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Conc-mg/L	Parameter	Mean	Min	Max	SD	CV%	N
		Auxiliary Data Summary					
DMW Control	% Survival	90.00	80.00	100.00	11.55	3.78	4
DC2 [0.02]		95.00	80.00	100.00	10.00	3.33	4
59		90.00	80.00	100.00	11.55	3.78	4
110		80.00	60.00	100.00	16.33	5.05	4
220		90.00	80.00	100.00	11.55	3.78	4
430		60.00	0.00	80.00	40.00	10.54	4
940		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
DC2 [0.02]		7.50	7.50	7.50	0.00	0.00	1
59		6.70	6.70	6.70	0.00	0.00	1
110		6.60	6.60	6.60	0.00	0.00	1
220		6.50	6.50	6.50	0.00	0.00	1
430		6.50	6.50	6.50	0.00	0.00	1
940		6.30	6.30	6.30	0.00	0.00	1
DMW Control	Cond uS/cm	168.70	168.70	168.70	0.00	0.00	1
DC2 [0.02]		76.50	76.50	76.50	0.00	0.00	1
59		75.90	75.90	75.90	0.00	0.00	1
110		76.10	76.10	76.10	0.00	0.00	1
220		75.60	75.60	75.60	0.00	0.00	1
430		74.70	74.70	74.70	0.00	0.00	1
940		73.00	73.00	73.00	0.00	0.00	1
DMW Control	DO %	104.50	104.50	104.50	0.00	0.00	1
DC2 [0.02]		91.30	91.30	91.30	0.00	0.00	1
59		107.80	107.80	107.80	0.00	0.00	1
110		103.40	103.40	103.40	0.00	0.00	1
220		106.60	106.60	106.60	0.00	0.00	1
430		108.30	108.30	108.30	0.00	0.00	1
940		114.10	114.10	114.10	0.00	0.00	1

Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2 [0.0]	1.0000	1.0000	1.0000	1.0000
1.2	1.0000	0.8000	1.0000	1.0000
2.4	1.0000	1.0000	1.0000	1.0000
5.3	0.8000	1.0000	1.0000	1.0000
10	1.0000	1.0000	0.6000	0.8000
21	0.0000	0.0000	0.4000	0.2000

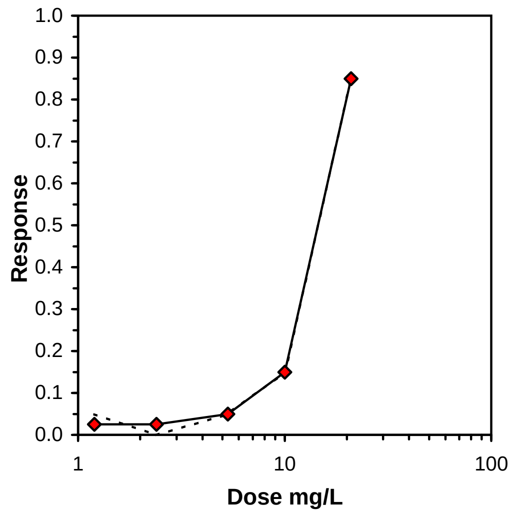
			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2 [0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		0	20
1.2	0.9500	0.9500	1.2857	1.1071	1.3453	9.261	4	16.00	10.00	1	20
2.4	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0	20
5.3	0.9500	0.9500	1.2857	1.1071	1.3453	9.261	4	16.00	10.00	1	20
10	0.8500	0.8500	1.1709	0.8861	1.3453	18.840	4	14.00	10.00	3	20
*21	0.1500	0.1500	0.3998	0.2255	0.6847	55.174	4	10.00	10.00	17	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.918644	0.916	-0.22884	0.55839
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	10	21	14.49138	
Treatments vs DC2 [0.0]				

Trimmed Spearman-Karber

Trim Level	EC50	95% CL	
0.0%			
5.0%			
10.0%			
20.0%	14.491	12.857	16.334
Auto-15.0%	14.491	12.857	16.334

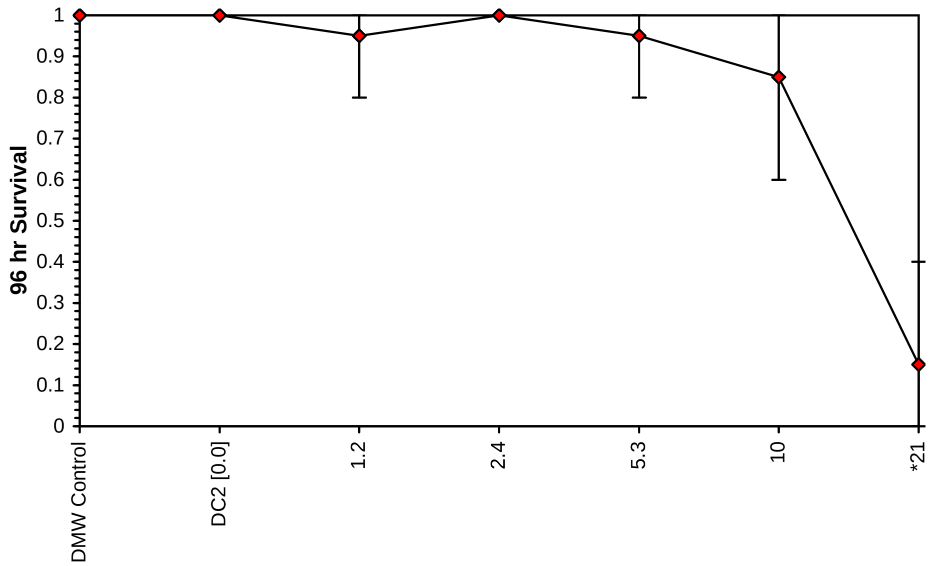


 ToxCalc v5.0.23 Reviewed by:_____

Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Dose-Response Plot



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

		Auxiliary Data Summary					
Conc-mg/L	Parameter	Mean	Min	Max	SD	CV%	N
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	4
1.2		95.00	80.00	100.00	10.00	3.33	4
2.4		100.00	100.00	100.00	0.00	0.00	4
5.3		95.00	80.00	100.00	10.00	3.33	4
10		85.00	60.00	100.00	19.15	5.15	4
21		15.00	0.00	40.00	19.15	29.17	4
DMW Control	pH	8.20	8.20	8.20	0.00	0.00	1
DC2 [0.0]		7.20	7.20	7.20	0.00	0.00	1
1.2		7.10	7.10	7.10	0.00	0.00	1
2.4		7.10	7.10	7.10	0.00	0.00	1
5.3		7.00	7.00	7.00	0.00	0.00	1
10		7.00	7.00	7.00	0.00	0.00	1
21		6.90	6.90	6.90	0.00	0.00	1
DMW Control	Cond uS/cm	166.70	166.70	166.70	0.00	0.00	1
DC2 [0.0]		76.40	76.40	76.40	0.00	0.00	1
1.2		82.80	82.80	82.80	0.00	0.00	1
2.4		89.70	89.70	89.70	0.00	0.00	1
5.3		103.10	103.10	103.10	0.00	0.00	1
10		129.00	129.00	129.00	0.00	0.00	1
21		178.90	178.90	178.90	0.00	0.00	1
DMW Control	DO %	104.70	104.70	104.70	0.00	0.00	1
DC2 [0.0]		105.80	105.80	105.80	0.00	0.00	1
1.2		104.40	104.40	104.40	0.00	0.00	1
2.4		102.60	102.60	102.60	0.00	0.00	1
5.3		102.90	102.90	102.90	0.00	0.00	1
10		105.70	105.70	105.70	0.00	0.00	1
21		109.80	109.80	109.80	0.00	0.00	1

Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
DC2 [0.0]	1.0000	1.0000	1.0000	1.0000
1.2	1.0000	0.8000	1.0000	1.0000
2.4	1.0000	1.0000	1.0000	1.0000
5.3	0.8000	1.0000	1.0000	1.0000
10	1.0000	1.0000	0.6000	0.8000
21	0.0000	0.0000	0.4000	0.2000

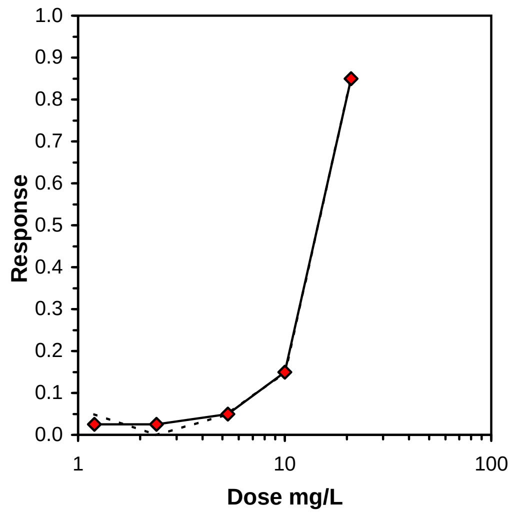
			Transform: Arcsin Square Root					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4				
DC2 [0.0]	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	*		1.0000	1.0000
1.2	0.9500	0.9500	1.2857	1.1071	1.3453	9.261	4	16.00	10.00	0.9750	0.9750
2.4	1.0000	1.0000	1.3453	1.3453	1.3453	0.000	4	18.00	10.00	0.9750	0.9750
5.3	0.9500	0.9500	1.2857	1.1071	1.3453	9.261	4	16.00	10.00	0.9500	0.9500
10	0.8500	0.8500	1.1709	0.8861	1.3453	18.840	4	14.00	10.00	0.8500	0.8500
*21	0.1500	0.1500	0.3998	0.2255	0.6847	55.174	4	10.00	10.00	0.1500	0.1500

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.918644	0.916	-0.22884	0.55839
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 1.00)	0	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	10	21	14.49138	
Treatments vs DC2 [0.0]				

Log-Logit Interpolation (200 Resamples)

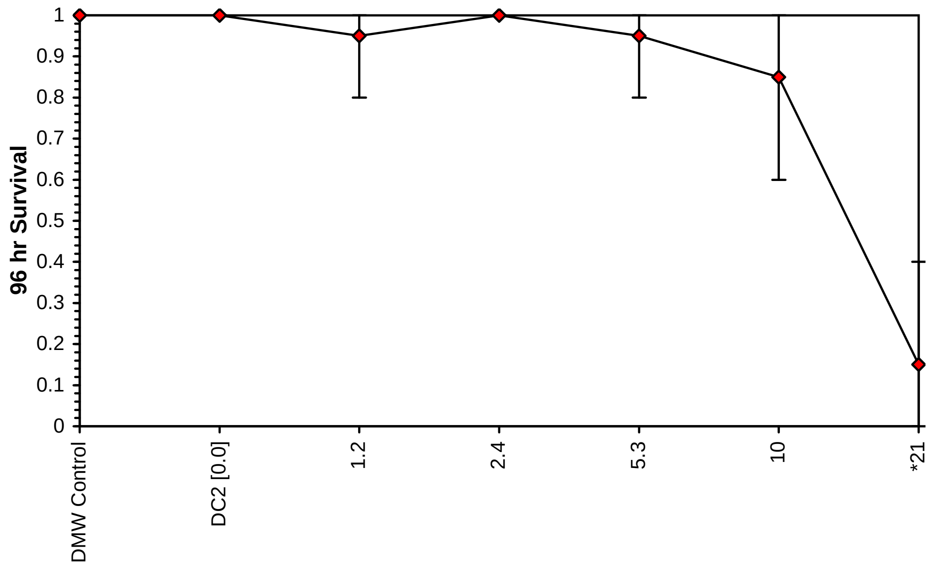
Point	mg/L	SD	95% CL(Exp)		Skew
IC05	5.300	2.680	0.609	14.652	0.5600
IC10	7.889	2.364	2.361	15.204	0.0143
IC15	10.000	1.863	2.480	15.345	-0.2153
IC20	10.793	1.466	7.134	15.761	0.6537
IC25	11.490	1.403	7.969	16.537	0.7634
IC40	13.346	1.503	9.159	18.755	0.2417
IC50	14.556	1.669	9.310	19.426	-0.0672



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

Dose-Response Plot



Freshwater Shrimp Acute Toxicity Test-96 hr Survival

Start Date:	16/05/2013 15:00	Test ID:	PR1030/37	Sample ID:	NAR_7102(2)_SURF_W + fluoride
End Date:	20/05/2013 15:00	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 123	Test Species:	PSP-Paratya australiensis
Comments:					

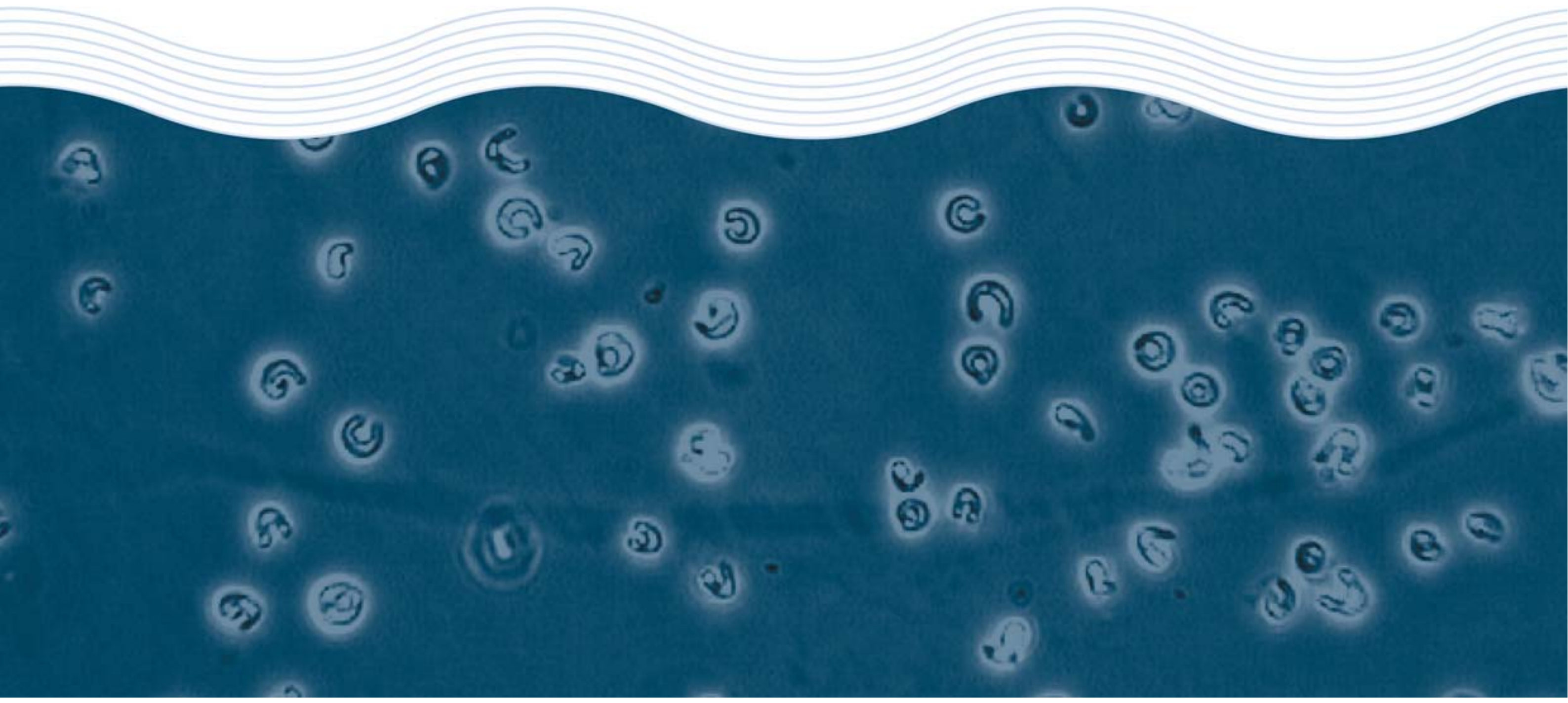
		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
DC2 [0.0]		100.00	100.00	100.00	0.00	0.00	4
1.2		95.00	80.00	100.00	10.00	3.33	4
2.4		100.00	100.00	100.00	0.00	0.00	4
5.3		95.00	80.00	100.00	10.00	3.33	4
10		85.00	60.00	100.00	19.15	5.15	4
21		15.00	0.00	40.00	19.15	29.17	4
DMW Control	pH	8.20	8.20	8.20	0.00	0.00	1
DC2 [0.0]		7.20	7.20	7.20	0.00	0.00	1
1.2		7.10	7.10	7.10	0.00	0.00	1
2.4		7.10	7.10	7.10	0.00	0.00	1
5.3		7.00	7.00	7.00	0.00	0.00	1
10		7.00	7.00	7.00	0.00	0.00	1
21		6.90	6.90	6.90	0.00	0.00	1
DMW Control	Cond uS/cm	166.70	166.70	166.70	0.00	0.00	1
DC2 [0.0]		76.40	76.40	76.40	0.00	0.00	1
1.2		82.80	82.80	82.80	0.00	0.00	1
2.4		89.70	89.70	89.70	0.00	0.00	1
5.3		103.10	103.10	103.10	0.00	0.00	1
10		129.00	129.00	129.00	0.00	0.00	1
21		178.90	178.90	178.90	0.00	0.00	1
DMW Control	DO %	104.70	104.70	104.70	0.00	0.00	1
DC2 [0.0]		105.80	105.80	105.80	0.00	0.00	1
1.2		104.40	104.40	104.40	0.00	0.00	1
2.4		102.60	102.60	102.60	0.00	0.00	1
5.3		102.90	102.90	102.90	0.00	0.00	1
10		105.70	105.70	105.70	0.00	0.00	1
21		109.80	109.80	109.80	0.00	0.00	1

Toxicity Assessment of River Water with the Addition of Boron

CH2M. Hill Pty Ltd

Test Report

January 2014



Toxicity Assessment of River Water with the Addition of Boron

CH2M. Hill Pty Ltd

Test Report

January 2014

ECOTOX Services Australasia Pty Ltd ABN>45 094 714 904
unit 27/2 chaplin drive lane cove nsw 2066 T>61 2 9420 9481 F>61 2 9420 9484 W>www.ecotox.com.au

NATA WORLD RECOGNISED ACCREDITATION

ecotox SERVICES AUSTRALASIA

Toxicity Test Report: TR1119/2

This document is issued in accordance with NATA's accreditation requirements

Client:	CH2M. Hill Pty Ltd Level 7, 9 Help Street Chatswood NSW 2067	**ESA Job #:**	PR1119
		Date Sampled:	13 March 2013
		Date Received:	14 March 2013
Attention:	Mark Favetta	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1119_q01

Lab ID No.:	Sample Name:	Sample Description:
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	Rainbowfish embryo hatching test using *Melanotaenia splendida splendida*
Test Protocol:	ESA SOP 126 (2013), based on USEPA (2002), but adapted for use with native rainbowfish
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Not applicable
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with nominal amount of boron. The spiked sample was then diluted with sample 5887 'NAR_7102(2)_SURF_W' to achieve the test concentrations. A DMW control and a diluent Control (NAR_7102(2)_SURF_W) were tested concurrently with the sample. The results are expressed as measured dissolved concentrations. The boron concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	22 January 2014 at 1500h

Sample 5887: *NAR_7102(2)_SURF_W + Boron*

Concentration (mg/L)	% Survival (Mean ± SD)
DMW Control	100 ± 0.0
Diluent Control [0.02]	85.0 ± 19.2
31	95.0 ± 10.0
60	75.0 ± 19.2
120	85.0 ± 19.2
240	0.0 ± 0.0
480	0.0 ± 0.0

13-d IC10 = 57.0 (29.8-166.4)mg/L
13-d EC50 = 145.7 (127.2-167.0)mg/L
NOEC = 120mg/L
LOEC = 240mg/L

Vacant

QA/QC Parameter	Criterion	This Test	Criterion met?
Control mean % survival	≥80.0%	100%	Yes
Reference Toxicant within cusum chart limit	11.4-435.0µg Cu/L	21.6µg Cu/L	Yes

Toxicity Test Report: TR1119/2

Test Report Authorised by: Dr Rick Krassoi, Director on 19 March 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. NATA is a signatory to the APLAC mutual recognition arrangement for the mutual recognition of the equivalence of testing, calibration and inspection reports. This document shall not be reproduced except in full.

Citations:

ESA (2013) *SOP 126- Rainbowfish Embryo Hatching Test*. Issue N°3. Ecotox Services Australasia, Sydney NSW

USEPA (2002) *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

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Report of Chemical Analyses

Envirolab Services Pty Ltd
ABN 37 112 535 645
12 Ashley St Chatswood NSW 2067
ph 02 9910 6200 fax 02 9910 6201
enquiries@envirolabservices.com.au
www.envirolabservices.com.au

CERTIFICATE OF ANALYSIS 104713

Client:
Ecotox Services Australasia Pty Ltd
Unit 27, 2 Chaplin Dr
Lane Cove
NSW 2066

Attention: Tina

Sample log in details:

Your Reference:	**PR1119**		
No. of samples:	12 waters		
Date samples received / completed instructions received	07/02/14	/	07/02/14

Analysis Details:
Please refer to the following pages for results, methodology summary and quality control data.
Samples were analysed as received from the client. Results relate specifically to the samples as received.
Results are reported on a dry weight basis for solids and on an as received basis for other matrices.
Please refer to the last page of this report for any comments relating to the results.

Report Details:

Date results requested by: / Issue Date:	14/02/14	/	14/02/14
Date of Preliminary Report:	Not issued		

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Accredited for compliance with ISO/IEC 17025. **Tests not covered by NATA are denoted with *.**

Results Approved By:

Jacinta Hurst
Laboratory Manager

Miscellaneous Inorganics						
Our Reference:	UNITS	104713-1	104713-2	104713-8	104713-9	104713-10
Your Reference	-------------	DMW Control	Diluent Control	NAR + Fluoride 31.3 mg/l	NAR + Fluoride 62.5 mg/l	NAR + Fluoride125 mg/l
Date Sampled	------------	22/01/2014	22/01/2014	22/01/2014	22/01/2014	22/01/2014
Type of sample		water	water	water	water	water
Date prepared	-	13/02/2014	13/02/2014	13/02/2014	13/02/2014	13/02/2014
Date analysed	-	13/02/2014	13/02/2014	13/02/2014	13/02/2014	13/02/2014
Fluoride, F	mg/L	<0.1	<0.1	32	64	120

Miscellaneous Inorganics			
Our Reference:	UNITS	104713-11	104713-12
Your Reference	-------------	NAR + Fluoride 250 mg/l	NAR + Fluoride 500 mg/l
Date Sampled	------------	22/01/2014	22/01/2014
Type of sample		water	water
Date prepared	-	13/02/2014	13/02/2014
Date analysed	-	13/02/2014	13/02/2014
Fluoride, F	mg/L	240	470

HM in water - dissolved						
Our Reference:	UNITS	104713-1	104713-2	104713-3	104713-4	104713-5
Your Reference	-------------	DMW Control	Diluent Control	NAR + Boron 31.3 mg/l	NAR + Boron 62.5 mg/l	NAR + Boron 125 mg/l
Date Sampled	------------	22/01/2014	22/01/2014	22/01/2014	22/01/2014	22/01/2014
Type of sample		water	water	water	water	water
Date prepared	-	10/02/2014	10/02/2014	10/02/2014	10/02/2014	10/02/2014
Date analysed	-	10/02/2014	10/02/2014	10/02/2014	10/02/2014	10/02/2014
Boron-Dissolved	µg/L	<5	18	31,000	60,000	120,000

HM in water - dissolved			
Our Reference:	UNITS	104713-6	104713-7
Your Reference	-------------	NAR + Boron 250 mg/l	NAR + Boron 500 mg/l
Date Sampled	------------	22/01/2014	22/01/2014
Type of sample		water	water
Date prepared	-	10/02/2014	10/02/2014
Date analysed	-	10/02/2014	10/02/2014
Boron-Dissolved	µg/L	240,000	480,000

Method ID	Methodology Summary
Inorg-026	Fluoride determined by ion selective electrode (ISE) in accordance with APHA 22nd ED, 4500-F-C.
Metals-022 ICP-MS	Determination of various metals by ICP-MS.

QUALITY CONTROL Miscellaneous Inorganics	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			10/02/2014	104713-1	13/02/2014 || 13/02/2014	LCS-W1	13/02/2014
Date analysed	-			10/02/2014	104713-1	13/02/2014 || 13/02/2014	LCS-W1	13/02/2014
Fluoride, F	mg/L	0.1	Inorg-026	<0.1	104713-1	<0.1 || <0.1	LCS-W1	101%

QUALITY CONTROL HM in water - dissolved	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			10/02/2014	104713-1	10/02/2014 || 10/02/2014	LCS-W1	10/02/2014
Date analysed	-			10/02/2014	104713-1	10/02/2014 || 10/02/2014	LCS-W1	10/02/2014
Boron-Dissolved	µg/L	5	Metals-022 ICP-MS	<5	104713-1	<5 || <5	LCS-W1	88%

QUALITY CONTROL Miscellaneous Inorganics	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Date prepared	-	[NT]	[NT]	104713-2	13/02/2014
Date analysed	-	[NT]	[NT]	104713-2	13/02/2014
Fluoride, F	mg/L	[NT]	[NT]	104713-2	106%

QUALITY CONTROL HM in water - dissolved	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Date prepared	-	[NT]	[NT]	104713-2	10/02/2014
Date analysed	-	[NT]	[NT]	104713-2	10/02/2014
Boron-Dissolved	µg/L	[NT]	[NT]	104713-2	96%

Report Comments:

Asbestos ID was analysed by Approved Identifier: Not applicable for this job
Asbestos ID was authorised by Approved Signatory: Not applicable for this job

INS: Insufficient sample for this test	PQL: Practical Quantitation Limit	NT: Not tested
NA: Test not required	RPD: Relative Percent Difference	NA: Test not required
<: Less than	>: Greater than	LCS: Laboratory Control Sample

Quality Control Definitions

Blank: This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.

Duplicate: This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.

Matrix Spike : A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.

LCS (Laboratory Control Sample) : This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.

Surrogate Spike: Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.
Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.
Spikes for Physical and Aggregate Tests are not applicable.
For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: <5xPQL - any RPD is acceptable; >5xPQL - 0-50% RPD is acceptable.
Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals; 60-140% for organics and 10-140% for SVOC and speciated phenols is acceptable.

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

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Statistical Printouts for the 10-day Fish Embryonic Development and Post-hatch Survival Tests

Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

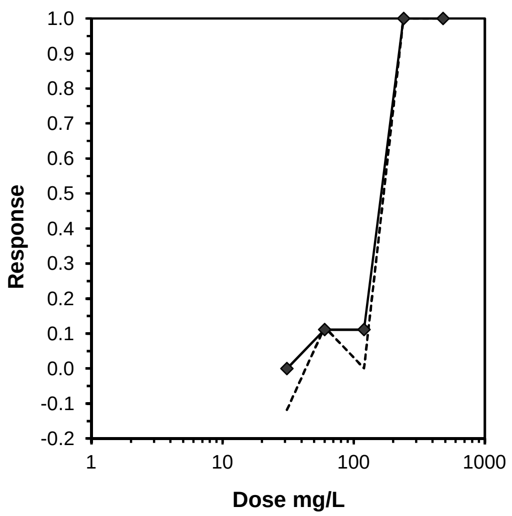
Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
Diluent Control	0.6000	1.0000	0.8000	1.0000
31	0.8000	1.0000	1.0000	1.0000
60	1.0000	0.8000	0.6000	0.6000
120	1.0000	1.0000	0.8000	0.6000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root						1-Tailed		Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Mean	N-Mean
DMW Control	1.0000	1.1765	1.3453	1.3453	1.3453	0.000	4					
Diluent Control	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	*			0.9000	1.0000
31	0.9500	1.1176	1.2857	1.1071	1.3453	9.261	4	-0.813	2.290	0.3234	0.9000	1.0000
60	0.7500	0.8824	1.0561	0.8861	1.3453	20.748	4	0.813	2.290	0.3234	0.8000	0.8889
120	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	0.000	2.290	0.3234	0.8000	0.8889
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				0.0000	0.0000

Auxiliary Tests					Statistic		Critical		Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)					0.928916		0.887		-0.21601	-1.10315
Bartlett's Test indicates equal variances (p = 0.76)					1.186782		11.34487			
The control means are not significantly different (p = 0.17)					1.580477		2.446912			
Hypothesis Test (1-tail, 0.05)	**NOEC**	**LOEC**	**ChV**	**TU**	**MSDu**	**MSDp**	**MSB**	**MSE**	**F-Prob**	**df**
Dunnett's Test	120	240	169.7056		0.286452	0.337614	0.035145	0.039883	0.478232	3, 12
Treatments vs Diluent Control										

Log-Logit Interpolation (200 Resamples)

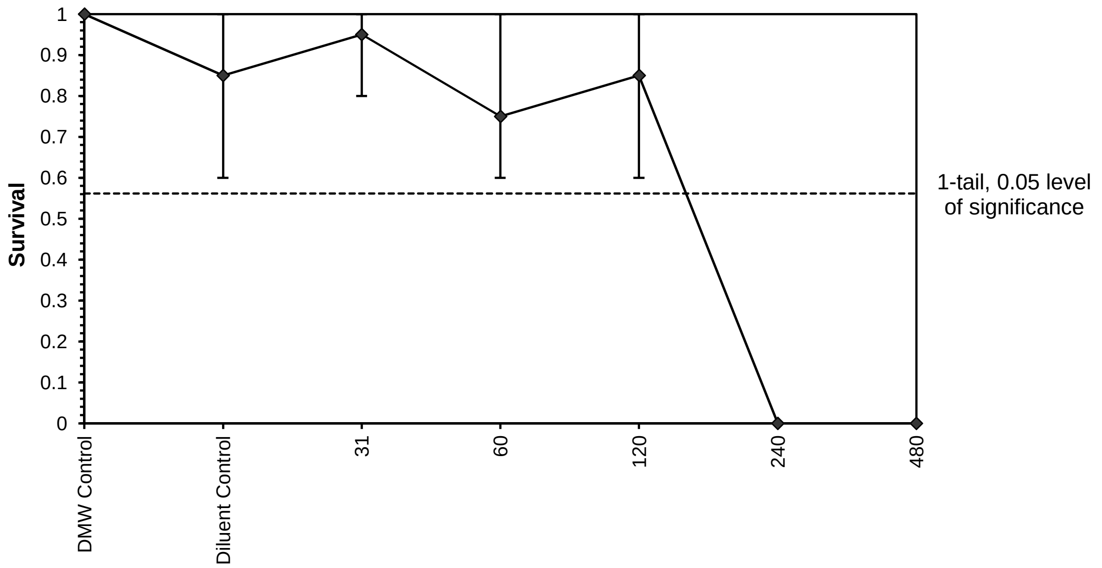
Point	mg/L	SD	95% CL(Exp)		Skew
IC05	43.80	31.94	10.07	170.33	1.1982
IC10	56.99	35.24	29.80	166.40	0.2465
IC15	121.63	32.02	3.57	131.29	-0.7450
IC20	123.53	21.97	12.96	133.10	-2.1826
IC25	125.27	12.22	20.08	134.77	-4.6072
IC40	130.04	3.09	120.94	139.32	0.4529
IC50	133.15	3.01	124.38	142.28	0.5059



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Dose-Response Plot



 ToxCalc v5.0.23 Reviewed by:_____

Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
Diluent Control		85.00	60.00	100.00	19.15	5.15	4
31		95.00	80.00	100.00	10.00	3.33	4
60		75.00	60.00	100.00	19.15	5.83	4
120		85.00	60.00	100.00	19.15	5.15	4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
Diluent Control		7.50	7.50	7.50	0.00	0.00	1
31		6.80	6.80	6.80	0.00	0.00	1
60		6.70	6.70	6.70	0.00	0.00	1
120		6.60	6.60	6.60	0.00	0.00	1
240		6.50	6.50	6.50	0.00	0.00	1
480		6.40	6.40	6.40	0.00	0.00	1
DMW Control	Conductivity (uS/cm)	177.10	177.10	177.10	0.00	0.00	1
Diluent Control		78.50	78.50	78.50	0.00	0.00	1
31		76.90	76.90	76.90	0.00	0.00	1
60		77.30	77.30	77.30	0.00	0.00	1
120		76.50	76.50	76.50	0.00	0.00	1
240		76.10	76.10	76.10	0.00	0.00	1
480		75.90	75.90	75.90	0.00	0.00	1
DMW Control	DO (% sat)	98.40	98.40	98.40	0.00	0.00	1
Diluent Control		114.40	114.40	114.40	0.00	0.00	1
31		111.90	111.90	111.90	0.00	0.00	1
60		110.00	110.00	110.00	0.00	0.00	1
120		109.40	109.40	109.40	0.00	0.00	1
240		109.30	109.30	109.30	0.00	0.00	1
480		108.20	108.20	108.20	0.00	0.00	1

Fish Embryonic Development and Post-Hatch Survival Test-Survival					
Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
Diluent Control	0.6000	1.0000	0.8000	1.0000
31	0.8000	1.0000	1.0000	1.0000
60	1.0000	0.8000	0.6000	0.6000
120	1.0000	1.0000	0.8000	0.6000
240	0.0000	0.0000	0.0000	0.0000
480	0.0000	0.0000	0.0000	0.0000

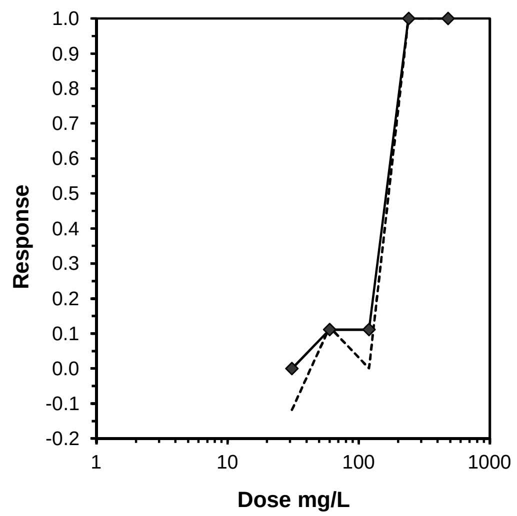
			Transform: Arcsin Square Root						1-Tailed		Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	t-Stat	Critical	MSD	Resp	Number
DMW Control	1.0000	1.1765	1.3453	1.3453	1.3453	0.000	4					
Diluent Control	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	*			3	20
31	0.9500	1.1176	1.2857	1.1071	1.3453	9.261	4	-0.813	2.290	0.3234	1	20
60	0.7500	0.8824	1.0561	0.8861	1.3453	20.748	4	0.813	2.290	0.3234	5	20
120	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	0.000	2.290	0.3234	3	20
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20
480	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4				20	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates normal distribution (p > 0.05)	0.928916	0.887	-0.21601	-1.10315
Bartlett's Test indicates equal variances (p = 0.76)	1.186782	11.34487		
The control means are not significantly different (p = 0.17)	1.580477	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU	MSDu	MSDp	MSB	MSE	F-Prob	df
Dunnett's Test	120	240	169.7056		0.286452	0.337614	0.035145	0.039883	0.478232	3, 12
Treatments vs Diluent Control										

Trimmed Spearman-Karber

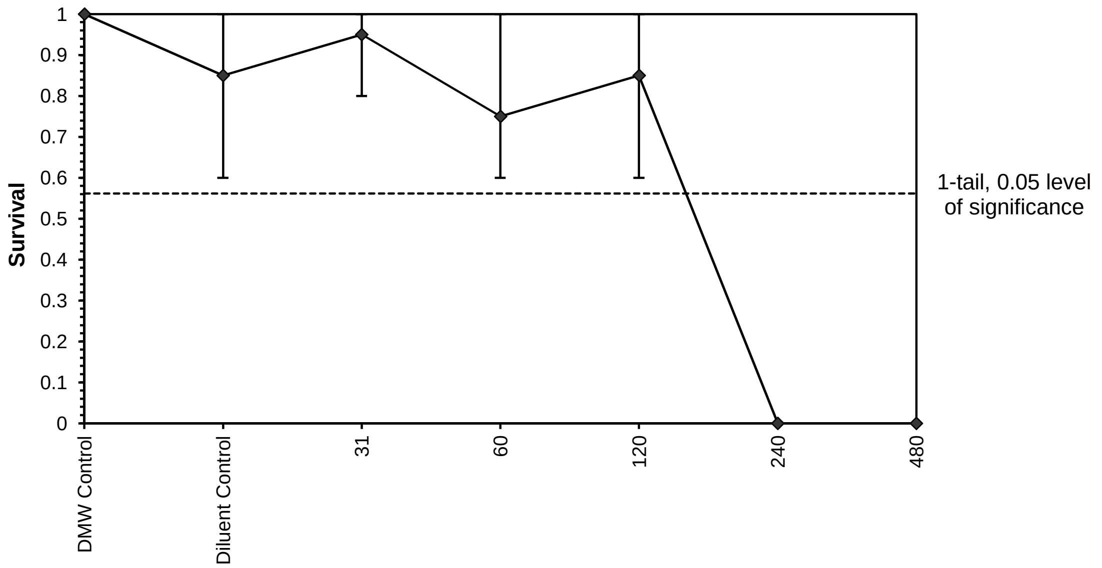
Trim Level	EC50	95% CL	
0.0%	145.74	127.19	167.00
5.0%	153.39	132.81	177.15
10.0%	160.89	139.76	185.21
20.0%	162.51	152.79	172.84
Auto-0.0%	145.74	127.19	167.00



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Dose-Response Plot



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/02	Sample ID:	NAR_7102(2)_SURF_W+Boron
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

		Auxiliary Data Summary					
Conc-mg/L	**Parameter**	**Mean**	**Min**	**Max**	**SD**	**CV%**	**N**
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
Diluent Control		85.00	60.00	100.00	19.15	5.15	4
31		95.00	80.00	100.00	10.00	3.33	4
60		75.00	60.00	100.00	19.15	5.83	4
120		85.00	60.00	100.00	19.15	5.15	4
240		0.00	0.00	0.00	0.00		4
480		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
Diluent Control		7.50	7.50	7.50	0.00	0.00	1
31		6.80	6.80	6.80	0.00	0.00	1
60		6.70	6.70	6.70	0.00	0.00	1
120		6.60	6.60	6.60	0.00	0.00	1
240		6.50	6.50	6.50	0.00	0.00	1
480		6.40	6.40	6.40	0.00	0.00	1
DMW Control	Conductivity (uS/cm)	177.10	177.10	177.10	0.00	0.00	1
Diluent Control		78.50	78.50	78.50	0.00	0.00	1
31		76.90	76.90	76.90	0.00	0.00	1
60		77.30	77.30	77.30	0.00	0.00	1
120		76.50	76.50	76.50	0.00	0.00	1
240		76.10	76.10	76.10	0.00	0.00	1
480		75.90	75.90	75.90	0.00	0.00	1
DMW Control	DO (% sat)	98.40	98.40	98.40	0.00	0.00	1
Diluent Control		114.40	114.40	114.40	0.00	0.00	1
31		111.90	111.90	111.90	0.00	0.00	1
60		110.00	110.00	110.00	0.00	0.00	1
120		109.40	109.40	109.40	0.00	0.00	1
240		109.30	109.30	109.30	0.00	0.00	1
480		108.20	108.20	108.20	0.00	0.00	1

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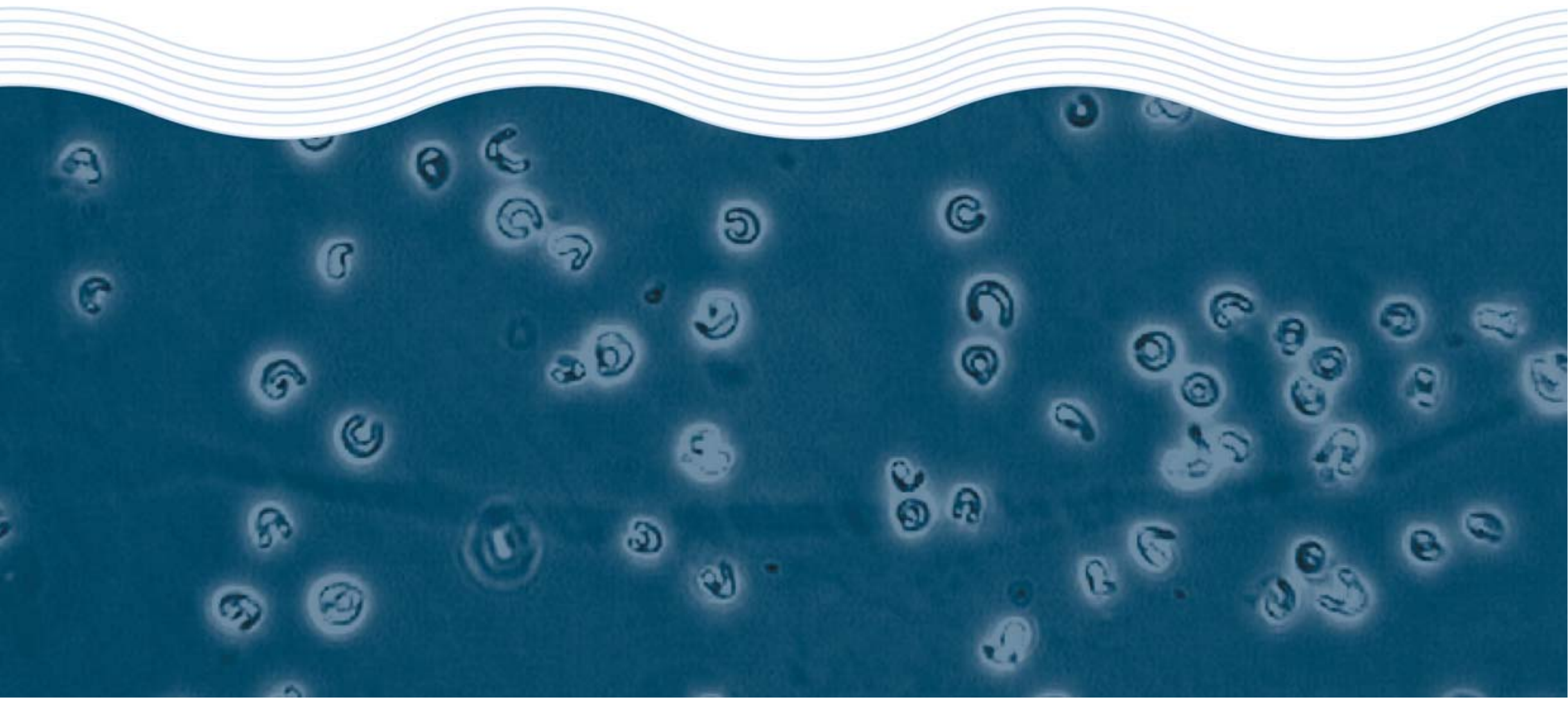
Toxicity Assessment of River Water with the Addition of Fluoride

CH2M. Hill Pty Ltd

Test Report

January 2014



Toxicity Assessment of River Water with the Addition of Fluoride

CH2M. Hill Pty Ltd

Test Report

January 2014

ECOTOX Services Australasia Pty Ltd ABN>45 094 714 904
unit 27/2 chaplin drive lane cove nsw 2066 T>61 2 9420 9481 F>61 2 9420 9484 W>www.ecotox.com.au

Toxicity Test Report: TR1119/1

This document is issued in accordance with NATA's accreditation requirements

Client:	CH2M. Hill Pty Ltd Level 7, 9 Help Street Chatswood NSW 2067	**ESA Job #:** **Date Sampled:** **Date Received:**	PR1119 13 March 2013 14 March 2013
Attention:	Mark Favetta	**Sampled By:**	Client
Client Ref:	Not supplied	**ESA Quote #:**	PL1119_q01

Lab ID No.:	**Sample Name:**	**Sample Description:**
5887	NAR_7102(2)_SURF_W	Aqueous sample, pH 6.7, conductivity 73.9µS/cm, total ammonia <2.0mg/L*. Sample received at 15ºC in apparent good condition.

*Ammonia analysis is not covered by Ecotox Services Australasia's scope of accreditation

Test Performed:	Rainbowfish embryo hatching test using *Melanotaenia splendida splendida*
Test Protocol:	ESA SOP 126 (2013), based on USEPA (2002), but adapted for use with native rainbowfish
Test Temperature:	The test was performed at 25±1°C.
Deviations from Protocol:	Not applicable
Comments on Solution Preparation:	Sample 5887 'NAR_7102(2)_SURF_W' was spiked with nominal amount of fluoride. The spiked samples were then diluted with sample 5887 'NAR_7102(2)_SURF_W' to achieve the test concentrations. A DMW control and a diluent Control (NAR_7102(2)_SURF_W) were tested concurrently with the sample. The results are expressed as measured dissolved concentrations. The fluoride concentrations of the diluent control are shown in brackets.
Source of Test Organisms:	ESA Laboratory culture
Test Initiated:	22 January 2014 at 1500h

Sample 5887: *NAR_7102(2)_SURF_W + Fluoride*

Concentration (mg/L)	**% Survival (Mean ± SD)**
DMW Control	100 ± 0.0
Diluent Control [0]	85.0 ± 19.2
32	80.0 ± 0.0
64	70.0 ± 20.0
120	0.0 ± 0.0
240	0.0 ± 0.0
470	0.0 ± 0.0

13-d IC10 = 41.8mg/L*
13-d EC50 = 78.7 (68.8-90.0)mg/L
NOEC = 64mg/L
LOEC = 120mg/L

*95% confidence limits are not reliable

QA/QC Parameter	**Criterion**	**This Test**	**Criterion met?**
Control mean % survival	≥80.0%	100%	Yes
Reference Toxicant within cusum chart limit	11.4-435.0µg Cu/L	21.6µg Cu/L	Yes

Test Report Authorised by: Dr Rick Krassoi, Director on 19 March 2014

Results are based on the samples in the condition as received by ESA.

NATA Accredited Laboratory Number: 14709

This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025. NATA is a signatory to the APLAC mutual recognition arrangement for the mutual recognition of the equivalence of testing, calibration and inspection reports. This document shall not be reproduced except in full.

Citations:

ESA (2013) *SOP 126- Rainbowfish Embryo Hatching Test*. Issue N°3. Ecotox Services Australasia, Sydney NSW

USEPA (2002) *Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.4th Ed.* United States Environmental Protection Agency, Office of Water, Washington DC.

Report of Chemical Analyses

Envirolab Services Pty Ltd
ABN 37 112 535 645
12 Ashley St Chatswood NSW 2067
ph 02 9910 6200 fax 02 9910 6201
enquiries@envirolabservices.com.au
www.envirolabservices.com.au

CERTIFICATE OF ANALYSIS 104713

Client:
Ecotox Services Australasia Pty Ltd
Unit 27, 2 Chaplin Dr
Lane Cove
NSW 2066

Attention: Tina

Sample log in details:

Your Reference:	**PR1119**		
No. of samples:	12 waters		
Date samples received / completed instructions received	07/02/14	/	07/02/14

Analysis Details:
Please refer to the following pages for results, methodology summary and quality control data.
Samples were analysed as received from the client. Results relate specifically to the samples as received.
Results are reported on a dry weight basis for solids and on an as received basis for other matrices.
Please refer to the last page of this report for any comments relating to the results.

Report Details:

Date results requested by: / Issue Date:	14/02/14	/	14/02/14
Date of Preliminary Report:	Not issued		

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Accredited for compliance with ISO/IEC 17025. **Tests not covered by NATA are denoted with *.**

Results Approved By:

Jacinta Hurst
Laboratory Manager

Miscellaneous Inorganics						
Our Reference:	UNITS	104713-1	104713-2	104713-8	104713-9	104713-10
Your Reference	-------------	DMW Control	Diluent Control	NAR + Fluoride 31.3 mg/l	NAR + Fluoride 62.5 mg/l	NAR + Fluoride125 mg/l
Date Sampled	------------	22/01/2014	22/01/2014	22/01/2014	22/01/2014	22/01/2014
Type of sample		water	water	water	water	water
Date prepared	-	13/02/2014	13/02/2014	13/02/2014	13/02/2014	13/02/2014
Date analysed	-	13/02/2014	13/02/2014	13/02/2014	13/02/2014	13/02/2014
Fluoride, F	mg/L	<0.1	<0.1	32	64	120

Miscellaneous Inorganics			
Our Reference:	UNITS	104713-11	104713-12
Your Reference	-------------	NAR + Fluoride 250 mg/l	NAR + Fluoride 500 mg/l
Date Sampled	------------	22/01/2014	22/01/2014
Type of sample		water	water
Date prepared	-	13/02/2014	13/02/2014
Date analysed	-	13/02/2014	13/02/2014
Fluoride, F	mg/L	240	470

HM in water - dissolved						
Our Reference:	UNITS	104713-1	104713-2	104713-3	104713-4	104713-5
Your Reference	-------------	DMW Control	Diluent Control	NAR + Boron 31.3 mg/l	NAR + Boron 62.5 mg/l	NAR + Boron 125 mg/l
Date Sampled	------------	22/01/2014	22/01/2014	22/01/2014	22/01/2014	22/01/2014
Type of sample		water	water	water	water	water
Date prepared	-	10/02/2014	10/02/2014	10/02/2014	10/02/2014	10/02/2014
Date analysed	-	10/02/2014	10/02/2014	10/02/2014	10/02/2014	10/02/2014
Boron-Dissolved	µg/L	<5	18	31,000	60,000	120,000

HM in water - dissolved			
Our Reference:	UNITS	104713-6	104713-7
Your Reference	-------------	NAR + Boron 250 mg/l	NAR + Boron 500 mg/l
Date Sampled	------------	22/01/2014	22/01/2014
Type of sample		water	water
Date prepared	-	10/02/2014	10/02/2014
Date analysed	-	10/02/2014	10/02/2014
Boron-Dissolved	µg/L	240,000	480,000

Method ID	Methodology Summary
Inorg-026	Fluoride determined by ion selective electrode (ISE) in accordance with APHA 22nd ED, 4500-F-C.
Metals-022 ICP-MS	Determination of various metals by ICP-MS.

QUALITY CONTROL Miscellaneous Inorganics	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			10/02/2014	104713-1	13/02/2014 || 13/02/2014	LCS-W1	13/02/2014
Date analysed	-			10/02/2014	104713-1	13/02/2014 || 13/02/2014	LCS-W1	13/02/2014
Fluoride, F	mg/L	0.1	Inorg-026	<0.1	104713-1	<0.1 || <0.1	LCS-W1	101%

QUALITY CONTROL HM in water - dissolved	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Date prepared	-			10/02/2014	104713-1	10/02/2014 || 10/02/2014	LCS-W1	10/02/2014
Date analysed	-			10/02/2014	104713-1	10/02/2014 || 10/02/2014	LCS-W1	10/02/2014
Boron-Dissolved	µg/L	5	Metals-022 ICP-MS	<5	104713-1	<5 || <5	LCS-W1	88%

QUALITY CONTROL Miscellaneous Inorganics	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Date prepared	-	[NT]	[NT]	104713-2	13/02/2014
Date analysed	-	[NT]	[NT]	104713-2	13/02/2014
Fluoride, F	mg/L	[NT]	[NT]	104713-2	106%

QUALITY CONTROL HM in water - dissolved	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Date prepared	-	[NT]	[NT]	104713-2	10/02/2014
Date analysed	-	[NT]	[NT]	104713-2	10/02/2014
Boron-Dissolved	µg/L	[NT]	[NT]	104713-2	96%

Report Comments:

Asbestos ID was analysed by Approved Identifier: Not applicable for this job
Asbestos ID was authorised by Approved Signatory: Not applicable for this job

INS: Insufficient sample for this test	PQL: Practical Quantitation Limit	NT: Not tested
NA: Test not required	RPD: Relative Percent Difference	NA: Test not required
<: Less than	>: Greater than	LCS: Laboratory Control Sample

Quality Control Definitions

Blank: This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.

Duplicate: This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.

Matrix Spike : A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.

LCS (Laboratory Control Sample) : This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.

Surrogate Spike: Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.
Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.
Spikes for Physical and Aggregate Tests are not applicable.
For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: <5xPQL - any RPD is acceptable; >5xPQL - 0-50% RPD is acceptable.
Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals; 60-140% for organics and 10-140% for SVOC and speciated phenols is acceptable.

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

ecotox
SERVICES AUSTRALASIA

Statistical Printouts for the 10-day Fish Embryonic Development and Post-hatch Survival Tests

Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
Diluent Control	0.6000	1.0000	0.8000	1.0000
32	0.8000	0.8000	0.8000	0.8000
64	0.4000	0.8000	0.8000	0.8000
120	0.0000	0.0000	0.0000	0.0000
240	0.0000	0.0000	0.0000	0.0000
470	0.0000	0.0000	0.0000	0.0000

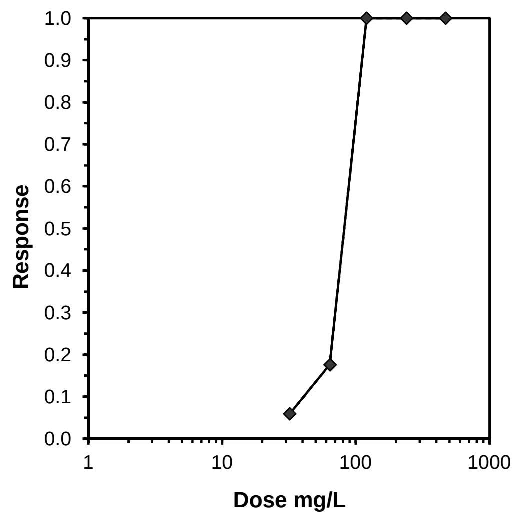
			Transform: Arcsin Square Root					Rank	1-Tailed	Number	Total
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Resp	Number
DMW Control	1.0000	1.1765	1.3453	1.3453	1.3453	0.000	4				
Diluent Control	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	*		3	20
32	0.8000	0.9412	1.1071	1.1071	1.1071	0.000	4	16.00	11.00	4	20
64	0.7000	0.8235	1.0015	0.6847	1.1071	21.089	4	14.50	11.00	6	20
120	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20
470	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			20	20

Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.850438	0.859	-1.10358	0.567821
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 0.17)	1.580477	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	64	120	87.63561	
Treatments vs Diluent Control				

Trimmed Spearman-Karber

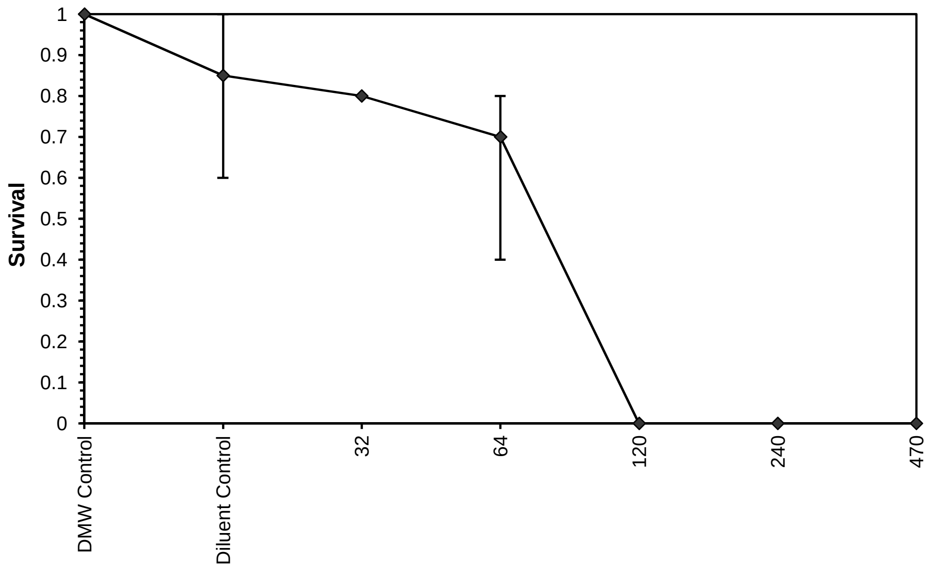
Trim Level	EC50	95% CL	
0.0%			
5.0%			
10.0%	80.406	69.197	93.432
20.0%	81.928	75.704	88.663
Auto-5.9%	78.698	68.834	89.975



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Dose-Response Plot



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Auxiliary Data Summary

Conc-mg/L	Parameter	Mean	Min	Max	SD	CV%	N
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
Diluent Control		85.00	60.00	100.00	19.15	5.15	4
32		80.00	80.00	80.00	0.00	0.00	4
64		70.00	40.00	80.00	20.00	6.39	4
120		0.00	0.00	0.00	0.00		4
240		0.00	0.00	0.00	0.00		4
470		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
Diluent Control		7.50	7.50	7.50	0.00	0.00	1
32		6.80	6.80	6.80	0.00	0.00	1
64		6.80	6.80	6.80	0.00	0.00	1
120		6.90	6.90	6.90	0.00	0.00	1
240		6.80	6.80	6.80	0.00	0.00	1
470		6.70	6.70	6.70	0.00	0.00	1
DMW Control	Conductivity (uS/cm)	177.10	177.10	177.10	0.00	0.00	1
Diluent Control		78.50	78.50	78.50	0.00	0.00	1
32		248.00	248.00	248.00	0.00	0.00	1
64		412.00	412.00	412.00	0.00	0.00	1
120		725.00	725.00	725.00	0.00	0.00	1
240		1322.00	1322.00	1322.00	0.00	0.00	1
470		2470.00	2470.00	2470.00	0.00	0.00	1
DMW Control	DO (% sat)	98.40	98.40	98.40	0.00	0.00	1
Diluent Control		114.40	114.40	114.40	0.00	0.00	1
32		105.50	105.50	105.50	0.00	0.00	1
64		108.60	108.60	108.60	0.00	0.00	1
120		108.00	108.00	108.00	0.00	0.00	1
240		109.00	109.00	109.00	0.00	0.00	1
470		108.30	108.30	108.30	0.00	0.00	1

Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Conc-mg/L	1	2	3	4
DMW Control	1.0000	1.0000	1.0000	1.0000
Diluent Control	0.6000	1.0000	0.8000	1.0000
32	0.8000	0.8000	0.8000	0.8000
64	0.4000	0.8000	0.8000	0.8000
120	0.0000	0.0000	0.0000	0.0000
240	0.0000	0.0000	0.0000	0.0000
470	0.0000	0.0000	0.0000	0.0000

			Transform: Arcsin Square Root					Rank	1-Tailed	Isotonic	
Conc-mg/L	Mean	N-Mean	Mean	Min	Max	CV%	N	Sum	Critical	Mean	N-Mean
DMW Control	1.0000	1.1765	1.3453	1.3453	1.3453	0.000	4				
Diluent Control	0.8500	1.0000	1.1709	0.8861	1.3453	18.840	4	*		0.8500	1.0000
32	0.8000	0.9412	1.1071	1.1071	1.1071	0.000	4	16.00	11.00	0.8000	0.9412
64	0.7000	0.8235	1.0015	0.6847	1.1071	21.089	4	14.50	11.00	0.7000	0.8235
120	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000
240	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000
470	0.0000	0.0000	0.2255	0.2255	0.2255	0.000	4			0.0000	0.0000

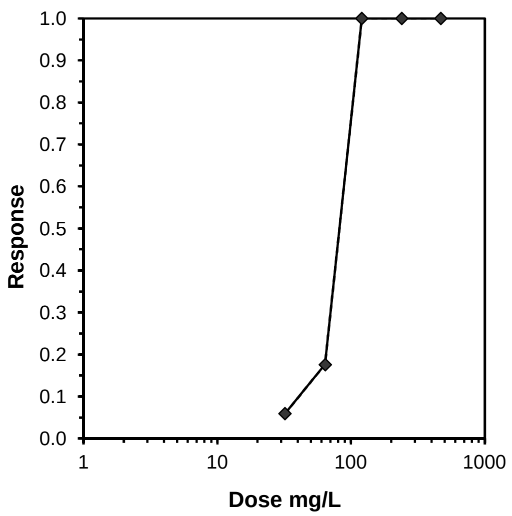
Auxiliary Tests	Statistic	Critical	Skew	Kurt
Shapiro-Wilk's Test indicates non-normal distribution (p <= 0.05)	0.850438	0.859	-1.10358	0.567821
Equality of variance cannot be confirmed				
The control means are not significantly different (p = 0.17)	1.580477	2.446912		

Hypothesis Test (1-tail, 0.05)	NOEC	LOEC	ChV	TU
Steel's Many-One Rank Test	64	120	87.63561	
Treatments vs Diluent Control				

Log-Logit Interpolation (200 Resamples)

Point	mg/L	SD	95% CL(Exp)		Skew
IC05*	19.474	19.044	0.000	92.063	0.5833
IC10	41.760	18.077	0.000	79.925	0.0733
IC15	55.631	14.248	10.211	72.756	-0.3491
IC20	64.377	10.945	12.574	68.607	-1.0077
IC25	65.146	8.163	23.727	69.210	-1.5527
IC40	67.324	2.999	54.024	71.029	-3.3416
IC50	68.785	2.022	62.529	72.316	-2.1449

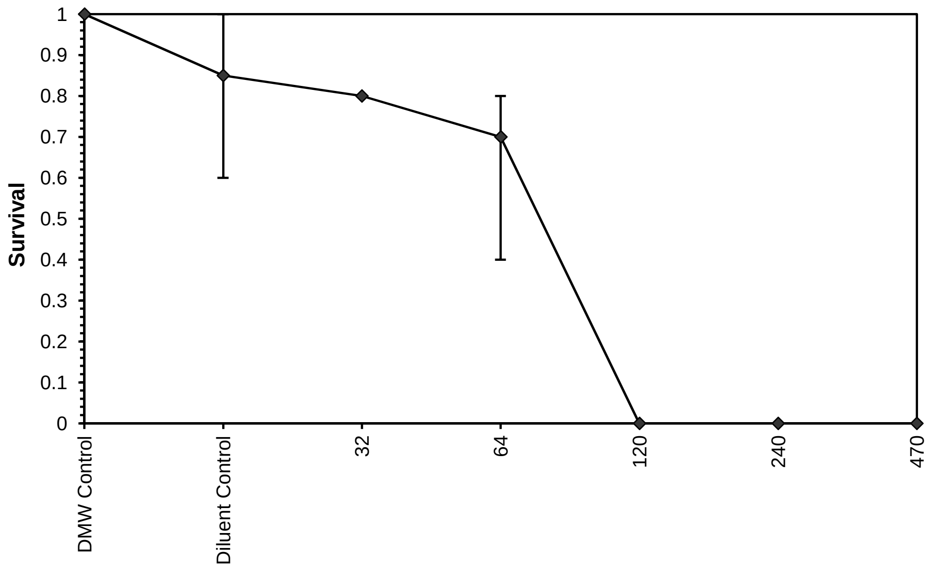
* indicates IC estimate less than the lowest concentration



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Dose-Response Plot



Fish Embryonic Development and Post-Hatch Survival Test-Survival

Start Date:	22/01/2014 15:00	Test ID:	PR1119/01	Sample ID:	NAR_7102(2)_SURF_W+Fluoride
End Date:	4/02/2014 10:30	Lab ID:	5887	Sample Type:	AQ-Aqueous
Sample Date:		Protocol:	ESA 126	Test Species:	MS-Melanotaenia splendida
Comments:	Measured concentrations				

Auxiliary Data Summary

Conc-mg/L	Parameter	Mean	Min	Max	SD	CV%	N
DMW Control	% Survival	100.00	100.00	100.00	0.00	0.00	4
Diluent Control		85.00	60.00	100.00	19.15	5.15	4
32		80.00	80.00	80.00	0.00	0.00	4
64		70.00	40.00	80.00	20.00	6.39	4
120		0.00	0.00	0.00	0.00		4
240		0.00	0.00	0.00	0.00		4
470		0.00	0.00	0.00	0.00		4
DMW Control	pH	8.10	8.10	8.10	0.00	0.00	1
Diluent Control		7.50	7.50	7.50	0.00	0.00	1
32		6.80	6.80	6.80	0.00	0.00	1
64		6.80	6.80	6.80	0.00	0.00	1
120		6.90	6.90	6.90	0.00	0.00	1
240		6.80	6.80	6.80	0.00	0.00	1
470		6.70	6.70	6.70	0.00	0.00	1
DMW Control	Conductivity (uS/cm)	177.10	177.10	177.10	0.00	0.00	1
Diluent Control		78.50	78.50	78.50	0.00	0.00	1
32		248.00	248.00	248.00	0.00	0.00	1
64		412.00	412.00	412.00	0.00	0.00	1
120		725.00	725.00	725.00	0.00	0.00	1
240		1322.00	1322.00	1322.00	0.00	0.00	1
470		2470.00	2470.00	2470.00	0.00	0.00	1
DMW Control	DO (% sat)	98.40	98.40	98.40	0.00	0.00	1
Diluent Control		114.40	114.40	114.40	0.00	0.00	1
32		105.50	105.50	105.50	0.00	0.00	1
64		108.60	108.60	108.60	0.00	0.00	1
120		108.00	108.00	108.00	0.00	0.00	1
240		109.00	109.00	109.00	0.00	0.00	1
470		108.30	108.30	108.30	0.00	0.00	1

Appendix 3 Output from species sensitivity distribution fitting for water from Bohena Creek using CADDIS software.

a. Boron results
b. Fluoride results

Species sensitivity distributions model the variation in the sensitivity of different species to a stressor. SSDs assist in the interpretation of site data for stressor identification and risk assessment by relating them to the proportion of species expected to be affected at prescribed concentrations. SSDs are usually created using data from laboratory toxicity tests (USEPA 2010).

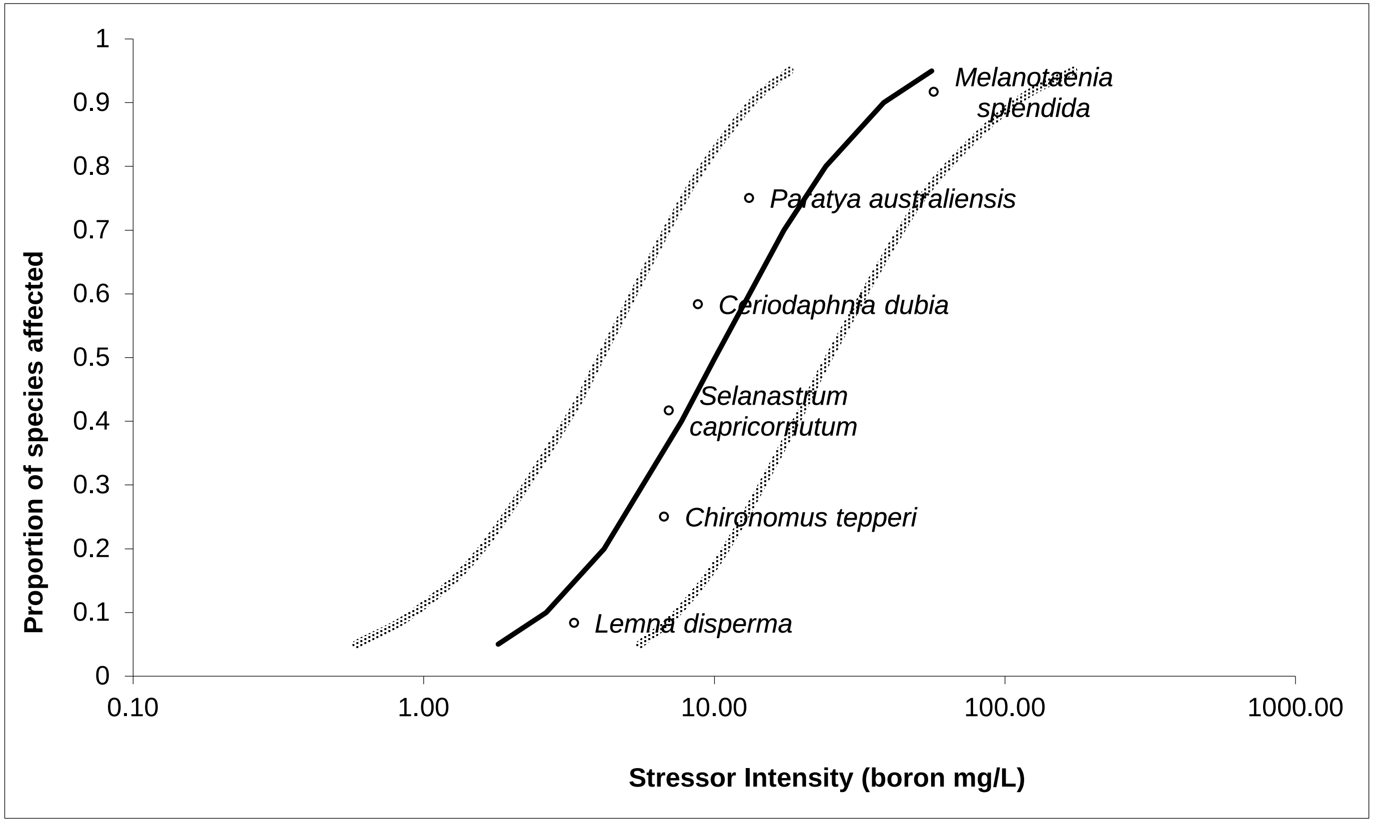
A. BORON

Taxa	Obs/ Species	Exposure mg/L	Taxon Log Exposure Geometric Mean	Standard Deviation	TaxonMean	Proportion	Rank	Probit	Probit Predicted	Difference^2	Counting Obs/ Species	Running product exposure mean
Selanastrum capricornutum	1	7	0.8451		7.0000	42%	3	4.7896	4.6533	0.0186	1	7.0E+00
Paratya australiensis	1	13.2	1.1206		13.2000	75%	5	5.6745	5.2612	0.1708	1	1.3E+01
Melanotaenia splendida	1	57	1.7559		57.0000	92%	6	6.3830	6.6633	0.0786	1	5.7E+01
Lemna disperma	1	3.3	0.5185		3.3000	8%	1	3.6170	3.9326	0.0996	1	3.3E+00
Chironomus tepperi	1	6.74	0.8287		6.7400	25%	2	4.3255	4.6170	0.0850	1	6.7E+00
Ceriodaphnia dubia	1	8.8	0.9445		8.8000	58%	4	5.2104	4.8726	0.1141	1	8.8E+00

PARAMETERS	
Slope	2.207
Intercept	2.788
R^2	0.883
GrandMean	1.002
SumSQ	6.901
CSSQ	0.874
MSE	0.142
Tcrit	2.132
N	6
df	4

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	0.257	0.052	0.745	-0.231	1.807	5.558	0.587
0.1	3.718	0.421	0.045	0.874	-0.031	2.639	7.490	0.930
0.2	4.158	0.621	0.039	1.041	0.201	4.177	10.980	1.589
0.4	4.747	0.887	0.034	1.283	0.492	7.716	19.170	3.106
0.5	5.000	1.002	0.034	1.395	0.610	10.051	24.825	4.069
0.7	5.524	1.240	0.036	1.643	0.836	17.371	43.978	6.861
0.8	5.842	1.384	0.039	1.803	0.964	24.186	63.580	9.200
0.9	6.282	1.583	0.045	2.036	1.130	38.275	108.616	13.487
0.95	6.645	1.748	0.052	2.236	1.259	55.916	172.026	18.175

Taxa	Mean Stressor Intensity	Proportion Taxa	Number of Observations
Lemna disperma	3.3	8%	1
Chironomus tepperi	6.74	25%	1
Selanastrum capricornutum	7	42%	1
Ceriodaphnia dubia	8.8	58%	1
Paratya australiensis	13.2	75%	1
Melanotaenia splendida	57	92%	1



SSD plot (solid line) showing the distribution of EC_{10}s for test species exposed to boron with 95% confidence limits (dotted lines).

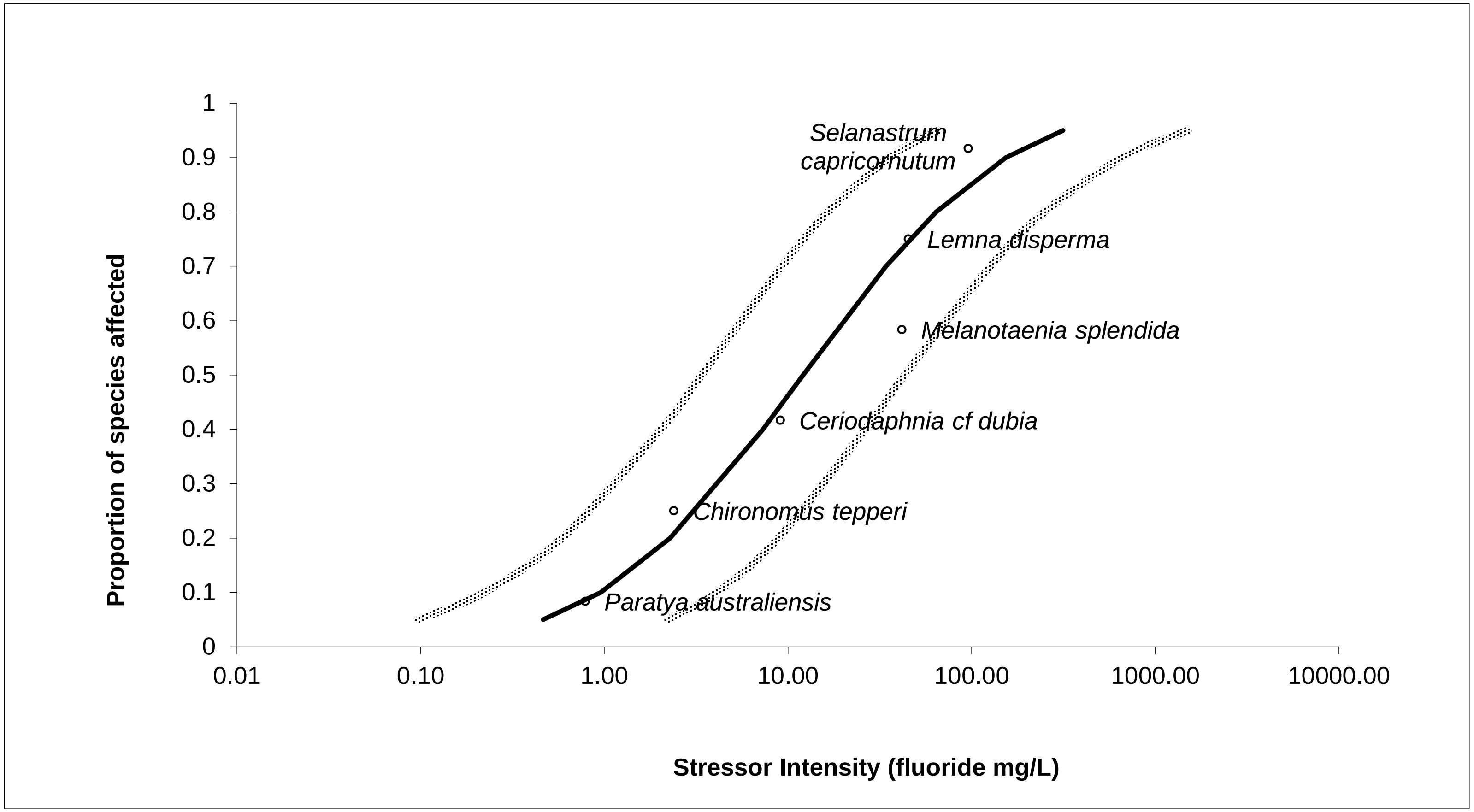
B. FLUORIDE

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-0.333	0.102	0.347	-1.013	**0.465**	2.225	0.097
0.1	3.718	-0.020	0.088	0.613	-0.653	0.955	4.102	0.222
0.2	4.158	0.359	0.076	0.947	-0.230	2.283	8.855	0.589
0.4	4.747	0.865	0.068	1.421	0.309	7.324	26.346	2.036
0.5	5.000	1.083	0.067	1.635	0.530	12.099	43.187	3.389
0.7	5.524	1.534	0.071	2.101	0.967	34.195	126.134	9.270
0.8	5.842	1.807	0.076	2.396	1.218	64.110	248.624	16.531
0.9	6.282	2.185	0.088	2.818	1.552	153.274	658.325	35.686
0.95	6.645	2.498	0.102	3.178	1.818	314.831	1506.680	65.786

Taxa	Mean Stressor Intensity	Proportion Taxa	Number of Observations
Paratya australiensis	0.79	8%	1
Chironomus tepperi	2.4	25%	1
Ceriodaphnia cf dubia	9.1	42%	1
Melanotaenia splendida	41.8	58%	1
Lemna disperma	45.3	75%	1
Selanastrum capricornutum	96	92%	1

PARAMETERS	
Slope	1.162
Intercept	3.742
R^2	0.935
GrandMean	1.083
SumSQ	10.375
CSSQ	3.341
MSE	0.078
Tcrit	2.132
N	6
df	4

Taxa	Obs/ Species	Exposure mg/L	Taxon Log Exposure Geometric Mean	Standard Deviation	TaxonMean	Proportion	Rank	Probit	Probit Predicted	Difference^2	Counting Obs/ Species	Running product exposure mean
Selanastrum capricornutum	1	96	1.9823		96.0000	92%	6	6.3830	6.0454	0.1140	1	9.6E+01
Paratya australiensis	1	0.79	-0.1024		0.7900	8%	1	3.6170	3.6227	0.0000	1	7.9E-01
Melanotaenia splendida	1	41.8	1.6212		41.8000	58%	4	5.2104	5.6258	0.1725	1	4.2E+01
Lemna disperma	1	45.3	1.6561		45.3000	75%	5	5.6745	5.6663	0.0001	1	4.5E+01
Chironomus tepperi	1	2.4	0.3802		2.4000	25%	2	4.3255	4.1836	0.0202	1	2.4E+00
Ceriodaphnia cf dubia	1	9.1	0.9590		9.1000	42%	3	4.7896	4.8562	0.0044	1	9.1E+00



SSD plot (solid line) showing the distribution of EC_{10}s for test species exposed to fluoride with 95% confidence limits (dotted lines).

Appendix C Aquatic Ecology & Stygofauna Assessment

ecological AUSTRALIA

Narrabri Gas Project

AQUATIC ECOLOGY AND STYGOFAUNA ASSESSMENT

Prepared for

Santos NSW (Eastern) Pty Ltd

August 2016

This report should be cited as 'Eco Logical Australia 2016. *Narrabri Gas Project – Aquatic Ecology and Stygofauna Assessment.* Prepared for Santos NSW (Eastern) Pty Ltd.'

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Abbreviations

Abbreviation	Description
ANZECC	The Australian and New Zealand Environment Conservation Council
BBAM	Biobanking Assessment Methodology

Abbreviation	Description
BSAL	Biophysical strategic agricultural land
CPOM	Coarse Particulate Organic Matter
CSG	Coal Seam Gas
DO	Dissolved Oxygen
EC	Electrical Conductivity
EEC	Endangered Ecological Community
EIS	Environmental Impact Statement
ELA	Eco Logical Australia Pty Ltd
EPA Act	NSW *Environmental Planning and Assessment Act 1979*
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
FM Act	NSW *Fisheries Management Act 1994*
FPOM	Fine Particulate Organic Matter
GDE	Groundwater Dependent Ecosystem
LGA	Local Government Area
MNES	Matters of National Environmental Significance
MRS	Managed Release Study
NOW	NSW Office of Water
NSW	New South Wales
OEH	NSW Office of Environment and Heritage
RCE	Riparian, Channel and Environmental
RO	Reverse Osmosis
Santos	Santos NSW (Eastern) Pty Ltd
SIGNAL	Stream Invertebrate Grade Number-Average Level
TSC Act	NSW *Threatened Species Conservation Act 1995*
TSR	Travelling Stock Reserve
WMF	Water Management Facility

Executive summary

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

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

To enable gas extraction, the depressurisation of coal seams is required. The project would thus involve the extraction of produced water from coal seams that would be treated at the Leewood Water Management Facility (WMF). As part of the project Environmental Impact Statement (EIS), treated water would be beneficially used for drilling, dust suppression, and irrigation, with releases to Bohena Creek occurring infrequently.

Managed release, which is the focus of this report, is required from time-to-time to maintain water management system operational reliability. Santos has elected to proceed only with episodic release, which is defined as infrequent release of treated water, to Bohena Creek during prolonged periods of wet weather when the creek is flowing (natural flows ≥ 100 ML/day). This Managed Release Study (MRS) is based on a proposed 25 year assessment period.

As part of the Managed Release Study, Eco Logical Australia (ELA) was commissioned to conduct an aquatic ecology and stygofauna assessment (this report) for the proposed surface water release location in Bohena Creek. Bohena Creek is an intermittent stream located near the Leewood WMF that drains northwards to meet the Namoi River just upstream of Mollee Weir. This assessment focusses in the current ecological condition of Bohena Creek, the Namoi River, and other ephemeral streams in the catchment.

This assessment establishes the current ecological conditions of Bohena Creek near the potential release location and further downstream in the Namoi River at the Bohena Creek confluence. It also assesses the ecological conditions of ephemeral tributaries of the Namoi River. As part of the assessment, freshwater and riparian flora and fauna species and ecological communities have been identified. The assessment then considers the impacts to aquatic ecosystems of episodic release water from the Leewood WMF to Bohena Creek. This is defined as an infrequent release of treated unamended water, typically during prolonged periods of wet weather when Bohena Creek is flowing at a rate greater than 100 ML/day.

Aquatic surveys and results

Aquatic ecology surveys were conducted in 2013 and 2014 to assess baseline ecological conditions in the mid-Namoi River catchment. Sampling was conducted at two spatial scales; one centred around the managed release site on Bohena Creek (Bohena Creek study), and one that assessed the ecological condition of aquatic sites in the mid-Namoi catchment (mid-Namoi catchment assessment). The Bohena Creek study sites were selected upstream and downstream of the proposed Leewood WMF release location, and included sites in the Namoi River upstream and downstream of the confluence of Bohena Creek. The mid-Namoi catchment assessment aimed to understand the regional condition of aquatic ecosystems, and included 19 sites on Namoi River and 9 tributaries.

Both surveys included AUSRIVAS assessments of site condition and macroinvertebrate community assemblages, aquatic habitat assessment, riparian condition, and water quality assessments. The Bohena Creek study also included surveys of the fish community and a detailed riparian floristic survey for most sites.

This assessment has determined that the aquatic ecological communities of Bohena Creek, the Namoi River, and all of the tributaries are in poor ecological condition, with each watercourse having a separate overriding regime that contributes to this. In the Namoi, flow regulation appears to be the main impact to the system, while in Bohena Creek the ecological condition is part of the normal drying cycle of the creek. Smaller tributaries are also impacted by regular drying, and have been degraded through historical agricultural practices.

Riparian habitat at all sites along Bohena Creek was in good to excellent condition. The Bohena Creek sites were in AUSRIVAS Bands of B and C, which indicated that aquatic habitat was either significantly or severely impaired. Invertebrate diversity was generally low for Bohena Creek, with a total of 38 taxa collected. For the sites that dried, diversity of active aquatic species will have declined because of the absence of surface water. However, there were still aquatic invertebrates present in the shallow groundwater, as eggs in the sand, or as diapausing stages in the moist sediment.

The Namoi River/Narrabri creek sites had moderate to good riparian habitat. These sites were in AUSRIVAS Bands B and C, indicating that the aquatic habitat was significantly or severely impaired. Aquatic invertebrate diversity was low, with only 27 fauna collected. The aquatic ecology of the Namoi River/ Narrabri Creek is impacted by flow regulation and changes to water level.

For most of the mid-Namoi ephemeral tributaries that were sampled, riparian habitat was in a poor or moderate condition, although a few sites had good RCE scores because of in-channel habitat characteristics. The mid-Namoi tributary sites were in AUSRIVAS Bands C and D, apart from Brigalow Creek, which was in Band B. Each site had between 6 and 22 macroinvertebrate taxa, with diversity higher in larger pools with complex habitat structure, and declining as pools dry out.

Eleven fish species were collected from the Namoi and Bohena Creek sites, including *Tandanas tandanas* (Eel-tailed Catfish) from the Namoi River. This species is listed as an endangered population in the Murray Darling Basin under the NSW *Fisheries Management Act 1994* (FM Act). *Melanotaenia fluviatilis* (Murray-Darling Rainbowfish), *Retropinna semoni* (Australian Smelt), and *Nematalosa erebi* (Bony Bream) are all native species that were collected at the Namoi River, but not Bohena Creek sites. Three exotic species: *Carassius auratus* (Goldfish), *Cyprinus carpio* (Common Carp), and *Gambusia holbrooki* (Plague Minnow) were collected from the Namoi River, and the latter two species were collected from Bohena Creek. Only *Craterocephalus stercusmuscarum fulvus* (Unspeckled Hardyhead) was collected from Bohena Creek and not Namoi River/Narrabri Creek.

Samples for stygofauna assessment were collected over three sample periods from production bores in the Permian strata of the Black Jack Group and Maules Creek Formation and monitoring bores in the colluvium at Leewood WMF, and monitoring bores and pits in the Bohena Creek Alluvium from March 2013 to July 2014. The monitoring bores in both locations were sampled on two occasions. No definite stygofauna were present in any of the nineteen samples.

Potential impacts and recommendations

Episodic release would occur when the creek is flowing naturally at equal to or greater than 100 ML/day. The environmental impact assessment for the Managed Release Study has assumed the use of up to 12 ML of treated water per day. Under this scenario there is likely to be very little change to the natural pattern of wetting and drying and as such little change to aquatic ecology. The episodic release option is dependent on there being sufficiently frequent natural flow events in Bohena Creek.

Overall, the proposed episodic release to Bohena Creek while it is flowing poses only minor threats to aquatic ecology. These impacts to the creek can be minimised by:

- releasing only in accordance with the managed release protocol: episodic release when there is natural surface flow equal to or greater than 100 ML/day in Bohena Creek
- ensuring water chemistry (including temperature and dissolved oxygen concentration) is as close as possible to that of receiving water
- releasing water in pulses (episodic release), so that the system retains some level of variability.

Road and pipeline crossings of creeks and waterways should comply with NSW *Guidelines for Riparian Corridors on Waterfront Land*, and *Guidelines for Watercourse Crossings and Controlled Activities: Guidelines for In-stream Works.*

The surveys reported in this study assessed the baseline ecological condition of Bohena Creek and other ephemeral creeks during a period of flow recession. No ecological samples have been collected from Bohena Creek during a flow period due to its unpredictable flow characteristics and timing of this assessment. If a flow event occurs prior to release, ecological samples should be collected during and after the event.

If and when managed release commences, monitoring should continue in autumn and spring to determine whether and how releases are affecting aquatic ecosystems. Sampling should also occur immediately following release events and at the period when the creek starts to break up into isolated pools during the natural drying cycle.

Sampling has not found any stygofauna in the alluvium of Bohena Creek, nor are extensive stygofauna communities likely because of the poor development of the aquifer and the frequency with which the aquifer dries out. However, if stygofauna were to occur in the aquifer, the managed release would have negligible impact to the community because the release will only occur when the aquifer is saturated. In addition, the thorough and rapid mixing of treated water released to the creek would ensure no change to groundwater chemistry in the alluvial aquifer. The adoption of field protocols for pipe crossings of any creeks will ensure that no impacts to potential stygofauna populations or habitat are realised through project operation.

1 Introduction

1.1 Overview

Santos NSW (Eastern) Pty Ltd (Santos) is proposing to develop natural gas from coal seams in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri (**Figure 1**).

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

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

- Development of a new source of gas supply into NSW would lead to an improvement in energy security and independence to the State. This would give NSW gas markets greater choice when entering into gas purchase arrangements. Potential would also exist for improved competition on price. Improved competition on price would have flow on benefits for NSW's economic efficiency, productivity and prosperity.
- The provision of a reduced greenhouse gas emission fuel source for power generation in NSW as compared to coal-fired power generation.
- Increased local production and regional economic development through employment and provision of services and infrastructure to the project.
- The establishment of a regional community benefit fund equivalent to five per cent of the royalty payment made to the NSW Government within the future production licence area. If matched by the NSW Government, the fund could reach $120 million over the next two decades.

1.2 Description of the project

The project would involve the construction and operation of a range of exploration and production activities and infrastructure including the continued use of some existing infrastructure. The key components of the project are presented in **Table 1**, and are shown on **Figure 1**.

Table 1: Key project components

Location	Infrastructure element
Major facilities	
Leewood	• a central gas processing facility for the compression, dehydration and treatment of gas to commercial specifications • a central water management facility including storage and treatment of produced water and brine • optional power generation for the project • a safety flare • treated water management infrastructure to facilitate the transfer of treated water for irrigation, dust suppression, construction and drilling activities • other supporting infrastructure including storage and utility buildings, staff amenities, equipment shelters, car parking, and diesel and chemical storage • continued use of existing facilities such as the brine and produced water ponds • operation of the facility
Bibblewindi	• in-field compression facility • a safety flare • supporting infrastructure including storage and utility areas, treated water holding tank, and a communications tower • upgrades and expansion to the staff amenities and car parking • produced water, brine and construction water storage, including recommissioning of two existing ponds • continued use of existing facilities such as the 5ML water balance tank • operation of the expanded facility
Bibblewindi to Leewood infrastructure corridor	• widening of the existing corridor to allow for construction and operation of an additional buried medium pressure gas pipeline, a water pipeline, underground (up to 132 kV) power, and buried communications transmission lines
Leewood to Wilga Park underground power line	• installation and operation of up to a 132kV underground power line within the existing gas pipeline easement
Gas field	
Gas exploration, appraisal and production infrastructure	• seismic geophysical survey • installation of up to 850 new wells on a maximum of 425 well pads: well types would include exploration, appraisal and production wells • installation of water and gas gathering lines and supporting infrastructure • construction of new access tracks where required • water balance tanks • communications towers • conversion of existing exploration and appraisal wells to production
Ancillary	• upgrades to intersections on the Newell Highway

Location	Infrastructure element
	• expansion of worker accommodation at Westport • a treated water pipeline and diffuser from Leewood to Bohena Creek o treated water irrigation infrastructure including: o pipeline(s) from Leewood to the irrigation area(s) • treated water storage dam(s) offsite from Leewood • operation of the irrigation scheme

The project is expected to generate approximately 1,300 jobs during the construction phase and sustain around 200 jobs during the operational phase; the latter excluding an ongoing drilling workforce comprising approximately 100 jobs.

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

1.3 Project location

The project would be located in north-western NSW, approximately 25 kilometres south-west of Narrabri, within the Narrabri local government area (LGA) (see Figure 1).

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

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

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

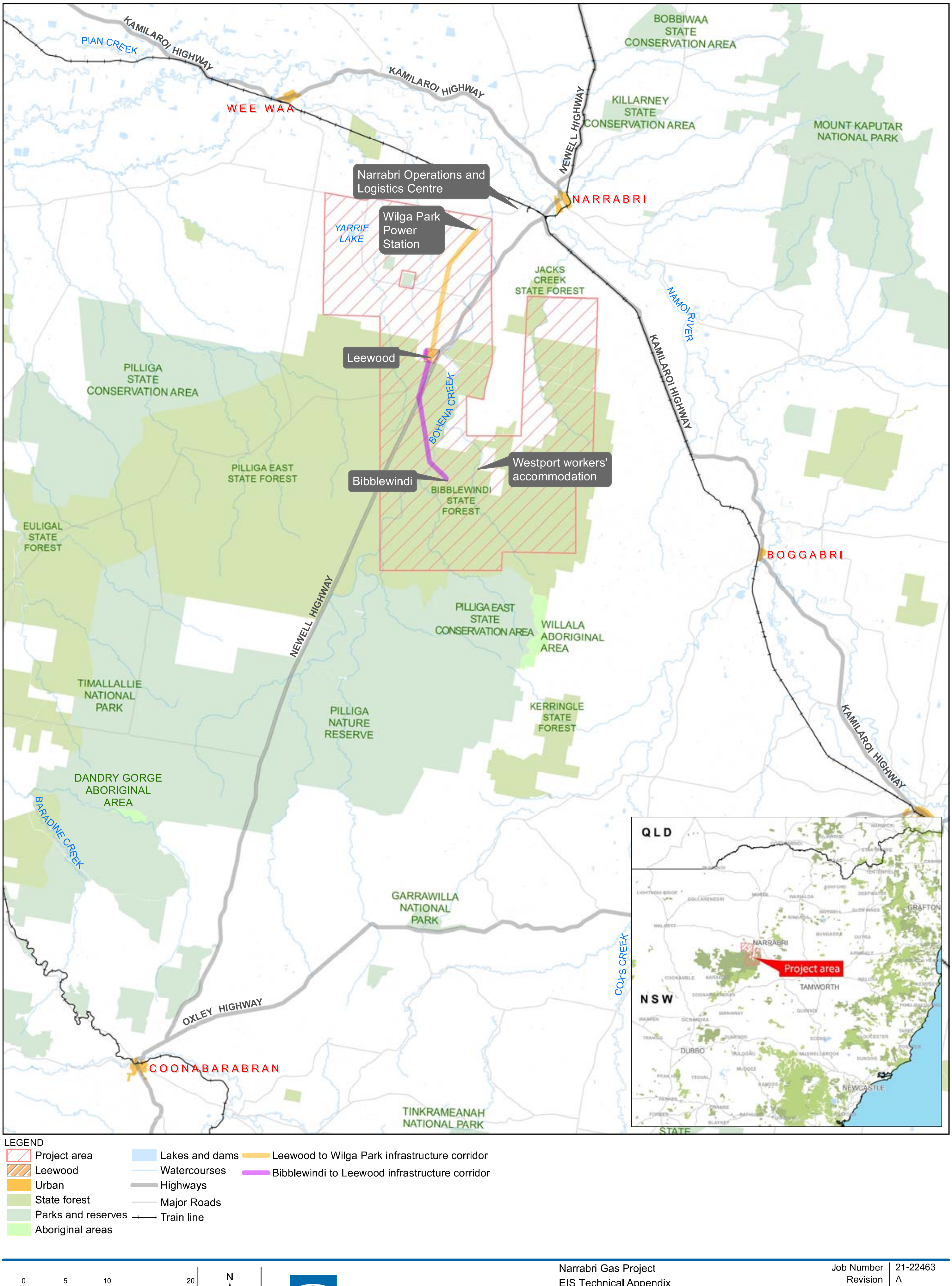
The ecology of the Pilliga has been fragmented and otherwise impacted by commercial timber harvesting and related activities over the last century through:

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

Within the Pilliga, the project would be developed in State forests identified as suitable for 'forestry, recreation and mineral extraction' under the NSW *Brigalow and Nandewar Community Conservation Area Act 2005*.

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

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



Narrabri Gas Project
EIS Technical Appendix

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context and location of key infrastructure

Figure 1

C:\Users\AFoddy\Desktop\21_22463_KBM29.mxd [KBM: 221]

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

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

1.4 Planning framework and structure of this report

1.4.1 Planning framework

The project is permissible with development consent under the NSW *State Environmental Planning Policy (Mining, Petroleum and Extractive Industries) 2007*, and is identified as 'State significant development' under section 89C (2) of the NSW *Environmental Planning and Assessment Act 1979* (EPA Act) and the NSW *State Environmental Planning Policy (State and Regional Development) 2011*.

The project is subject to the assessment and approval provisions of Division 4.1 of Part 4 of the EPA Act. The Minister for Planning is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Secretary of the Department of Planning and Environment or to any other public authority.

The project is also a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The project was declared to be a controlled action on 5 December 2014, to be assessed under the bilateral agreement between the Commonwealth and NSW Governments, and triggering the following controlling provisions:

- listed threatened species and ecological communities
- a water resource, in relation to coal seam gas development and large coal mining development
- Commonwealth land.

This aquatic ecology and stygofauna assessment identifies the potential environmental issues associated with construction and operation of the project and addresses the Secretary's environmental assessment requirements for the project. The assessment will be used to support the Environmental Impact Statement (EIS) for the project. The requirements addressed in this report include:

- Document threatened freshwater and riparian species, endangered populations and ecological communities as listed under the FM Act, the NSW *Threatened Species Conservation Act 1995* (TSC Act), and the EPBC Act, and their habitats, which are known or considered likely to occur in the study area.
- Obtain database records of freshwater and riparian flora and fauna species to identify the potential occurrence of threatened and endangered species.
- Provide baseline ecological data to a standard that can be used to predict and assess the significance of impacts of the project on flora and fauna of conservation significance as provided by the statutory requirements of the relevant legislation.
- Conduct targeted surveys of aquatic flora and fauna species and communities (including macroinvertebrates, fish and stygofauna) in the study area.
- Investigate and describe the vegetation associations, aquatic habitats and species occurring in the study area.
- Define the risks associated with the project on freshwater flora and fauna species and communities, including any key threatening processes.
- Develop appropriate mitigation and monitoring measures to be incorporated into the construction and operational phases of the project to minimise and monitor impacts.

1.4.2 Structure of report

The report is structured as follows:

- **Chapter 1 – Introduction -** This chapter introduces the project and the proponent and describes the project area.
- **Chapter 2 – Study area and assessment methods -** This chapter defines the study area assessed in this report and describes the steps undertaken in the assessment.
- **Chapter 3 – Legislative context -** This chapter outlines the relevant Commonwealth and State legislation relating to the assessment. Any guidelines and assessment criteria (where applicable) relevant to the gas field construction, operation and decommissioning are also identified.
- **Chapter 4 – Existing environment -** This chapter describes the existing environmental values of the study area relevant to aquatic ecosystems; including the results of desktop assessments and field investigations. Results from the field assessments are displayed as separate sections, with the mid-Namoi Catchment Regional surveys presented ahead of the Bohena Creek and Namoi surveys that concentrated on the potential impacts of the Leewood discharge.
- **Chapter 5 – Project water management** - This chapter outlines the plan for the managed release of treated water from the Leewood treatment facility.
- **Chapter 6 – Impact assessment -** This chapter examines the potential environmental impacts associated with the construction and operation of the project.
- **Chapter 7 – Mitigation measures.** This chapter outlines the proposed mitigation strategies to be implemented during the life of the project to manage the potential environmental impacts.
- **Chapter 8 – Conclusion.** This chapter presents a conclusion to the report and presents suggested next steps in the advancement of the project.

2 Study area and assessment methods

2.1 Study area

2.1.1 Catchment summary

Bohena Creek is a sand-bed intermittent stream that flows northward through the eastern Pilliga Forest. The creek typically experiences surface flow if rainfall exceeds 100 to 110 mm per month, which results in flow approximately 15% of the time. During dry periods, the water table is an estimated 2 m below the creek bed (AGE 2006). Bohena Creek joins the Namoi River at Mollee W

eir, just upstream of the Narrabri Creek confluence.

The Namoi River is a major tributary of the Murray-Darling river system. It flows west from the foothills of the Great Dividing Range near Tamworth to join the Barwon River at Walgett. The river splits into two anabranches prior to reaching Narrabri, with Narrabri Creek as the northern channel receiving a greater proportion of flow than the Namoi River anabranch to the south. The two channels converge again upstream of Mollee Weir west of town. Mollee Weir is a small weir approximately 20 km west of Narrabri. The weir is 5 m high, 60 m wide and has a storage capacity of 3,300 ML.

2.1.2 Site selection and survey timing

This aquatic ecology survey was conducted across two spatial scales. To gather background data at and around the potential discharge reach, survey sites were established in Bohena Creek and in the Namoi around the confluence. These surveys are referred to as the 'Bohena Creek study' and also included a stygofauna component, used to assess whether there were likely to be any groundwater invertebrates impacted by the managed release. To gain an understanding of the regional condition of aquatic ecosystems, a broader survey program was established with 19 sites on Namoi River and tributaries. These surveys are referred to as the mid-Namoi catchment assessment. Below is a brief summary of the aquatic surveys by AUSRIVAS-defined seasons.

Examples of sites types are shown in **Figure 2**. **Figure 3** and **Figure 4** show the location of sites for each survey component. Hydrographs showing flow at gauging stations in the waterways included in the aquatic ecology assessment are provided in **Figure 5** and **Figure 6**. Summaries of site location, survey methods, survey timing, are given in **Table 2**, **Table 3** and **Table 4**, while photographs of all sites are included in **Appendix A**.

2.1.2.1 Mid-Namoi catchment assessment

Spring 2013: 28 October – 1 November 2013

Twelve ephemeral sites and six regulated sites were sampled during spring 2013. The survey period for this study coincided with a peak release for the water year from Keepit Dam, resulting in high water levels at the regulated sites (Narrabri Creek 7529 and 7531, Namoi River 7533 and 7538, and Pian Creek 7534). Sites were sampled for macroinvertebrates using AUSRIVAS protocol, riparian condition, and physico-chemistry.

Autumn 2014: 5-8 May 2014

Thirteen sites on ephemeral streams, and six sites on the regulated Namoi River were sampled. Water level and discharge at all waterways in the study area are affected by rainfall events; however, the regulated sites are also affected throughout the year by environmental and regulated releases from Keepit Dam. The purpose of water released from Keepit Dam is for irrigation, and water is stored at Mollee and Gunidgera Weirs. Sites were sampled for macroinvertebrates using AUSRIVAS protocol, riparian condition, and physico-chemistry.

Spring 2014: 18-21 October 2014

Fourteen sites on ephemeral streams and five sites on the regulated Namoi River and Narrabri Creek were visited during this survey. Only thirteen sites had sufficient water for sampling during spring 2014. Of these, eight of the ephemeral sites were isolated pools, while the five permanent sites were connected with continuous flow. Sites were sampled for macroinvertebrates using AUSRIVAS protocol, riparian condition, and physico-chemistry.

2.1.2.2 Bohena Creek study

Survey dates, and the type of sampling conducted at each site are summarised in **Table 3**. The program initially included four sites along Bohena Creek and three along Namoi River/ Bohena Creek, but another three sites were added in autumn 2014 because some of the initial sites began to dry out with progressing drought. These sites (Teds Hole, BCS02, BCS07 and BCS09) retain water longer, and were selected to provide an aquatic assessment of waterholes with varying levels of permanence along Bohena Creek.

Autumn 2013: 12-14 March

Sites were selected in March 2013 when continuous creek flow in Bohena Creek had ceased and surface water was expressed as a series of isolated pools. The managed release point is proposed for a section of Bohena Creek east of the Pilliga No. 2 Rest area. Sampling sites were selected approximately 0.2 and 2.7 km downstream (BCD and BCDS respectively), and 0.2 and 3.1 km upstream (BCUSD and BCUS respectively) of this point. Namoi River sites were selected at Mollee Weir, 400 m downstream from the Bohena Creek confluence (site code MW), as well as 4.7 km upstream in Narrabri Creek (NCUS) and 3.6 km downstream in the Namoi River (NRDS, **Figure 3**). All sites were assigned a number and a site code (**Table 3**). These site codes are used throughout this report as they more intuitively describe the purpose and location of the site.

Samples for stygofauna assessment were collected from monitoring bores at ‘Leewood’, the proposed site of the Leewood WMF. Seven monitoring bores exist on the property, but only two bores had water in them at the time of sampling. The two bores sampled penetrated the saturated sediment of the lower colluvium, which consisted of sandy clay.

Spring 2013: 21 and 25 October 2013, 3-5 December 2013

By December, three of the Bohena Creek sites had become dry: BCDS, BCD, and BCUS. Drying is a natural part of Bohena Creek flow regime, and the ecological communities along the creek possess life history strategies that are adapted to this. From the sites sampled in March, only BCUSD had sufficient water remaining in its isolated pool for a sample to be collected. This waterhole had receded to a shallow pool approximately 40 m long, 7 m wide and 0.3 m deep. As an alternative to BCDS, samples were collected from Teds Hole, a more permanent waterhole along Bohena Creek. Teds Hole was sampled on 21 October 2013 and is approximately 1.7 km downstream of the proposed release location.

Samples for stygofauna assessment were collected on 25 October 2013 from three monitoring bores installed in the bed of Bohena Creek.

Autumn 2014: 6 May, 3-6 June, 29-31 July 2014

Additional sites in the Bohena Creek sub-catchment were added to the sampling program for autumn 2014, to provide extra ecological information for Bohena Creek. These sites (BCS02, BCS07 and BCS09,

Figure 3) are permanent waterholes and were selected to provide an aquatic assessment of waterholes with varying levels of permanence along Bohena Creek.

For the autumn 2014 sampling round, three of the original Bohena Creek sites did not have water (Sites BCDS, BCD and BCUS). To provide a consistent riparian assessment across all sites, a riparian ecological assessment was still conducted at these sites. An aquatic assessment (water quality, macroinvertebrates and fish) was only conducted at the sites that held water: three sites along the Namoi River/ Narrabri Creek and the five along Bohena Creek. Although site BCUSD had sufficient water for this round, and was sampled, it was less than 15 cm deep and likely to be dry soon after sampling

From 29 to 31 July 2014, samples for stygofauna assessment were collected from two monitoring bores at Leewood WMF, three monitoring bores in the Bohena Creek Alluvium within Bohena Creek and five shallow pits dug in the bed of Bohena Creek. Additionally, water from four production bores was passed through a sampling sieve to determine whether stygofauna were present in the deeper aquifers.

Spring 2014: 20-21 October 2014

Three sites were sampled on the Namoi River and Narrabri Creek, and eight along Bohena Creek. For the spring 2014 sampling round BCDS, BCD, BCUS, and BCUSD were dry or had insufficient water for sampling. To provide a consistent riparian assessment across all sites, a riparian ecological assessment was still conducted at these sites. An aquatic assessment (water quality, macroinvertebrates and fish) was only conducted at the sites that held water: three sites along the Namoi River/ Narrabri Creek and the five along Bohena Creek.

2.1.3 Site hydrology

2.1.3.1 Bohena Creek study

Bohena Creek is an intermittent waterway, with a highly variable flow regime. Most of the creek is dry for extended periods, although there are deeper pools interspersed along the creek that contain water for longer periods of time, potentially permanently. Annual rainfall in the region averages 600-700 mm, and mostly occurs in summer (NSW Department of Primary Industries, 2011). Rainfall runoff modelling indicates Bohena Creek flows when rainfall in the local catchment exceeds 100-110 mm in a given month, achieving maximum flows of 100 ML/day approximately 15% of the time.

At the time of site selection in March 2013, surface flow in Bohena Creek had ceased and surface water was restricted to isolated pools. In December, flow had receded even further and there were fewer expressions of surface water. A single flow gauging station exists on Bohena Creek, but appears to be no longer working. The station, operated by the Department of Primary Industries - Water (DPI Water), is located at the Bohena Creek Newell Highway bridge. The Namoi River and Narrabri Creek were once also likely to be intermittent and experience periods of no flow. However, they now flow permanently, due to regulated water releases from the upstream Keepit Dam. River heights along the Namoi River and Narrabri Creek for 2013 and 2014 are shown in **Figure 5**.

Figure 2: Examples of stream types sampled during this assessment.

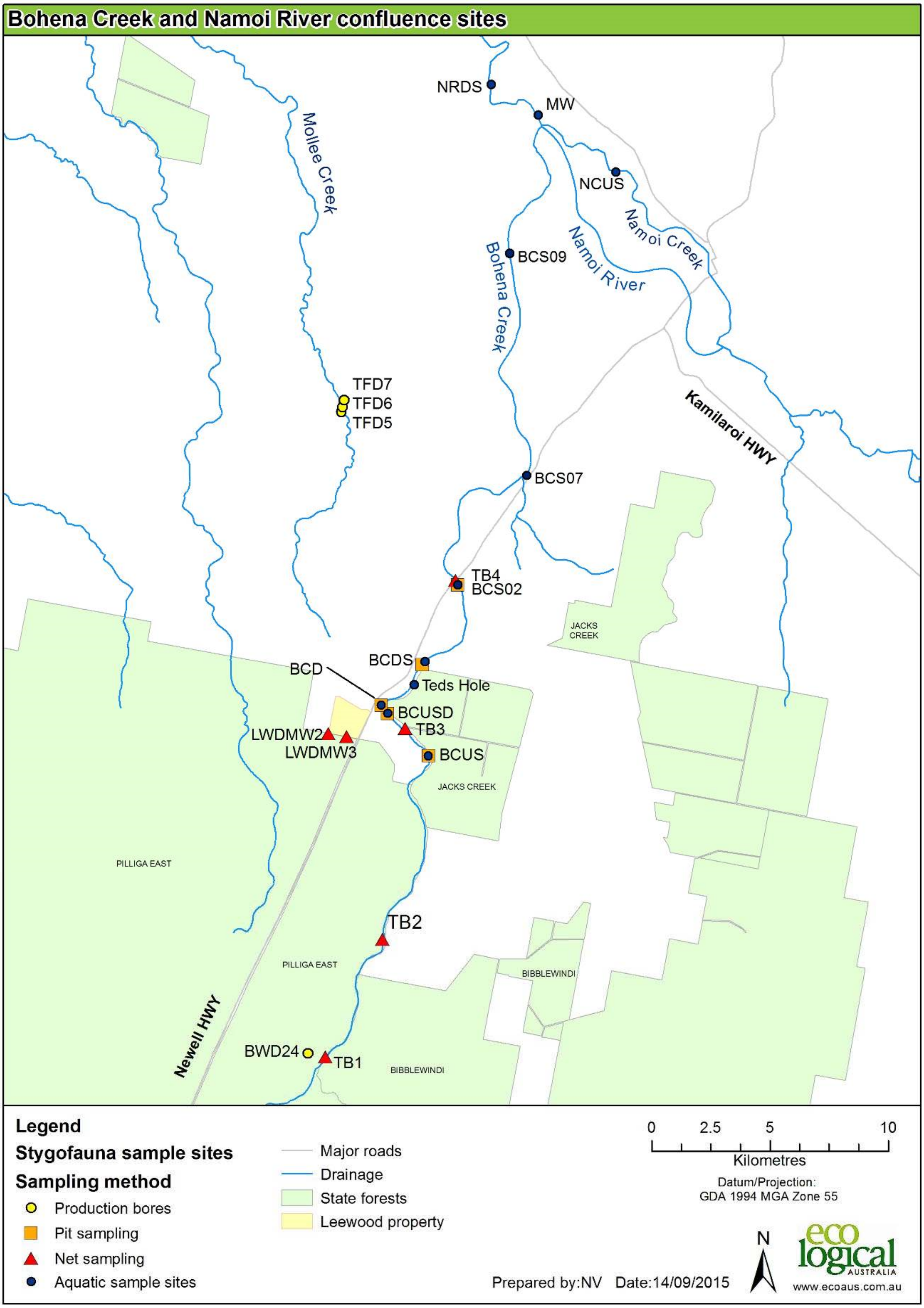


Figure 3: Aquatic ecology survey site locations for the Bohena Creek Study.

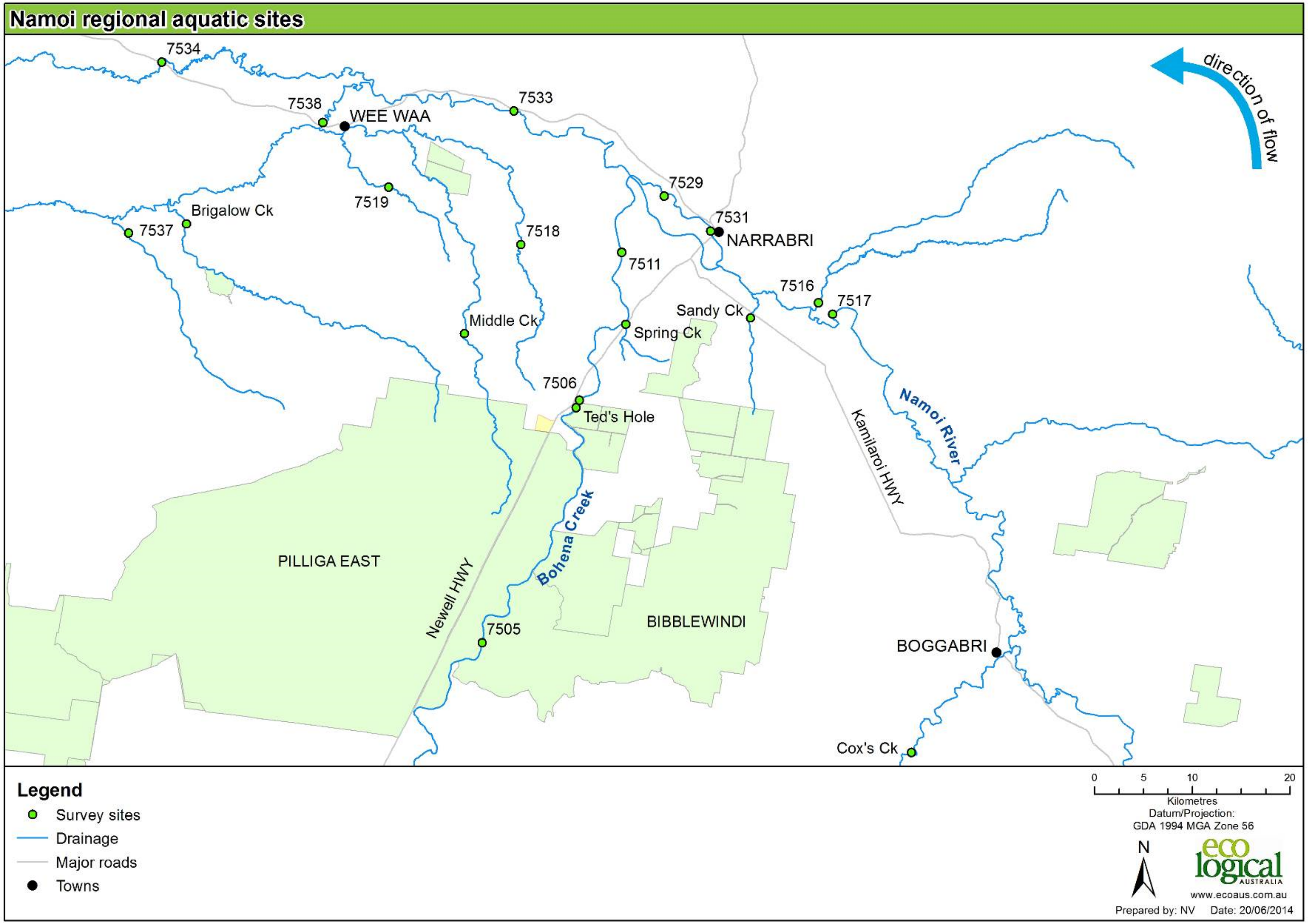


Figure 4: Location of Mid-Namoi regional assessment sites

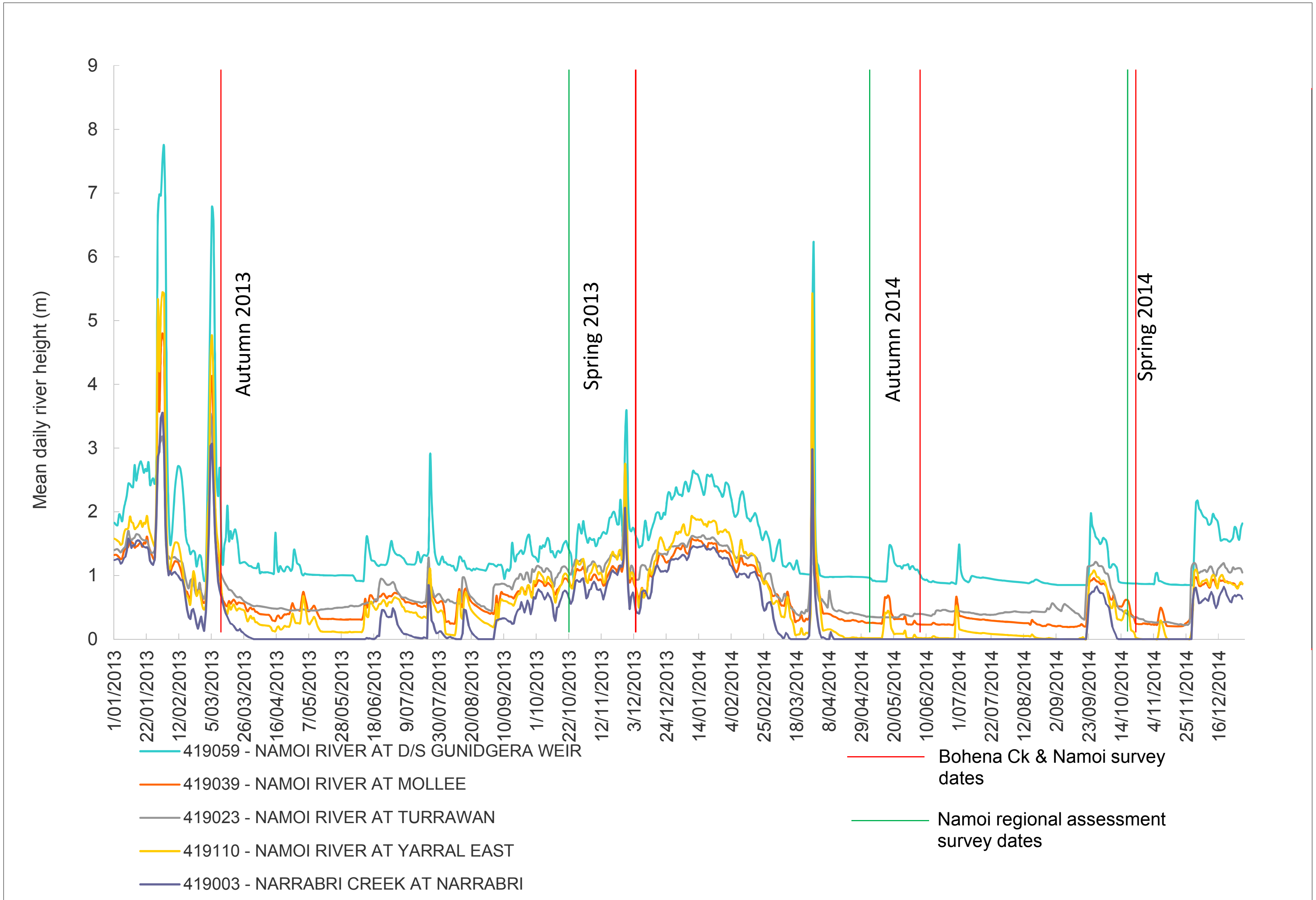


Figure 5: River height data in Namoi River and Narrabri Creek in 2013 to 2014.

2.1.3.2 Mid-Namoi Catchment assessment

Fourteen sites on ephemeral streams and five sites on the regulated Namoi River and Narrabri Creek were visited during this survey. Not all ephemeral sites had water for every survey period but the five permanent sites were connected with continuous flow. Water level and discharge at all waterways in the study area are affected by rainfall events; however the regulated sites are also affected throughout the year by environmental and regulated releases from Keepit Dam. The purpose of water released from Keepit Dam is for irrigation, and water is stored at Mollee and Gunidgera Weirs. Flow in Pian Creek comes from cotton irrigation channels and storage dams, and the creek was flowing at the time of sampling in spring 2014.

Of the 15 ephemeral sites, gauging station data were available for three (Brigalow Creek, Pian Creek and Cox's Creek; **Table 2**). River height data is displayed on **Figure 6** for the gauging stations indicated in **Table 2**. The volume and timing of flow at these sites is relatively natural and is characterised by long periods of no flow. For all three survey periods, water in Bohena Creek was restricted to isolated pools. At Brigalow Creek and Cox's Creek, water was also restricted to pools. The pool at Cox's Creek was approximately 20 m long and occurred in a depression beneath a road bridge. The Brigalow Creek pool was much larger, extending at least 200 m upstream from the sample location.

Mean water level at the gauging stations along the Namoi River and Narrabri Creek are shown in **Figure 5**. Flow peaked in January 2013, with occasional spikes in water level in other months. Most of the unregulated creeks did not experience this increase in water level, which was caused by managed releases from Keepit Dam.

Table 2: Sites of the mid-Namoi catchment assessment.

MM	Zone	Easting	Northing	Stream	Nearest Gauging Station	Spring 2013	Autumn 2014	Spring 2014
7505	55J	746152	6600825	Bohena Creek	No station	RCE	RCE	RCE
7506	55J	755352	6625016	Bohena Creek	No station	RCE	RCE	RCE
7511	55J	759353	6640524	Bohena Creek	No station	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7516	55J	776734	6634477	Bullawa Creek	No station	RCE	RCE	RCE
7517	55J	777667	6633344	Namoi River	Namoi R @ Turrawan (419023)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7518	55J	749972	6641781	Nuable Creek	No station	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7519	55J	738552	6647583	Illaroo Creek	No station	RCE	AUSRIVAS and RCE	RCE
7529	55J	763544	6645899	Narrabri Creek	Narrabri Ck @ Narrabri (419003)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7531 (NCUS)	55J	763276	6646058	Narrabri Creek	Narrabri Ck @ Narrabri (419003)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7533	55J	750277	6655086	Namoi River	Namoi R @ Yarral East (419110)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7534	55J	718590	6660200	Pian Creek	Pian Ck @ Cubbaroo (419088)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7537	55J	715373	6643629	Werah Creek	No station	RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
7538	55J	732921	6654359	Namoi River	Namoi R @ D/S Gunidgera (419059)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE

MM	Zone	Easting	Northing	Stream	Nearest Gauging Station	Spring 2013	Autumn 2014	Spring 2014
Brigalow Creek	55J	721143	6643513	Brigalow Creek	Brigalow Ck @ Tharlane (419083)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
Cox's Creek	55J	783227	6588814	Cox's Creek	Cox's Ck @ Boggabri (419032)	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
Middle Creek	55J	744939	6631912	Middle Creek	No station	AUSRIVAS and RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
Sandy Creek	55J	770938	6633538	Sandy Creek	No station	RCE	AUSRIVAS and RCE	RCE
Spring Creek	55J	759378	6632686	Spring Creek	No station	RCE	AUSRIVAS and RCE	AUSRIVAS and RCE
Teds Hole (TH)	55J	754812	6624514	Bohena Creek	Bohena @ Newell (419905)	N/A	AUSRIVAS and RCE	AUSRIVAS and RCE

(Including survey methods and sampling season; and the names of upstream dams, weirs and gauging stations)

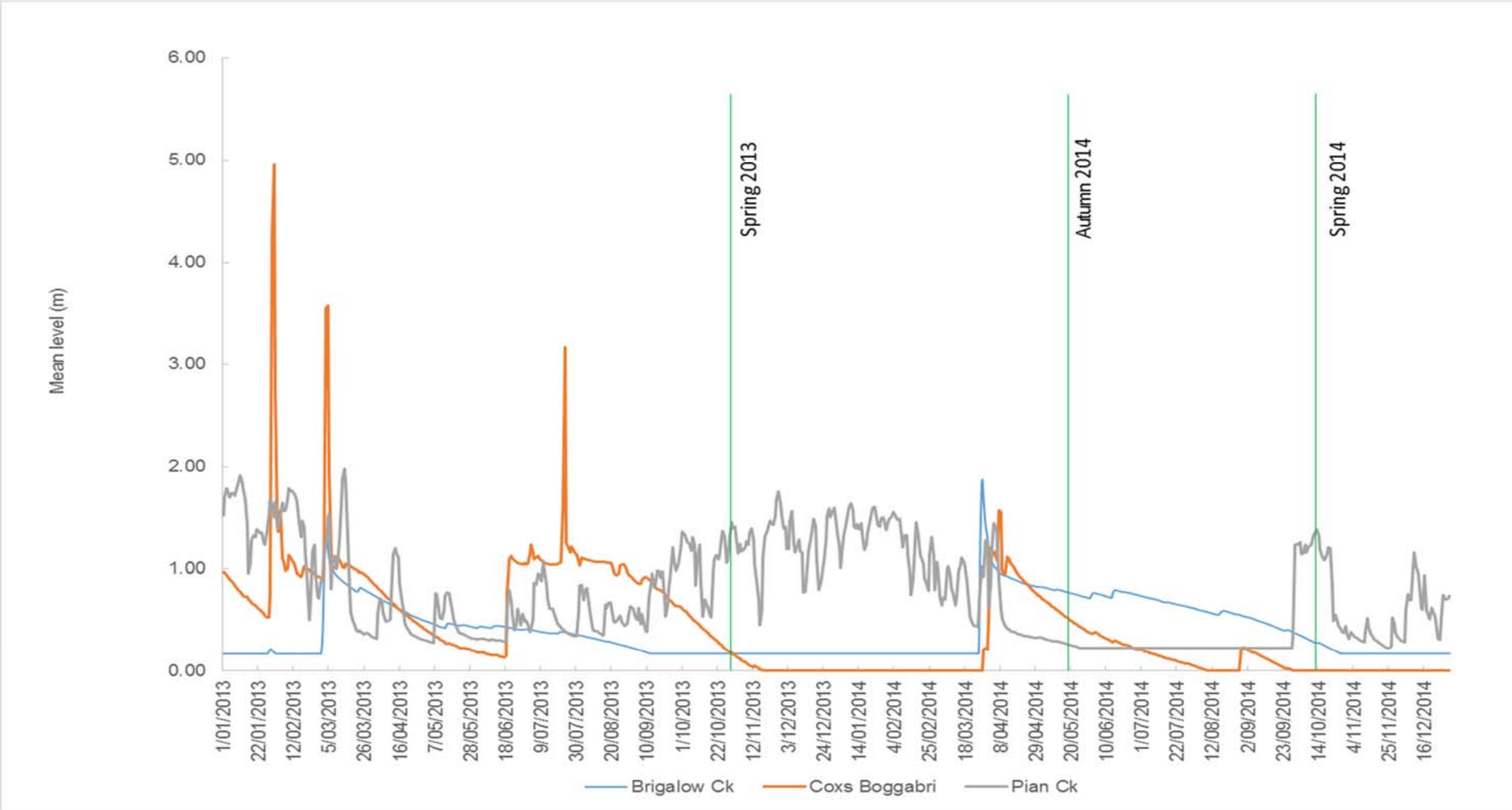


Figure 6: River height at three gauging stations on three ephemeral creeks.

Green lines indicate survey dates.

Table 3: Survey types and sampling seasons for sites in the Bohena Creek study.

Site Code	Site Descriptor	Location			Season Sampled				Survey Type				
		Zone	Easting	Northing	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Riparian assessment	Water Quality	Aquatic Habitat	Invertebrates	Fish
BCUS	Bohena Creek downstream	55J	755344	6621355	X	X			X	X			
BCUSD	Bohena Creek upstream of release site	55J	753607	6623137	X	X	X		X	X	X	X	X
BCD	Bohena Creek at release site	55J	753346	6623477	X	X			X	X			
TH	Teds Hole	55J	754812	6624514		X	X	X	X	X	X	X	X
BCDS	Bohena Creek at downstream	55J	755075	6625198	X	X			X				
BCS02	Bohena Creek upstream of Newell Highway	55J	756584	6628578			X	X	X	X	X	X	X
BCS07	North of Cains Crossing Road	55J	759497	6633206			X	X	X	X	X	X	X
BCS09	Upstream of Culgoora Road	55J	758775	6642601			X	X	X	X	X	X	X
NCUS	Narrabri Creek upstream of Bohena Creek confluence	55J	763276	6646058	X	X	X	X	X	X	X	X	X
MW	Namoi River near confluence	55J	759992	6648463	X	X	X	X	X	X	X	X	X

Site Code	Site Descriptor	Location			Season Sampled				Survey Type				
		Zone	Easting	Northing	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014	Riparian assessment	Water Quality	Aquatic Habitat	Invertebrates	Fish
NRDS	Namoi River downstream of confluence	55J	758000	6649750	X	X	X	X	X	X	X	X	X

Table 4: Stygofauna sampling sites and the dates of sampling

Site Code	Site Descriptor	Location			Season Sampled			
		Zone	Easting	Northing	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014
BCUS	Bohena Creek downstream	55J	755344	6621355			X	
BCUSD	Bohena Creek upstream of release site	55J	753607	6623137			X	
BCD	Bohena Creek at release site	55J	753346	6623477			X	
TH	Teds Hole	55J	754812	6624514			x	
BCDS	Bohena Creek at downstream	55J	755075	6625198			X	
MW3D	Stygofauna site 1 - Leewood colluvium	55J	751877	6622157	X		X	

Site Code	Site Descriptor	Location			Season Sampled			
		Zone	Easting	Northing	Autumn 2013	Spring 2013	Autumn 2014	Spring 2014
MW2D	Stygofauna site 2 - Leewood colluvium	55J	751106	6611192	X		X	
TB1	Bohena Creek Stygofauna site 1	55J	750975	6608590		X	X	
TB2	Bohena Creek Stygofauna site 2	55J	753394	6613564		X	X	
TB3	Bohena Creek Stygofauna site 3	55J	754360	6622502		X	X	
TFD5	Black Jack Formation, Hosskissons Seam	55J	751654	6635898			X	
TFD6	Black Jack Formation, Hosskissons Seam	55J	751704	6636105			X	
TFD7	Black Jack Formation, Hosskissons Seam	55J	751774	6636393			X	
BWD24	Maules Creek Formation, Bohena Seam	55J	750230	6608726			X	

2.2 Literature and data review

Prior to conducting fieldwork, a review of relevant literature and data pertaining to the study sites and locality was undertaken. From the review a list of threatened flora and fauna species was compiled and assessed to determine the potential presence of threatened biota in the study area. The data sources used in this review included (but were not limited to) the following:

- NSW BioNet, Atlas of NSW Wildlife Database (NSW Office of Environment and Heritage)
- Fishing and Aquaculture Threatened and Protected Species records viewer (NSW Department of Primary Industries).
- Commonwealth Government Protected Matters Search Tool (http://www.environment.gov.au/epbc/pmst/).
- Records published in scientific journals, reports and general flora and fauna distribution texts.
- Results of local environmental studies, including studies prepared by consultants, local government authorities, biological organisations, universities and other sources.
- Anecdotal reports from local land holders, authorities and local ecologists / naturalists.
- Records of Threatened Species, Population and Ecological Communities of NSW.

2.3 Riparian habitat assessment

Riparian habitat was assessed at all sites for both the Bohena Creek study and the mid-Namoi catchment assessment. Riparian condition assessment was undertaken using a version of the Riparian, Channel and Environmental (RCE) inventory (Peterson 1992) that was modified for Australian conditions (Chessman *et al*. 1997). The modified RCE has 13 descriptors, each with a score from 1 to 4. Descriptors included width and condition of the riparian zone, surrounding land use, extent of bank erosion, stream width, water depth, occurrence of pools, riffles and runs, sub-stratum type, presence of snags and woody debris, in stream and emergent macrophytes, algae and barriers to fish passage. The total score for each site was then derived by summing the score for each descriptor and calculating the result as a percentage of the highest possible score.

Sites with a high RCE score (up to 52, or 100%) indicate that the riparian zone is unmodified by human activity, while those with a low score have undergone substantial modification. Based on the original classification established by Peterson (1992), site condition was rated as:

- poor for RCE scores of 0-24%
- fair for RCE scores of 25-43%
- good for RCE scores of 44-62%
- very good for RCE scores of 63-81%
- excellent for RCE scores of 82-100%

Each site was photographed and the GPS location recorded.

2.4 Aquatic habitat assessment

Aquatic habitat variables (environmental data) were assessed at all sites for both the Bohena Creek study and the mid-Namoi catchment assessment. Habitat features were recorded using AUSRIVAS datasheets at each sample site. Site and environmental characters included assessments of:

- general signs of disturbance

- habitat type
- channel topography
- current water level
- bank and bed slope
- degree of river shading
- amount of detritus
- macrophyte type and extent
- riparian zone width
- snags and large woody debris coverage
- stream width and depth
- surrounding land use
- description of the natural substrate
- extent of bank overhang
- amount of trailing bank vegetation.

Each site was photographed and the location recorded using a portable GPS device.

2.5 Water quality

Dissolved oxygen (DO), pH, electrical conductivity (EC), and temperature were measured at each site for both the Bohena Creek study and the mid-Namoi catchment assessment using a calibrated YSI-556 multi-parameter water meter. Turbidity measurements were taken with a Hach 2100Q Turbidimeter.

Water quality from the survey was compared with the ANZECC (2000) guidelines for protection of aquatic environments. The ANZECC (2000) guidelines provide different ranges for upland and lowland streams, with upland streams being those above 150 m AHD altitude. For the Murray-Darling Basin, an altitude of 250 m is a more appropriate trigger to distinguish between upland and lowland rivers (NSW Government 2006). All sites surveyed for this project were lower than 250 m AHD, so are considered as lowland river sites.

2.6 Macroinvertebrate communities

Macroinvertebrate communities were assessed for both the Bohena Creek study and the mid-Namoi Catchment Assessment. The area at each site selected for macroinvertebrate sampling was determined as either a 100 m length or 10 times the width, depending on whichever was greater. At each site, macroinvertebrates were collected from edge habitats. Edge habitats were defined as the creek bank in areas of little or no flow, including alcoves and backwaters, with abundant leaf litter, fine sediment deposits, macrophyte beds and overhanging bank vegetation (Turak *et al*. 2004). Edge samples were collected from 10 m of representative edge habitats using a standard AUSRIVAS kick net with 250 μm mesh. The net was bounced along the bottom to disturb resting invertebrates, and then rapidly passed again through the water column to collect them.

Macroinvertebrate samples were live-sorted in the field for a minimum of 40 minutes. If new taxa were collected in the period 30 to 40 minutes, picking continued for 10 minutes. If no new taxa were found after the additional 10 minutes, sorting stopped. If new taxa were found, picking continued for a further 10 minutes. The maximum sorting time was 60 minutes. All picked animals were preserved in ethanol and transferred to the laboratory for identification. Specific care was taken to ensure cryptic, fast moving or microcrustacean taxa were represented. Picked specimens were placed in jars, preserved in 70 per cent ethanol solution and transported to the laboratory.

Macroinvertebrates were identified to the family level, except for Chironomidae which was identified to subfamily as required by the AUSRIVAS model, and Oligochaeta and Acarina, which were identified to order.

The AUSRIVAS program uses mathematical models to compare observed macroinvertebrate taxa against a modelled reference condition. These comparisons provide a measure of biological impairment. Predictor variables (including physical habitat variables, latitude, longitude, altitude, slope and distance from source) are used to model the predicted reference condition for each sampling site. Latitude, longitude, altitude, slope and distance from source were determined from 1:25,000 topographic maps. Physical habitat variables were qualitatively assessed or directly measured at each site.

The AUSRIVAS model software outputs specify the 'Observed' (macroinvertebrates collected during sampling) to 'Expected Ratios' (macroinvertebrates which are predicted to occur in reference conditions). Both measures relate to macroinvertebrates that have a predicted probability greater than 50 per cent of occurring at the site if it is in reference condition. The 'Observed' value is the number of these macroinvertebrate families that are actually collected at the site. Each observed family contributes a score of 1 to the 'Observed' value. The 'Expected' value is the sum of the probabilities for all taxa that are predicted to occur at that site with a probability greater than 50 per cent. Families that have a 50 per cent probability of occurring at the site contribute a score of 0.5 to the 'Expected' value, while families that have a 90 per cent probability of occurrence contribute a score of 0.9. An Observed to Expected ratio (O/E50 score) close to 1 indicates that the macroinvertebrate fauna are similar to those of the modelled reference condition. A ratio close to zero indicates severe impairment compared to reference condition. Based upon these O/E50 scores, a band ranking indicating the ecological health of the river can be assigned (**Table 5**).

The AUSRIVAS software also calculates the expected (under reference condition) and actual (observed) SIGNAL (Stream Invertebrate Grade Number-Average Level) scores for each site. SIGNAL is a biotic index that allocates a value to each macroinvertebrate family based upon their sensitivity to pollution. A macroinvertebrate family with a value of 10 indicates high sensitivity, while a value of 1 indicates high pollution tolerance (Chessman 1995). The SIGNAL score for the entire site is calculated by summing the SIGNAL grades for each family collected at that site and then dividing by the total number of families collected. SIGNAL scores are used to grade water quality into the following categories:

- Signal Score > 6: Healthy Habitat
- Signal Score 5-6: Mild Pollution
- Signal Score 4-5: Moderate Pollution
- Signal Score <4: Severe Pollution

Table 5: Explanation of the O/E50 AUSRIVAS scores and bands

Band	O/E50 upper limit for edge samples		Band Description
	Autumn	Spring	
X	Infinite	Infinite	Macroinvertebrate assemblage is more biologically diverse than reference sites
A	1.195	1.182	Site is in reference condition with most/all of the expected families found
B	0.83	0.814	Site is significantly impaired, indicating a potential impact either on water quality and/or habitat quality which has resulted in a loss of taxa
C	0.464	0.501	Site is severely impaired; indicating a loss of biodiversity due to substantial impacts on water and/or habitat quality
D	0.098	0.16	Site is extremely impaired; few expected taxa remain, indicating extremely poor water and/or habitat quality resulting in a highly degraded waterway

2.7 Fish surveys

Fish surveys were only included in the Bohena Creek study. At each site along the Namoi River/Narrabri Creek, six bait traps (three baited and three unbaited, 45 × 25 × 25 cm with 25 mm diameter opening) and two fyke nets (5 m wing, 60 cm diameter, 19 mm mesh) were set overnight. Where possible, traps were set near stands of emergent vegetation, areas with submerged vegetation, or snag piles, as these areas are likely to support a greater diversity and abundance of small-bodied fish. The tail end of each fyke net was attached to a star picket so that it was 30 to 40 cm above the water (**Plate 1**). This was to allow access to air for bycatch such as turtles and water rats. Fish captured during macroinvertebrate sampling were also identified and are included in the survey results.

From December 2013, sites were also sampled with a Seine net. A 10 m long net of 1 cm mesh net was dragged through the water at each site. Any fish collected were stored in plastic tubs of water, identified, counted, and released immediately.

Plate 1: Fyke net set at Narrabri Creek upstream site.

2.8 Stygofauna

Three different methods were used to sample for stygofauna. To sample monitoring bores, a weighted net with 50 µm mesh was used. This was lowered to the bottom of each bore and raised slowly through the entire water column 6 times to collect fauna. For production bores, 60 L of water was extracted through a bleed valve into buckets, then poured through a 50 µm mesh sieve. For sites on Bohena Creek where no bores were available, pits were dug down to the water table, and 10 to 50 L of water was filtered through a 50 µm mesh sieve. In all cases, net or sieve contents were preserved in a jar of 100% ethanol. Samples were analysed under a microscope and any stygofauna present were identified as far as possible using available taxonomic keys and expertise.

2.9 Riparian vegetation

Riparian floristic community was sampled only during March 2013 for four sites on Bohena Creek and three along the Namoi/Narrabri Creek. At each site a monitoring plot was positioned on the banks of the relevant watercourse and surveyed in accordance with the Biobanking Assessment Methodology (BBAM) outlined in Seidel and Briggs (2008). Plots were located as close the water's edge as possible, to include any riparian vegetation. In some cases on Bohena Creek this meant that some or all of plots were located on the sandy stream bed where riparian and other vegetation occurred next to the water body.

Data collected in monitoring plots focussed on measuring species diversity, condition, and structure within plots, and the overall distribution of vegetation types present. Survey data was recorded on field data sheets from a series of 20 x 20 m plots (0.04 ha) and 50 m line transects as shown in **Figure 7**. The geographic location of the plot was recorded with a hand-held GPS unit at the start of each transect and recorded on the data sheet for the site.

Data collected included quantitative data for native species richness; native versus exotic species cover; hollow bearing trees; over-storey regeneration; and length of fallen logs in accordance with the BBAM. Native canopy and mid-storey cover were visually estimated at 10 points along the 50 m line transect and divided by 10 to provide an estimated projected foliage cover for the plot. The projected foliage cover (%) of ground covers (native grasses, shrubs, other and exotic species) was calculated by recording their presence/absence at 50 points along the 50 m line transect and dividing the total number of hits by 50.

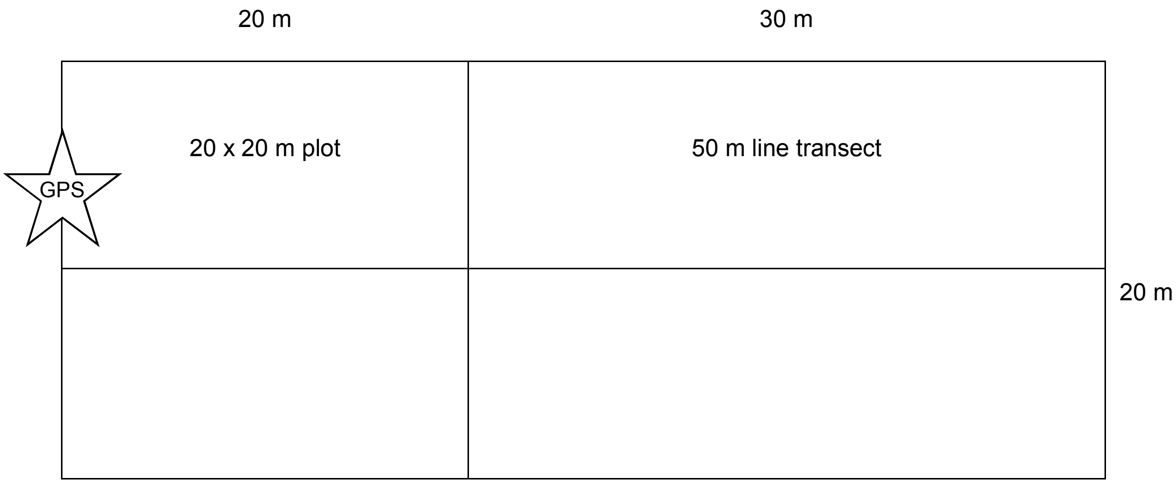


Figure 7: Biobanking plot layout used during vegetation surveys

Plot data was categorised into BioMetric vegetation types according to the Vegetation Types Database (October 2008, OEH 2013a), compared against the Vegetation Type Benchmarks (OEH 2013b), and then scored using the matrix in **Appendix B** (Seidel and Briggs 2008) to develop an accurate and repeatable condition score for each plot. Note that Biometric Vegetation Types for the Namoi CMA were updated in October 2015. The vegetation type classification and assessment contained in this report was undertaken in accordance with the Biometric Vegetation Types October 2008.

The plot data for each site attribute was compared against the relevant benchmark for the vegetation type using the BioMetric tool (out of a maximum 100 points). Site condition was categorised as:

- **low** if scored between 0 and 16;
- **low to moderate** if between 17 and 33;
- **moderate**, if between 34 and 50;
- **moderate to high** if between 51 and 67;
- **high** if between 68 and 84; or
- **very high** if between 85 and 100.

3 Legislative context

This assessment was undertaken in accordance with relevant legislation as summarised in **Table 6**.

Table 6: Legislation relevant to this assessment.

Legislation	Summary
EPBC Act	The primary objective of the EPBC Act is to 'provide for the protection of the environment, especially those aspects of the environment that are Matters of National Environmental Significance.' Environmental approvals under the EPBC Act are required for an 'action' that is likely to have a significant impact on matters of national environmental significance (MNES) including: • World Heritage Areas • National Heritage Places • Ramsar wetlands of international importance • Nationally listed threatened species and ecological communities • Listed migratory species • Commonwealth marine areas • Nuclear actions • Great Barrier Reef Marine Park • A water source, in relation to coal seam gas and large coal mining development. In addition, the EPBC Act confers jurisdiction over actions that have a significant impact on the environment: • Where the actions affect, or are taken on, Commonwealth land. • Which are carried out by a Commonwealth agency (even if that significant impact is not on one of the nine matters of 'national environmental significance'). An 'action' is considered to include a project, development, undertaking, activity or series of activities. The project was referred to the Commonwealth Department of the Environment on 3 November 2014 (2014/7376). The project was determined a 'controlled action' on 1 December 2014 due to potential impacts on listed threatened species and communities, a water resource, in relation to coal seam gas development and large coal mining development and commonwealth land. Assessment of the project has been delegated to the State under the assessment bilateral agreement with the NSW Government.
NSW *Environmental Planning and Assessment Act 1979* (EPA Act)	The EPA Act is the principal planning legislation for NSW. It provides a framework for land use control and assessment, determination and management of development. The project is being assessed under Division 4.1 of Part 4 of the EPA Act. The Minister for Planning is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Secretary of the Department of Planning and Environment or to any other public authority.
NSW Groundwater Dependent	The *NSW Groundwater Dependent Ecosystems Policy 2002* is designed to protect ecosystems which rely on groundwater for survival, and the ecological processes and biodiversity associated with them. The policy applies the following principles:

Legislation	Summary
Ecosystem Policy	• The scientific, ecological, aesthetic and economic values of Groundwater Dependant Ecosystems (GDEs), and how threats to them may be avoided, should be identified and action taken to ensure that the most vulnerable and the most valuable ecosystems are protected. • Groundwater extractions should be managed within the sustainable yield of aquifer systems, so that the ecological processes and biodiversity of their dependent ecosystems are maintained and/or restored. Management may involve establishment of threshold levels that are critical for ecosystem health, and controls on extraction in the proximity of GDEs. • Priority should be given to ensure that sufficient groundwater of suitable quality is available at the times when it is needed: o For protecting ecosystems which are known to be, or are most likely to be, groundwater dependent. o For GDEs which are under an immediate or high degree of threat from groundwater-related activities. • Where scientific knowledge is lacking, the Precautionary Principle should be applied to protect GDEs. The development of adaptive management systems and research to improve understanding of these ecosystems is essential to their management. • Planning, approval and management of developments and land-use activities should aim to minimise adverse impacts on GDEs by: o Maintaining, where possible, natural patterns of groundwater flow and not disrupting groundwater levels that are critical for ecosystems. o Not polluting or causing adverse changes in groundwater quality. o Rehabilitating groundwater systems where practical.

4 Existing environment

4.1 Threatened species searches

4.1.1 Endangered Ecological Communities

The database and literature search revealed the presence of fifteen endangered ecological plant communities in the Namoi River catchment (**Table 7**). None of these were considered likely to occur in the study area; however some are likely to occur in adjoining areas (e.g. floodplains).

Table 7: Endangered ecological communities in the Namoi River catchment.

Name	TSC Act	EPBC Act	Likelihood of Occurring in the Study Area
Artesian Springs Ecological Community	E3	E	Unlikely
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregions	E3	E	Unlikely
Cadellia pentastylis (Ooline) community in the Nandewar and Brigalow Belt South Bioregions	E3		Unlikely
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions	E3		Unlikely
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions	E3		Unlikely
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion	E3	E	Unlikely
Fuzzy Box Woodland on Alluvial Soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South Bioregions	E3		Unlikely
Howell Shrublands in the New England Tableland and Nandewar Bioregions	E3		Unlikely
Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South Bioregions	E3	E	Unlikely
Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes bioregions	E3	E	Unlikely
Native Vegetation on Cracking Clay Soils of the Liverpool Plains	E3	CE	Unlikely
New England Peppermint (*Eucalyptus nova-anglica*) Woodland on Basalts and Sediments in the New England Tableland Bioregion	E3	CE	Unlikely

Name	TSC Act	EPBC Act	Likelihood of Occurring in the Study Area
Ribbon Gum-Mountain Gum-Snow Gum Grassy Forest/Woodland of the New England Tableland Bioregion	E3		Unlikely
Semi-evergreen Vine Thicket in the Brigalow Belt South and Nandewar Bioregions	E3	E	Unlikely
White Box Yellow Box Blakely's Red Gum Woodland	E3	CE	Unlikely

E= Endangered
E3= Endangered Community
CE= Critically Endangered

4.1.2 Threatened plant species

Searches of online databases and literature revealed the potential for 22 threatened plant species to occur within a 10 km radius of the Namoi River and Bohena Creek study area (**Table 8**). Habitat preferences for each species are included in **Appendix D.**

Table 8: Threatened plant species known or predicted to occur in the study area.

Common Name	Scientific Name	Status		Likelihood of Occurring In The Study Area
		TSC Act	EPBC Act	
Coolabah Bertya	*Bertya opponens*	V	V	No
Lobed Bluegrass	***Bothriochloa biloba***		**V**	**Potential on adjoining floodplains**
Ooline	*Cadellia pentastylis*	V	V	Unlikely
	Cyperus conicus	E1		Unlikely
Bluegrass	*Dichanthium setosum*	V	V	Unlikely
Finger Panic Grass	***Digitaria porrecta***	**E1**	**E**	**Potential on adjoining floodplains**
Pine Donkey Orchid	*Diuris tricolor*	V		Unlikely
Square Raspwort	***Haloragis exalata* subsp. *exalata***	**V**	**V**	**Potential on adjoining banks and floodplains**
Belson's Panic	*Homopholis belsonii*	E1	V	Unlikely
Spiny Peppercress	*Lepidium aschersonii*	V	V	Unlikely
Winged Peppercress	***Lepidium monoplocoides***	**E1**	**E**	**Potential on adjoining floodplains**
Large-leafed Monotaxis	*Monotaxis macrophylla*	E1		Unlikely
	Philotheca ericifolia		V	Unlikely
Native Milkwort	*Polygala linariifolia*	E1		Unlikely

Common Name	Scientific Name	Status		Likelihood of Occurring In The Study Area
		TSC Act	EPBC Act	
Scant Pomaderris	*Pomaderris queenslandica*	E1		Unlikely
Greenhood Orchid	*Pterostylis cobarensis*	V		Unlikely
	Rulingia procumbens	V	V	Unlikely
Shrub Sida	***Sida rohlenae***	**E1**		**Potential on adjoining banks and floodplains**
Velvet Thread-petal	*Stenopetalum velutinum*	E4		Unlikely
Slender Darling Pea	***Swainsona murrayana***	**V**	**V**	**Potential on adjoining floodplains**
Austral Toadflax	*Thesium australe*	V	V	Unlikely
	Tylophora linearis	V	E	Unlikely

V= Vulnerable

E= Endangered

E1= Endangered

E4 = Extinct

A search of the National Parks and Wildlife Service (NPWS) Wildlife Online database and review of the species risk assessment found no aquatic plant species of conservation significance were previously known from the study area.

4.1.3 Threatened animal species

On the basis of regional records, the literature review and the presence of suitable habitat, a total of nine threatened fauna species are known to occur or predicted to potentially occur in the study area (**Table 9**). The predicted presence is based on the known geographical distribution, preferred habitats for each species and the corresponding habitats in the study area.

Bidyanus bidyanus (Silver Perch), *Maccullochella peelii peelii* (Murray Cod) and *Tandanus tandanus* (Eel-tailed Catfish) are expected to be present, while *Notopala sublineata* (River Snail) may occur. *Elseya belli* (Bell's Turtle), *Litoria booroolongensis* (Booroolong Frog), *Litoria daviesae* (Davies' Tree Frog), *Crinia sloanei* (Sloanes Froglet), and *Adelotus brevis* (Tusked Frog) are considered unlikely to occur in the study area.

Table 9: Threatened riparian and aquatic animals in the Namoi River catchment.

Common name	Scientific name	Status			Habitat description	Likelihood of occurring in the study area
		EPBC Act	FM Act	TSC Act		
INVERTEBRATES						
River Snail	*Notopala sublineata*	-	E	-	Flowing rivers, found attached to logs and rocks, or crawling in the mud (NSW DPI 2007). River Snail was once common and widespread in the Murray-Darling river system, but has undergone a rapid decline such that it is now considered virtually extinct in their natural range (NSW DPI 2007). Remaining populations appear restricted to artificial habitats (e.g. irrigation pipelines) in the Murray and Darling systems.	Potential – there are records for the species at Namoi River near Mollee Weir. *Last record 2007 or earlier.*
FISHES						
Murray-Darling Basin population of Eel-tailed Catfish	*Tandanus tandanus*	-	E	-	A relatively sedentary species of slow-flowing streams and lake habitats. Widespread throughout the Murray-Darling Basin, but generally in the lower, slow-flowing rivers (Lintermans 2007).	Likely- Known to occur in the Namoi River downstream and upstream of the Mollee Weir. *Last record was 2009.*
Silver Perch	*Bidyanus bidyanus*	CE	V	-	Fast-flowing, open waters in lowland, turbid and slow-flowing rivers (Lintermans 2007). Originally present throughout most of the Murray-Darling drainage system, except upper reaches, they have now declined to low numbers or disappeared from most of their former range (NSW DPI 2005).	Potential - Known to occur in the Namoi River downstream and upstream of Mollee Weir. *Last record was 2005.*
Murray Cod	*Maccullochella peelii peelii*	V	-	-	A wide range of warm water habitats, ranging from clear, rocky streams to slow-flowing turbid rivers and billabongs in the Murray-Darling Basin (Allen et al 2003). Favours deeper water around boulders, logs, undercut	Potential - Known to occur in the Namoi River downstream and upstream of Mollee Weir.

Common name	Scientific name	Status			Habitat description	Likelihood of occurring in the study area
		EPBC Act	FM Act	TSC Act		
					banks and overhanging vegetation (Allen *et al.* 2003).	
REPTILES						
Bell's Turtle	*Elseya belli*	V	-	V	Narrow sections of rivers in granite country, in shallow pools in upper reaches or small tributaries of major rivers. The pools are typically less than 3 m deep, where there is a sandy or rocky substrate, and patches of macrophytes (NSW OEH 2012a). Known only from the headwaters of the Namoi and Gwydir Rivers, NSW.	Unlikely – the study site is a lowland stream and river, away from the known distribution for the species.
AMPHIBIANS						
Booroolong Frog	*Litoria booroolongensis*	E		E1	Permanent streams with fringing vegetation cover such as ferns, sedges or grasses. Adults occur on or near cobble banks and other rock structures along the stream (NSW OEH 2012b). Typically inhabits rocky western-flowing creeks and their headwaters, although a small number of animals have also been recorded in eastern-flowing streams (NSW OEH 2012b).	Unlikely – Bohena Creek is intermittent, and Namoi River habitat in the study area does not meet habitat requirements. *Last record was 2009.*
Davies' Tree Frog	*Litoria daviesae*			V	All records for the species are from permanently flowing streams and adjacent riparian vegetation at elevations above 400 m. Its habitat is restricted to the region from Carrai Plateau to the Barrington Tops area of the Great Divide (NSW OEH 2012c).	Unlikely – the study sites are below 400 m elevation, in the lowland reaches of the Namoi River.
Sloane's Froglet	*Crinia sloanei*			V	Breeding habitat is ephemeral areas in grassland, woodland and disturbed habitats. Foraging habitat is areas adjacent to breeding habitat, in natural or	Unlikely – the species is known to occur in the Pilliga Outwash, outside the project area, but

Common name	Scientific name	Status			Habitat description	Likelihood of occurring in the study area
		EPBC Act	FM Act	TSC Act		
					highly modified environments (NSW OEH 2012d). It occurs in suitable habitat in floodplains throughout the Murray-Darling Basin.	the last record for the species in the Namoi River catchment is from 1996.
POPULATIONS						
Tusked Frog *Adelotus brevis* Population in the Nandewar and New England Tableland Bioregions				E2	Rainforests, wet forests, flooded grassland and pasture, usually near creeks, ditches and ponds hidden amongst vegetation or debris (NSW OEH 2012e). The species was once found throughout the New England Tableland and North West Slopes, but has declined throughout this area, and is now considered very rare in the region (NSW OEH 2012e).	Unlikely – the study sites are in lowland areas, outside of the predicted and known distribution of the species in the region.

CE = Critically Endangered

E= Endangered

E1= Endangered

E2= Endangered population

V= Vulnerable

There were no records for threatened aquatic species in Bohena Creek, reflecting the ephemeral nature of the creek and the limited aquatic habitat available for freshwater fauna.

4.2 Field survey results for the mid-Namoi catchment

4.2.1 Aquatic habitat assessment

Water level at all sites varied throughout this assessment. In the regulated sites, water level fluctuated through releases from Keepit Dam that variably exposed and inundated lateral gravel bars and standing dead timber. Ephemeral sites were generally drying out during the two years of the survey, so the amount of aquatic habitat generally declined with the contraction of waterhole size. Habitat characteristics of the ephemeral and permanent sites remained relatively consistent throughout this assessment. Ephemeral sites generally contained large woody debris with leaf litter and other organic debris. Macrophyte beds were present at most ephemeral sites.

Habitat present at each site is summarised in **Table 10**. Site photographs are shown in **Appendix A**.

Table 10: Habitat assessment for sites in the mid-Namoi Catchment Assessment.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
7505	Bohena Creek	Pilliga State Forest at Garlands Crossing	Ephemeral	25	Low energy stream with long shallow pools and runs when flowing. Banks and substrate are comprised of sand. Bench on both sides of stream, with billabong behind them. Banks stable and vegetated with no signs of erosion.	Excellent aquatic macroinvertebrate and fish habitat when flowing. Some large woody debris instream.	Dominant riparian species is River Red Gum and Box Gum. *Eleocharis* sp. (Spike Rush) is scattered along the substrate and along the banks.	This section of stream is relatively undisturbed with riparian strip contiguous with upland vegetation. It is in Pilliga State Forest.
7506	Bohena Creek	Northern section of Jacks Creek State Forest	Ephemeral	21	Low energy stream with long shallow pools and runs when flowing. Banks and substrate are comprised of sand. Banks stable and vegetated with no signs of erosion.	Excellent aquatic macroinvertebrate and fish habitat when flowing. Some large woody debris instream.	Dominant riparian species are Cypress Pine and River Red Gum with occasional Currajong. Spike rush and *Brachiaria* sp. (Para Grass) present on substrate and banks.	Dryland agriculture.
7511	Bohena Creek	Yarrie Lake Road	Ephemeral	2	Straight, incised channel with flow constricted to shallow, isolated pools. Substrate primarily comprised of sand (80-90 %), with remainder being gravel, pebbles and cobbles. Abundant	Phragmites provides habitat for aquatic macroinvertebrates and fish when stream is flowing.	Dominant riparian tree species is River Red Gum. Site has dense patches of Phragmites within the stream and on the banks.	Dryland agriculture.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
					Fine Particulate Organic Matter (FPOM).			
7516	Bullawa Creek	Old Gunnedah Road	Ephemeral	28	Banks are eroded and undercut at parts. Sand deposition from the bridge to approximately 30 m upstream, substrate then changes to being cobble dominant with a large cobble bar causing the channel to narrow. Site highly susceptible to erosion during high energy flows.	Habitat available in form of large woody debris, undercut banks and the interstices of the cobble substrate.	Dominant riparian tree species is River Red Gum. Weeds present throughout substrate and on banks.	Dryland agriculture.
7517	Namoi River	Tarriaro Reserve by Old Gunnedah Road	Regulated	13	Site is an anabranch of the Namoi River and comprised of runs and pools. One small section of riffle, but this may be bigger at lower flow. Substrate is comprised of sand, gravel and pebbles. The bank is eroded in parts, and susceptible to erosion during periods of high-flow due to absence of	Habitat includes large woody debris, backwater created by mid-stream bar, and substrate interstices.	Willows grow on the mid-stream bar. Occasional Casuarina and River Red Gums on banks. Sparse *Phragmites* sp. and *Paspalum* sp. on the stream edge.	Dryland agriculture.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
					trees and shrubs. There is patchy ground cover.			
7518	Nuable Creek	Yarrie Lake Road	Ephemeral	4	Incised channel, which when flowing would be primarily comprised of runs. Substrate is largely comprised of sand (85 %) with the remainder being clay and silt.	Habitat includes large woody debris and Coarse Particulate Organic Matter (CPOM).	Dominant riparian tree species is River Red Gum. Groundcover is primarily exotic. *Cyperus* sp. and Spike Rush fringe the stream bank.	Dryland agriculture.
7519	Illaroo Creek	Yarrie Lake Road	Ephemeral	4	The stream is shallow and splits in two on both sides of the road. Substrate is covered with a silt crust.	Habitat available at macrophyte beds on bends where water shallows and slows. Some large woody debris and CPOM.	Dominant tree species are isolated, mature Box Gum and Wilga, with juvenile trees scattered throughout. *Typha* sp. occur in shallower parts of the channel.	Dryland agriculture.
7529	Narrabri Creek	Kamilaroi Hwy	Regulated	45	Site is a Travelling Stock Route in poor condition. Banks are bare and slumping on both sides. Sand and gravel dominate the substrate. Site has litter and evidence of fires from recreational use.	With the exception of some large woody debris, there is very little habitat for macroinvertebrates.	Mature River Red Gums are the dominant riparian tree species. Willows are also present.	Dryland agriculture.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
7531	Narrabri Creek	Narrabri	Regulated	40	The site is a pool and run sequence with one area of riffle and a small backwater. The substrate is mostly sand (70 %) with the remaining fraction comprised of cobbles and gravel.	Habitat is provided by fringing grassy vegetation, undercut banks, some large woody debris and the interstices between the cobbles.	Riparian tree species are a mix of Eucalypts and some Casuarinas on the left bank, with no trees on the right bank. Small patches of Phragmites and Spike Rush occur on the right bank.	Urban development. Two storm-water outlets drain into the creek and a carpark and recreational park are on the right bank.
7533	Namoi River	Cotton Research Station Kamilaroi Hwy	Regulated	35	Site is a Travelling Stock Route. Banks are bare and steep in places. Susceptible to erosion during times of high flow. Substrate is predominantly sand (90 %), with gravel and pebbles making up the remaining fraction.	Limited habitat availability; however, large woody debris from fallen River Red Gums provide some habitat.	Dominant riparian tree species is River Red Gum, although some appear to be suffering from die-back. Willows also occur on site. A mixture of native and exotic species are present as groundcover. Spike Rush and Phragmites occur in small patches along the banks.	Irrigated agriculture and grazing.
7534	Pian Creek	West of Merah North	Regulated	14	The site is a long straight section of the channel, comprised of a long run. Substrate was difficult to determine at the time of sampling due to high flow; likely to be	Limited habitat available provided by stands of macrophytes on shallow sections of stream and some large woody debris.	Dominant riparian tree species is River Red Gum and Weeping Myall, with occasional Willows. Some River Red Gums have experienced die-back.	Intensive agriculture.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
					comprised of sand and silt.		*Rumex* sp. and Spike Rush line the banks.	
7537	Werah Creek	Pilliga-Narrabri Road	Ephemeral	8	Substrate is comprised of mobile sand and sediments with areas of deposition and erosion.	Fringing Spike Rush, large woody debris and CPOM provide habitat during periods of flow.	Dominant riparian tree species is River Red Gum and Casuarina, with Acacia and Iron Bark also present. Spike Rush fringes most sections of the stream.	Dryland agriculture.
7538	Namoi River	Tulledunna Bridge at Wee Waa	Regulated	20	This site has steep, almost vertical banks with erosion occurring on banks near rail bridge. There is a fine layer of silt/black mud covering a predominantly sandy substrate.	Abundant large woody debris in-stream and against rail bridge.	Dominant tree species is River Red Gum and Acacia. Ground cover is comprised of a mix of natives and exotics. Phragmites and Spike Rush fringe the stream.	Irrigated agriculture.
Brigalow Creek	Brigalow Creek	Pilliga-Narrabri Road	Ephemeral	21	Incised channel with banks stabilised by rushes and tree roots. Depressions in the landscape adjacent to stream would fill during times of high flow and hold water. Substrate largely comprised of	Abundant large woody debris along length of stream, and stands of Phragmites provide habitat for fauna.	Dominant riparian tree species is River Red Gum. The groundcover is dominated by Spike Rush.	Irrigated agriculture.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
					sand, with flow restricted by road crossing.			
Cox's Creek	Cox's Creek	Grain Valley Road	Ephemeral	3	Erosion evident on bends, benches also present on bends. Stabilised by grass. Substrate is primarily comprised of silt and sand with some pebbles and gravel. Site affected by cattle grazing.	Limited habitat available, some scour pools and large woody debris around the base of bridge pylons.	Isolated River Red Gums are the only woody riparian vegetation. There is a mix of native and exotic ground cover species.	Dryland agriculture.
Middle Creek	Middle Creek	Yarrie Lake Road	Ephemeral	4	The substrate is comprised of mobile sand, with areas of erosion and deposition.	Abundant large woody debris, and Spike Rush and sedges on sand bars/bench provide habitat for fauna.	Dominant riparian tree species are River Red Gum, Cypress Pine, and Box Gum. Spike Rush dominates the ground layer.	Irrigated agriculture.
Sandy Creek	Sandy Creek	Newell Highway	Ephemeral	15	Shallow channel with gently sloping banks and numerous flood-runners. Sandy substrate.	Large amounts of large woody debris, stands of Spike Rush, CPOM and FPOM provide abundant habitat	Dominant riparian tree species is River Red Gum. Spike Rush dominates the ground layer.	Relatively natural.

Site	Stream name	Location	Flow	Stream width* (m)	Physical condition	Habitat availability	Vegetation	Adjacent land-use
						for frogs, fish and aquatic invertebrates when wet.		
Spring Creek	Spring Creek	Narrabri/Jacks Creek Road	Ephemeral	2	Natural, incised channel and extensive swamp area between Spring Creek and Bohena Creek. Substrate comprised of mobile sand. Banks stabilised by Spike Rush.	Abundant large woody debris and CPOM, and Spike Rush fringing the stream provide habitat for fauna.	Dominant riparian tree species are Box Gum, River Red Gum and Acacia, with Cypress Pine dominant beyond the riparian zone. Some die-back is occurring. Spike Rush dominates the ground layer.	Relatively natural.
Teds Hole	Bohena Creek	Northern section of Jacks Creek State Forest	Permanent waterhole on Bohena Creek	10	Banks and substrate are comprised of sand. Banks stable and vegetated with no signs of erosion.	Some large woody debris and CPOM.	Dominant riparian species are Cypress Pine and River Red Gum. Spike rush and *Lomadra* sp. present on banks.	This section of stream is relatively unidisturbed with riparian strip contiguous with upland vegetation. It is located within the Jacks Creek State Forest.

4.2.2 Riparian habitat assessment

Riparian and channel environment (RCE) score varied little through time at each sites (**Table 11**). RCE scores were between 56% (Cox's Creek) and 83% (Teds Hole) over the three seasons surveyed. Of the sites surveyed 15.8% had riparian habitat that was in Good condition, 78.9% were in very good condition.

Except for site 7529, RCE scores generally increased with distance downstream in the Namoi River, indicating an improvement in riparian habitat (**Table 11**). The sites that scored well were characterised by more intact and wider riparian zones, more stream detritus and vegetation within 10 m of the channel, and less bank undercutting in comparison to sites with relatively low scores. The sites with the most degraded riparian zones and channels were Cox's Creek, site 7517 on the Namoi River, and sites 7529 and 7531 on Narrabri Creek. These sites were characterised by little or no riparian vegetation, undercut and/or eroding banks, and were all adjacent to agricultural land. There was little change in RCE scores between sampling periods, with slight fluctuations in scores attributed to parameters that have relatively rapid ecological responses such as ground cover, and macrophyte and algal cover.

Table 11: RCE scores for each site in the mid-Namoi catchment assessment.

Site	Spring 2013	Autumn 2014	Spring 2014
7505	77	77	77
7506	73	73	73
7511	69	67	69
7516	67	67	67
7517	58	58	58
7518	67	67	73
7519	67	67	67
7529	60	60	60
7531 (NCUS)	63	63	63
7533	73	73	73
7534	73	75	81
7537	77	73	69
7538	73	71	73
Brigalow Creek	77	75	77
Cox's Creek	56	56	56
Middle Creek	75	77	73
Sandy Creek	79	79	82
Spring Creek	73	71	73
Teds Hole (TH)	n/a	83	83

Shading indicates riparian condition – pale green= good, mid-green= very good, dark green= excellent

4.2.3 Water quality

Water at all sites fell outside the ANZECC range for at least one variable (**Table 12**). Turbidity and DO were the main variables where measurements were outside the recommended guideline range. Turbidity was consistently too high for four ephemeral sites. Only Cox's Creek and site 7531 at Narrabri Creek had turbidity that was inside the ANZECC range for all sampling seasons (**Table 12**). DO concentration was below the recommended minimum ANZECC level on 30 occasions and above the maximum on seven occasions (**Table 12**).

Temperature was between 10 and 27.04ºC across all sites (**Table 12**). Temperature followed seasonal trends, and was more stable through time in the Namoi River and Narrabri Creek than in the ephemeral streams.

EC was within the recommended ANZECC range for all sites, although temporarily fell below the minimum at Nuable Creek and Middle Creek in autumn, and at Spring Creek in spring (**Table 12**). In the regulated Namoi system, EC was between 219 and 823 µS/cm, with higher readings at periods of low flow. Of the ephemeral sites, all except the site on Cox's Creek were below 544 µS/cm. At Cox's Creek, EC was 1360 µS/cm in spring 2013 and fell to 384 µS/cm by spring 2014.

Generally, pH was compliant with the recommended ANZECC range at all sites, although there were five low measurements taken in autumn 2013 (**Table 12**). In spring 2014, pH was inside the ANZECC range at all sites. Throughout the surveys, pH was between 5.7 at site 7517 on the Namoi River, and 9.2 at the same site.

Alkalinity was between 23 and 431 ppm and was highest at Cox's Creek, with measurements of between 180 and 431 ppm (**Table 12**). Alkalinity at all other ephemeral sites was much lower. Bohena Creek sites had alkalinity between 42 and 132 ppm, while at other non-regulated sites it was between 23 to 116 ppm. Alkalinity was higher for the Namoi River and Narrabri Creek than at all ephemeral sites (except Cox's Creek), with measurements between 91 and 220 ppm (**Table 12**).

Table 12: Physico-chemical parameters measured at mid-Namoi Catchment sites.

Site		Parameter																					
		Temperature (°C)				Conductivity (µS/cm)				DO (% saturation)				pH				Turbidity (NTU)			Alkalinity (ppm)		
		Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14
ANZECC (2000) recommended range		n/a				125 -2200				85 - 110				6.5 - 8.5				6 - 50			n/a		
7511	Bohena Creek	12.3	16.3	18.7	24.9	223	438	445	408	93.3	61.5	57	167	6.2	7.4	6.4	7.2	101	104	73.8	132	119	98
7517	Namoi River	14.8	15.6	17.9	23.2	621	226	219	553	106	84.5	201	84.2	5.7	8.4	9.2	7.8	54.6	160	17.9	130	91	181
7518	Nuable Creek	13.2	12.1	16.2	18.1	57	276	97	135	75.9	41.7	102	89.6	6.1	7.4	7.4	7.2	125	116	315	116	29	45
7519	Illaroo Creek	13.3	n/a	18.2	n/a	181	n/a	190	n/a	84.8	n/a	89.7	n/a	6.3	n/a	7.3	n/a	n/a	71.6	n/a	n/a	83	n/a
7529	Narrabri Creek	17.5	16.3	15.4	n/a	627	332	457	n/a	74.7	73.9	110	n/a	8.1	8.6	8.3	n/a	58.6	12.5	n/a	129	173	n/a
7531	Narrabri Creek	16.1	14.9	16.1	24	823	327	588	570	100	63.7	133	102	7.1	8.5	8.2	7.6	47.6	11.7	23.8	129	220	182
7533	Namoi River	16.4	13.2	14.3	24.3	504	336	429	553	110	61.6	97.9	71.1	7.6	8.4	8.1	7.8	68.9	16.8	15.7	130	167	183
7534	Pian Creek	15.3	12.2	11.8	19	446	336	360	544	113	49.6	145	83.6	5.9	8.1	8.1	8.0	77.9	63.4	44.1	132	155	182
7537	Werah Creek	n/a	n/a	14.4	20.4	n/a	n/a	151	190	n/a	n/a	62.7	77.5	n/a	n/a	6.7	8.1	n/a	44.2	122	n/a	24	44
7538	Namoi River	15.7	12.9	13.8	18.6	481	346	292	557	101	49.6	121	91.8	7.4	9.1	8.3	8.2	43.3	51.4	35.2	131	116	183
Teds Hole	Bohena Creek	n/a	n/a	12.1	23.4	n/a	n/a	256	247	n/a	n/a	82.9	52.2	n/a	n/a	7.9	7.9	n/a	64.1	33.8	n/a	52	42
Brigalow Creek		n/a	11	20.2	24.1	n/a	339	138	175	n/a	46.7	75.4	64.6	n/a	7.3	7.1	7.6	131	58.7	150	37	33	34

Site	Parameter																					
	Temperature (°C)				Conductivity (µS/cm)				DO (% saturation)				pH				Turbidity (NTU)			Alkalinity (ppm)		
	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14
Cox's Creek	n/a	10	12.1	13	n/a	1360	430	384	n/a	30.1	51.9	43.7	n/a	5.4	7.5	7.7	19.1	19.4	25	431	195	180
Middle Creek	n/a	18.8	14.6	16	n/a	172	91	139	n/a	85.6	82.8	70.1	n/a	7.7	7.4	6.7	65.2	72.5	164	44	23	42
Sandy Creek	n/a	n/a	15.7	n/a	n/a	n/a	184	n/a	n/a	n/a	69.6	n/a	n/a	n/a	7.7	n/a	n/a	47.7	n/a	n/a	24	n/a
Spring Creek	n/a	14.6	14.2	27	n/a	114	142	121	n/a	41.4	109	46.3	n/a	7.0	8.4	8.2	97.3	40.1	359	28	37	26

Autumn 2013 data was provided by CH2M Hill. Data was not collected from sites that were dry when visited.

4.2.4 Macroinvertebrate assessment

Macroinvertebrates were collected from 16 sites, although not on every occasion because some sites were dry. Invertebrate diversity was poor at all sites, with only 4 – 22 families collected each survey period (**Table 13**). Diversity was highest in autumn 2014 at 11 sites. Diversity at Namoi River and Narrabri Creek sites was low, between 4 and 13. Illaroo and Cox's Creek had the highest diversity in autumn 2014, with 21 and 22 taxa. Middle Creek had 21 taxa in spring 2013, but that fell on subsequent survey periods.

Corixidae, Chironomidae and Baetidae were the only taxa to occur at all sites. These three taxa are generally widespread and tolerant of poor water quality and degraded aquatic habitats. Simuliidae and Caenidae only occurred in permanent sites along the Namoi River and Narrabri Creek.

SIGNAL scores below 4 indicate severe pollution, or poor condition. Scores between 4 and 5 indicate moderate pollution. Apart from four exceptions, the average SIGNAL score was consistently less than 4 at all sites and in every survey period (**Table 13**). SIGNAL scores were 4 or more at three sites in autumn 2014, and one site in spring 2013.

Not all sites fit within the guidelines for AUSRIVAS modelling. Two sites in spring 2013, eight in autumn 2014 Cox's Creek and Middle Creek were outside the model experience, and in spring 2014 site 7537 and Spring Creek were outside the model experience (**Table 13**). Most sites were in Band C or D (**Table 13**), which indicates severe impairment (C), with lost diversity from poor water or habitat quality, or extreme impairment (D), with few of the expected taxa remaining. Only on four occasions were sites in Band B (**Table 13**). These sites were still significantly impaired and the invertebrate diversity here is potentially impacted by poor water quality and habitat loss. Two sites were in Band B in spring 2013 (7533 and Brigalow Creek), and two sites in spring 2014 (7531 and Middle Creek, **Table 13**).

Table 13: Invertebrate community indices for mid-Namoi Catchment Assessment.

Site Code		Spring 2013				Autumn 2014				Spring 2014			
		SIGNAL	Taxa Richness	AUSRIVAS O/E50	AUSRIVAS Band	SIGNAL	Taxa Richness	AUSRIVAS O/E50	AUSRIVAS Band	SIGNAL	Taxa Richness	AUSRIVAS O/E50	AUSRIVAS Band
7511	Bohena Creek	3.8	13	0.18	D	3.2	14	0	D	2.89	9	0.27	C
7517	Namoi River	3.8	9	0.36	C	3.4	9	0.17	C	3.6	10	0.36	C
7518	Nuable Creek	4.2	6	0.18	D	3.7	15	OM	OM	2.77	13	0.36	C
7519	Illaroo Creek					3.5	21	OM	OM				
7529	Narrabri Creek	2.5	4	0.09	D	4	13	0.35	C	3.09	10	0.45	C
7531 (NCUS)	Narrabri Creek	3.7	6	0.27	C	3.5	13	0.26	C	3.5	12	0.55	B
7533	Namoi River	3.3	13	0.55	B	3.7	7	0	D	2.88	8	0.18	C
7534	Pian Creek	2.7	8	0.27	C	3.3	10	OM	OM	3.36	14	0.36	C
7537	Werah Creek					4.1	18	OM	OM	3.38	13	OM	OM
7538	Namoi River	3.5	12	0.36	C	3.5	12	0.26	C	3.55	11	0.36	C
Brigalow Creek		3.5	19	0.55	B	3.2	19	0.35	C	3	11	0.35	C

Site Code	Spring 2013				Autumn 2014				Spring 2014			
	SIGNAL	Taxa Richness	AUSRIVAS		SIGNAL	Taxa Richness	AUSRIVAS		SIGNAL	Taxa Richness	AUSRIVAS	
			O/E50	Band			O/E50	Band			O/E50	Band
Cox's Creek	3.6	15	OM	OM	3.7	22	OM	OM	2.71	14	0.45	C
Middle Creek	3.6	21	OM	OM	3.8	17	OM	OM	3.29	14	0.55	B
Sandy Creek					3.7	12	0.26	C				
Spring Creek	3.4	13	0.15	C	3.8	11	OM	OM	2.62	13	OM	OM
Teds Hole (TH)					4.3	13	OM	OM	2	6	0.18	C

C-D indicate AUSRIVAS Band, OM indicates that site was outside of the model experience.

4.3 Field survey results for the Bohena Creek study

4.3.1 Aquatic habitat assessment

Photos of each site are located in **Appendix A**, and a map showing site locations is in **Figure 3**.

4.3.1.1 Bohena Creek Upstream Reference Site (BCUS)

This site was only sampled in March 2013, when it was a shallow, isolated, 20 by 120 m pool. Habitat in the pool was provided by occasional woody debris, leaf packs, and fringing rushes. The bed was made completely of sand and had very little topographic variation. Most of the pool was up to 20 cm deep, although this increased to 40 cm near the middle. *Chelodina longicollis* (Eastern Longneck Turtle) was observed in the deepest part of this pool.

When re-visited in December 2013 all that remained of surface water was a puddle 2-3 cm deep and 25 cm diameter. This was not large enough to sample. The site was dry for subsequent visits.

4.3.1.2 Bohena Creek Upstream of Proposed Release Site (BCUSD)

This site consisted of an isolated pool approximately 120 m long and 3 to 9 m wide when first sampled in March 2013. Most of the pool was shallower than 20 cm, though it deepened to 60 cm near its upstream end where sampling occurred. By December 2013, the deepest part of the pool was 30 cm, and it had receded in size to 40 m by 8 m wide. *Phragmites australis* (Common Reed) grew densely along both banks and *Leptospermum polygalifolium* subsp. *transmontanum* (Tantoon) and *Eucaltypus blakelyi* (Blakely's Red Gum) dominated the middle and overstorey of the riparian zone.

The bed was dominated by sand with little topographic variation apart from near the right bank at the upstream (southern) end. Small packs of leaf litter and sticks were present in the deeper sections beneath the overhanging riparian vegetation. Iron flocs occurred in the far-upstream end of the pool where water was less than 3 cm deep.

The pool at this site was smaller in autumn 2014, and was dry in spring 2014.

4.3.1.3 Bohena Creek at Proposed Release Site (BCD)

The nearest pool to the proposed release site was a small body of water fringed with *Phragmites australis*. The pool was 4 m wide, 20 m long and 50 cm deep. There was little structure apart from *P. australis* and the water was turbid with iron flocs along the edges. The bed consisted entirely of sand. This site had relatively poor habitat for aquatic fauna, although there were large numbers of Plague Minnow, which were concentrated as the pool diminished and became a bigger threat to native species vulnerable to fin-pecking such as Spangled Perch.

When visited in December 2013, this site was dry and had been overgrown by *P. australis.* The site was dry for all subsequent surveys.

4.3.1.4 Teds Hole

Teds Hole is a deep pool on Bohena Creek and is accessed via McCanns Road. The pool is approximately 55 m by 7 m and has a maximum depth of 1.6 m. It retains water for long periods of time because of its likely link with alluvial groundwater. Banks are steep and drop 1.5 m to the water. Both ends of the pool are densely vegetated with *Juncus* sp., *Callistemon linearis* and *Leptospermum polygalifolium.* Water was turbid, and the pool had a low structural complexity, with only a few logs and woody debris. This pool is likely to be representative of more permanent waterholes that occur along the creek, and is a refuge for aquatic fauna when most of the creek is dry. The pool retained water for all subsequent survey periods

4.3.1.5 Bohena Creek Downstream of Proposed Release Site (BCDS)

This site is downstream of the McCanns Road crossing and in March consisted of a shallow pool 70 m long and 4 m wide. The left bank dropped steeply to the water, while the right bank sloped gently away from the water and was made of coarse sand. A small amount of riparian shading was provided by *Callitris glaucophylla* (White Cypress Pine) growing on top of the left bank. Sedges and young *P. australis* grow along the sandy bank and are densest at the upstream and downstream ends of the pool.

In December 2013, this pool was completely dry and it remained dry for 2014.

4.3.1.6 Bohena Creek Upstream of the Newell Highway (BCS002)

This site was sampled first in autumn 2014, when it was an isolated pool approximately 50 m long and 15 m wide. The pool had a sandy bottom covered with organic detritus, and was approximately 1.9 m deep. *Phragmites australis* grew around 85 % of the edge and there was no overhanging woody vegetation. There were occasional snags in the water to provide fish habitat.

The pool had contracted to approximately 40 m long when visited the second time in spring 2014.

4.3.1.7 Bohena Creek North of Cains Crossing Road (BCS007)

This site is accessed from the Newell Highway and was first sampled in autumn 2014. The site is a pool of water approximately 100 m long, 20 m wide, and 2 m deep. The pool had a sandy bed with detritus in some parts, and a sparse covering of coarse woody debris. Half of the pool was fringed by *Phragmites australis* and *Leptospermum polygalifolium* grew along the eastern shore. Water level dropped a further 50 cm in spring 2014.

4.3.1.8 Bohena Creek upstream of Culgoora Road (BCS09)

This was a shallow pool with a sand bed that extended 200 m along Bohena Creek. The pool was 20 m wide and fringed around 75% of the edge with *P. australis*. The pool is shallow for the southern half, then deepens to 1.6 m in the northern half. Occasional pieces of large woody debris lie in the water, providing habitat for fish.

4.3.1.9 Narrabri Creek upstream of Mollee Weir (NCUS)

This site is located on a Travelling Stock Reserve (TSR) and is used regularly by the public. During both sampling periods, this was evident by the amount of litter present on the bar. At this site, Narrabri Creek is approximately 100 m wide and flows westward around a broad bend. A large gravel and sand bar, 50 m wide, extends 450 m along the inside of the bend. Upstream of the gravel bar, large trees had fallen into the river near the northern bank and had created deep scour pools. The water had a high silt content and was very turbid. Mud was deposited on the upstream edge of the bar by flooding prior to sampling. Banks on both sides of the river showed evidence of recent erosion.

The most notable habitat structures present at the site were the fallen trees near the northern bank. The limbs, roots, and trunk of these provide solid structure and shelter for invertebrates and fish. They also contribute to changing the bed topography so that deeper pools are scoured. Riparian vegetation was sparse along the bank and absent from the bar, so the water was mostly unshaded.

No macrophyte communities were observed. Submerged plants may have been present but were not observed in the turbid water.

The river bed was loosely consolidated and dominated by gravel or sand. Fine sediments accumulated in the slower flowing areas along the bar and bank margins, and some of the sand and gravel appeared recently deposited. Upstream of the bar, the bed was muddy and had moderate packs of accumulated detritus. Beside the bar and downstream, the river bed was dominated by sand and gravel. A shallow backwater downstream was overhung with willows and provided calm, still refuge from the steadily flowing main channel.

4.3.1.10 Namoi River at Mollee Weir (MW)

The sampling site, on the north-eastern shore Mollee Weir, is downstream of the confluence of Bohena Creek, Namoi River, and Narrabri Creek, and 300 m upstream of the Mollee Weir wall. The weir created an essentially lentic environment for aquatic fauna. A mud bank, 1.8 m high, slopes steeply into the water, which is approximately 2 m deep only 5 m from the bank. The top of the bank was vegetated with grass. The bare bank indicated that there were rapid and frequent fluctuations in river level caused by water backing up from the weir.

The river bed consists of a layer of grey mud overlying sand, with little solid substrate apart from occasional woody debris and drowned standing trees. Fallen branches and eucalypt roots extend from the bank into the water, and at the downstream end of the study reach, *Salix babylonica* (Weeping Willow) trailed branches in the water. No aquatic vegetation was observed at the site, although the turbidity of the water may have prevented observation.

4.3.1.11 Namoi River Downstream of Mollee Weir (NRDS)

The downstream site on the Namoi River was accessed via a TSR and although still accessible to the public was more remote and apparently less regularly frequented than the upstream site. A lateral bar extends approximately 250 m along the north-eastern bank of the river, which flows northward.

Upstream of the bar, the river is less than 1 m deep and 45 m wide. The bed consists of mixed pebble, gravel and sand. A shallow riffle extends 25 m along the upstream end of the bar. This deepens into a run along the further bank. A deep backwater occurs between the trailing edge of the bar and a small bay cut into the eastern bank.

Salix babylonica grows along both banks and is the dominant species shading the water. Further from the water, *Eucalyptus camaldulensis* (River Red Gum) and *E. largiflorens* (Black Box) dominated the riparian community. The bar is devoid of vegetation, and no aquatic vegetation was observed in the water.

4.3.2 Riparian habitat assessment

4.3.2.1 Riparian, Channel and Environmental (RCE) inventory

Based on the RCE scores and the classification of Peterson (1992), every site had very good or excellent riparian and channel habitat except for BCDS. This site had RCE scores between 56 and 62%. For the other sites, scores changed little through time and ranged from 67% at NCUS, BCUS and BCD, to 87% at NRDS (**Table 14**). All sites had a good cover of mixed native vegetation and continuous strips of woody riparian vegetation more than 30 m wide. *Salix babylonica* lined the water at the NRDS, and were present as scattered individuals at MW and NCUS, but in all cases the willows were surrounded by large, hollow-bearing native tree species dominated by *E. camaldulensis* and *E. largiflorens*. The willows at NRDS were removed before the spring 2014 survey period. At Bohena Creek sites, the riparian zone was dominated by native species such as *L. polygalifolium* subsp*. transmontanum*, *E. blakelyi* and *C. glaucophylla*, and extended into the surrounding forest.

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Table 14: Riparian, Channel and Environmental inventory scores for each site.

Attribute	BCUS				BCUSD				BCD				BCDS				Teds Hole			
	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
Land-use pattern beyond immediate riparian zone	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3		4	4	4
Width of riparian strip of woody vegetation	3	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3		4	4	4
Completeness of riparian strip of woody vegetation	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3		4	4	4
Vegetation of riparian zone within 10 m of channel	4	4	4	4	4	4	4	4	4	3	4	4	3	3	4	4		4	4	4
Stream bank structure	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3		3	3	3
Bank undercutting	4	4	4	4	4	3	3	3	4	4	4	4	3	3	3	3		3	4	4
Channel form	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2		4	3	3
Riffle/pool sequence	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2
Retention devices in stream	1	1	1	1	3	2	3	3	1	1	1	1	2	1	1	1		1	2	2
Channel sediment accumulations	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2	2	2
Stream bottom	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1
Stream detritus	3	2	2	2	2	2	3	3	3	2	2	2	2	1	1	1		2	3	4
Aquatic vegetation	2	2	1	1	4	3	3	3	1	2	1	1	2	2	1	1		4	4	4
Total score	**36**	**36**	**35**	**35**	**40**	**37**	**39**	**39**	**36**	**35**	**35**	**35**	**32**	**29**	**29**	**29**		**38**	**40**	**41**
Percent	**69**	**69**	**67**	**67**	**77**	**71**	**75**	**75**	**69**	**67**	**67**	**67**	**62**	**56**	**56**	**56**		**73**	**77**	**79**

Attribute	BCS02				BCS07				BCS09				NCUS				MW				NRDS			
	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
Land-use pattern beyond immediate riparian zone			4	4			4	4			4	4	3	3	3	2	3	3	3	3	3	3	3	4
Width of riparian strip of woody vegetation			4	4			4	4			4	4	4	4	4	3	3	3	3	3	4	4	4	4
Completeness of riparian strip of woody vegetation			4	4			3	3			4	4	3	3	1	2	4	2	3	3	4	4	4	3
Vegetation of riparian zone within 10 m of channel			4	4			4	4			4	4	3	3	3	3	3	3	3	3	3	3	3	4
Stream bank structure			3	3			4	4			3	4	3	3	3	1	4	2	3	3	4	3	3	3
Bank undercutting			4	4			4	4			4	4	2	3	3	2	3	2	2	2	4	3	3	3
Channel form			3	3			3	3			3	4	3	3	3	4	3	3	3	3	3	3	3	3
Riffle/pool sequence			2	2			2	2			2	2	2	2	2	3	1	2	1	1	2	3	3	3
Retention devices in stream			1	1			1	1			2	1	2	3	3	2	2	3	2	2	3	3	3	2
Channel sediment accumulations			2	2			2	2			2	2	2	2	3	2	2	2	4	4	3	3	3	4
Stream bottom			1	1			2	2			2	2	2	2	3	1	2	2	2	2	3	2	3	4
Stream detritus			3	3			3	3			3	3	2	1	2	2	2	2	3	3	3	3	3	4
Aquatic vegetation			2	2			2	2			2	2	4	4	4	4	4	4	4	4	4	4	4	4
Total score			**37**	**37**			**38**	**38**			**39**	**40**	**35**	**36**	**37**	**31**	**36**	**33**	**36**	**36**	**43**	**41**	**42**	**45**
Percent			**71**	**71**			**73**	**73**			**75**	**77**	**67**	**69**	**71**	**60**	**69**	**63**	**69**	**69**	**83**	**79**	**81**	**87**

Stream banks were strongly stabilised by trees and shrubs at all sites except BCDS and NCUS. At these sites there was still a lot of stabilising woody vegetation, but stability was also provided to sections of bank by grasses and herbs. Banks were undercut at some curves and constrictions at MW, but undercutting was slightly more extensive at NCUS. There was no significant undercutting at any of the other sites.

Pool/riffle sequences were absent from all sites apart from BCDS. At Bohena Creek, the absence of riffles was caused by the low gradient sand bed and a lack of continuous surface flow between pools. For NCUS and MW, the river was too deep and broad for riffles as water was backed up from the weir.

There were no large rocks or logs to act as retention devices or solid substrate at BCUS and BCUSD, but occasional logs were present at all other sites, though not to a degree where they had a significant damming or retention effect on flow. Bars and beds of sand were common at all sites along Bohena Creek, and large mixed bars of cobble, sand and gravel occurred at the NCUS and NRDS sites.

No aquatic vegetation was observed at any of the Namoi River sites. Submerged vegetation may have been present but obscured by the turbid water. At Bohena Creek, macrophyte growth was dominated by *P. australis*, *Juncus spp.* and *Cyperus* spp.

4.3.2.2 Riparian community vegetation types

A total of 112 species from 31 plant families were recorded from the seven vegetation plots surveyed on Bohena Creek and the Namoi River. Of the 112 species observed 34 (30%) were exotic. A greater number of exotic species were recorded at the Namoi River sites than at Bohena Creek. Species lists for the vegetation plots are provided in **Appendix C**.

The following two biometric vegetation types were present in the study area:

- Namoi River - River Red Gum riverine woodlands and forests in the Nandewar and Brigalow Belt South Bioregions
- Bohena Creek - Rough-barked Apple riparian forb/grass open forest of the Nandewar Bioregion

Vegetation on the banks and floodplains of the Namoi River has been affected by clearing for agriculture, water infrastructure, roads and tracks, grazing and by disturbance events such as fires, flooding, erosion, rabbits and hares and weed invasion. This has resulted in degraded woodlands, especially on the banks of the river, in which the shrub and ground layer are dominated by exotic plant species. However, there are also some patches present which are dominated by native grasses and shrubs.

Vegetation on the banks and floodplains of Bohena Creek has experienced a lesser degree of disturbance and is also contiguous with large areas of relatively intact woodland of the Pilliga Forest (>1000 ha). This vegetation is generally dominated by native species, although exotic species are also present in high densities in some areas. The major disturbance regimes of this vegetation are likely to be fire, flood and weed invasion.

The vegetation types are described below, followed by a description of each site.

River Red Gum riverine woodlands and forests in the Nandewar and Brigalow Belt South Bioregions

This vegetation type occurs along the flood affected banks of the Namoi River. The structure varied from open woodland to woodland in structure (Specht and Specht 2002) with trees up to 20 m in height and with an average projected foliage cover of the canopy in the order of 29%.

The canopy was dominated by *E. camaldulensis* and the introduced *S. babylonica*. The midstorey was mostly sparse and was dominated by exotic species including *Lycium ferocissimum* (African Boxthorn) and *Ricinus communis* (Castor Oil Plant). Native mid-storey plants were very sparse and included *Senna barclayana* (Smooth Senna). The groundcover was generally grassy, depending largely on disturbance history, and commonly recorded groundcover species included the native *Cynodon dactylon* (Couch) and *Aristida* spp. Introduced species were abundant in the ground layer and included *Bromus catharticus* (Prairie Grass) and *Bidens subalternans* (Greater Beggar's Ticks).

This vegetation type had an average of 3 hollow bearing trees and an average of 10.6 m of fallen logs with a diameter greater than 10 mm per plot.

Rough-barked Apple riparian forb/grass open forest of the Nandewar Bioregion

This vegetation type occurs along the riparian zone of Bohena Creek and its intermittent tributaries. The structure varied from open woodland to woodland (Specht and Specht 2002) with trees up to 14 m in height and an average projected foliage cover of the canopy in the order of 15%.

The canopy was dominated by *E. blakelyi*, *Angophora floribunda* (Rough-barked Apple) and occasionally *C. glaucophylla*. The midstorey was generally sparse and shrubs species included *Callistemon linearis* (Narrow-leaved Bottlebrush), *L. polygalifolium* and *Acacia deanei* (Green Wattle). However, these shrubs were not widespread and usually consisted of dense clumps within the sandy bed at of Bohena Creek.

The groundcover was generally grassy and is likely to be dependent on fire history. It was relatively dense and dominated by *Imperata cylindrica* (Blady Grass) and *P. australis*. The exotic weed *B. subalternans* was also abundant in some areas.

This vegetation type had an average of three hollow bearing trees per plot and an average of 17 m of fallen logs with a diameter greater than 10 mm.

4.3.2.3 Vegetation community at each site

Namoi River Downstream (NRDS)

This site was located approximately 1.5 km north west and downstream of Mollee Weir. This site was located in woodland on the edge of the Namoi River.

No in-stream vegetation was present at this site. The banks at this site were flat, however, further away from the river the land was undulating and contained small swales and hills. The soil was a dark brown clay loam with high clay content.

The woodland on the site was dominated by *E. camaldulensis* of varying ages and the introduced *S. babylonica*. This woodland also had patches of open areas where there were no canopy species. The shrubby understory at this site was dominated by clumps of the exotic *R. communis* and *S. babylonica*. The ground layer was grassy and dominated the exotic *B. catharticus* and the native *C. dactylon* (**Plate 2**). The overall BioMetric value for this site was 32, which means it is in low to moderate condition.

The vegetation between this site and the Kamilaroi Highway consisted of grassy woodland dominated by *E. largiflorens* and *E. populnea* subsp. *bimbil* (Poplar Pox) which was dissected by roads, drains and fences and had been affected by clearing and grazing. This woodland is considered to be included within the TSC Act listed Endangered Ecological Community (EEC) Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion, however no detailed assessment of this vegetation was undertaken due to its distance from the river.

Plate 2: Namoi River Downstream site.

Namoi River at Mollee Weir (MW)

This site was located approximately 200 m upstream of Mollee Weir on a flat area in a relatively narrow strip of woodland located next to the Namoi River.

No in-stream vegetation was present. River banks were steep, up to 1.5 m high and usually devoid of vegetation. The soil was a dark brown light sandy loam with medium clay content.

At this site woodland was located on the flatter ground on the top of the bank and was dominated by *E. camaldulensis* of varying ages. Within 10 m of the river the dominant canopy species was the introduced *S. babylonica*. The shrubby understory at this site was dominated by clumps of the exotic species *L. ferocissimum*. The ground layer was grassy and dominated by *C. dactylon* (**Plate 3**). The overall BioMetric value for this site was 50, and it is considered to be in moderate condition.

The vegetation between this site and the Kamilaroi Highway consisted of grassy woodland dominated by *E. largiflorens* and *E. populnea* subsp. *bimbil* which is considered to be included within the TSC Act listed Endangered Ecological Community (EEC) Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion, however no detailed assessment of this vegetation was undertaken due to its distance from the river.

Plate 3: Namoi River at Mollee Weir

Narrabri Creek Upstream (NCUS)

NCUS was located approximately 6 km north west of Narrabri and 4.7 km upstream of Mollee Weir. This site was in a patch of woodland located on a raised floodplain next to Narrabri Creek.

No in-stream or bank vegetation was present at this site. The banks very steep and eroded, with the floodplain bench approximately 3 m above the water level and littered with occasional flood debris. The soil was a brown clay loam with a high gravel and clay content.

Woodland was located on the flatter ground on top of the bank and was dominated by sparse *E. camaldulensis*. The sparse shrubby understory at this site was dominated by clumps of the exotic species *L. ferocissimum*. The ground layer was grassy and dominated by *Aristida* spp. and the introduced *B. subalternans* (**Plate 4**). This site was in moderate condition, with a BioMetric value of 50.

The vegetation between this site and the Kamilaroi Highway consisted of grassy woodland dominated by *E. largiflorens* and *E. populnea* subsp. *bimbil* which is considered to be included within the TSC Act listed Endangered Ecological Community (EEC) Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion, however no detailed assessment of this vegetation was undertaken due to its distance from the river.

Plate 4: Narrabri Creek upstream site.

Bohena Creek Downstream of Proposed Release Location (BCDS)

This site was located approximately 2.7 km downstream of the proposed release location north of an unsealed road creek crossing. This sampling plot was located on the eastern side of the creek on the sandy creek bed adjacent to the standing water (high flow channel) where aquatic sampling was undertaken.

This site includes riparian vegetation (shrubs and sedges) on the creek bed as well as some woodland on the adjacent higher ground. The banks of the creek were relatively gently sloped, up to 2 m high and supported woodland. The bed of the creek supported clumps of shrubs and sedges. The substrate at this site was coarse sand.

The canopy was dominated by *E. blakelyi*. The understory consisted of a number of scattered *Callistemon linearis* and *L. polygalifolium.* The ground layer was dominated by a sparse cover of *I. cylindrica* and *P. australis*. Sedges included *Juncus* sp., *Persicaria* sp. and *Cyperus exaltatus* (**Plate 5**).

The riparian vegetation at this site was in moderate to high condition and had a BioMetric score of 57.

Plate 5: Bohena Creek downstream site (facing downstream).

Bohena Creek at Proposed Release Location (BCD)

This site was located approximately 200 m downstream of the proposed release location in dense vegetation next to a small anabranch of Bohena Creek (approximately 50 m west of the main channel of Bohena Creek). The survey site was positioned to the east of a small creek line with standing water in which aquatic sampling was undertaken.

This site included some riparian vegetation (grasses and sedges) on undulating sand. There were no defined banks associated with the small creek with and the grassy ground layer of the surrounding woodland extended to the water's edge. Some sedges occurred at the water's edge.

The canopy was dominated by *E. blakelyi*. The understory consisted of scattered shrubs of *L., polygalifolium*. The dense ground layer was dominated by *I. cylindrica* and *P. australis*. Sedges included *Juncus* sp. and *Carex* sp. Introduced species included *Glandularia aristigera* (Mayne's Pest) (**Plate 6**).

This site had vegetation in moderate condition, with a BioMetric score of 48.

Plate 6: Bohena Creek release site.

Bohena Creek Upstream (BCUS)

Bohena Creek Upstream was located approximately 3.1 km upstream of the proposed release location on the main arm of Bohena Creek. The sampling plot was located fully within the extent of the Bohena Creek bed on the western side of open water in which the aquatic sampling was undertaken.

The substrate was sandy coarse brown sand with limited organic material and supported clumps of shrub and scattered annual herbs and grasses. Sedges also occurred at the water's edge.

The canopy was dominated by scattered *E. blakelyi* and *A. floribunda*. The understory consisted of dense clumps of the shrub *Callistemon linearis* and *Acacia deanei*. The ground layer was sparse and dominated by *P. australis* and *I. cylindrica* and ephemeral herbs (**Plate 7**).

This site had a riparian zone in a moderate condition, with a BioMetric score of 42.

Plate 7: Bohena Creek upstream site.

Bohena Creek Upstream of Release Location (BCUD)

BCUD was approximately 200 m upstream of the proposed release location in dense vegetation next to the main channel of Bohena Creek. This sampling plot was located adjacent to a relatively large body of standing water in which aquatic sampling was undertaken.

This site includes some riparian vegetation (grasses and sedges) on undulating land with sandy soil. Banks were steep, 1 to 2 m high, and supported a sparse cover of sedges, woodland grasses and shrubs. The soil was a very dark brown sandy clay loam.

The canopy was dominated by *E. blakelyi*. The understory consisted of scattered shrubs of *L. polygalifolium*. The dense ground layer was dominated by *I. cylindrica* and *P. australis*. Sedges included *Juncus* sp. and *Carex* sp. Introduced species included *G. aristigera* (**Plate 8**).

This site had a BioMetric score of 61, representing a riparian zone in moderate to high condition.

Plate 8: Bohena Creek upstream of release site.

4.3.3 Water quality

4.3.3.1 Electrical Conductivity

The EC of water in Bohena Creek alluvial aquifer was 173 to 242 μS/cm and generally decreased with distance downstream (**Table 15**). The two bores at Leewood had electrical conductivity of 1094 and 2096 μS/cm.

Surface water in the isolated pools along Bohena Creek was between 62 and 349 μS/cm, and generally increased through time as pools became smaller. The Namoi River had higher EC than Bohena Creek, with measurements of 342 to 641 μS/cm (**Table 15**). Both the Namoi River and Bohena Creek were within the ANZECC/ARMCANZ (2000) target range for electrical conductivity in lowland rivers of 125-2,200 μS/cm. Exceptions were BCUS and BCD, which were lower than the target range.

4.3.3.2 pH

The Bohena Creek aquifer had a pH between 6.27 and 6.87, while pH in the colluvium at Leewood had a pH of 6.3 and 6.7. Surface pools in Bohena Creek had pH between 5.6 and 8.7 (**Table 15**). The Namoi River/Narrabri Creek sites, had pH between 7.5 and 8.5 (**Table 15**). All surface sites were within the ANZECC target range for pH of between 6.5 and 8, except for BCD in March, and BCUSD and NRDS in December.

4.3.3.3 Dissolved Oxygen

Groundwater DO was between 3.9 and 16.6% saturation in Bohena Creek Alluvium, and 18.4 and 18.8% saturation in the Leewood Colluvium. In isolated pools along Bohena Creek, DO was 32.1 to 118%

saturation (**Table 15**). DO concentrations were generally higher in the Namoi River/Narrabri Creek sites, with concentrations between 53.1 and 101% saturation.

4.3.3.4 Turbidity

Turbidity was highest in the permanently flowing sites in March, measuring between 91.4 Nephelometric Turbidity Units (NTU) at Mollee Weir and 129 NTU at the upstream site (**Table 15**). Turbidity at all of the Namoi sites had more than doubled by spring 2013, then fell again for the next two survey periods.

Turbidity in Bohena Creek was much lower than in the Namoi. In autumn 2013 it was between 18.6 and 75.7 NTU, but this increased to between 68.7 and 81.4 NTU in spring 2013, but fell in autumn and spring 2014.

Table 15: Physicochemical parameters at sites in the Bohena Creek Study.

Site	Parameter																							
	Temperature (°C)				Conductivity (µS/cm)				DO (% saturation)				pH				Turbidity (NTU)				Alkalinity (ppm)			
	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
ANZECC (2000) recommended range	n/a				125 -2200				85 - 110				6.5 - 8.5				6 - 50				n/a			
NCUS	25.2	23.9	16.6	25.9	392	502	641	617	53.3	51	89.2	65.5	8.0	7.5	8.2	8.2	129	437	18.4	52.3			201	203
MW	24.9	24.6	18.5	22.9	385	358	593	572	82.5	68.3	101	101	7.9	8.0	8.4	8.5	91.4	219	23.8	33.5			238	192
NRDS	26.1	24	13.3	21.7	390	342	351	573	77.8	89.4	53.1	71.2	7.7	8.1	8.1	8.0	112	312	93.8	32.3			126	191
BCUS	21				62				32.3				6.1				75.7							
BCUSD	24.9	34.3	12.1		157	172	141		45.6	118	91.7		6.6	8.1	8.0		35.9	81.4	30.8				42	
BCD	22.5				79				44.4				5.6				18.6							
TH		22.7	12.1	23.4		275	256	247		32.1	82.9	52.2		6.9	7.9	7.9		68.7	64.1	33.8			52	42
BCDS	30.6				124				32.2				6.3				43.5							
BCS02			17.3	29.5			288	304			61.1	72.1			7.5	8.1			34.5	28			61	63
BCS07			14.2	20.3			90	125			105	100			7.7	8.7			36.1	22.2			19	28
BCS09			14.5	22.4			274	349			62.9	87.8			7.6	7.7			21.9	11.8			32	69
LWDMW3D	23.5				1094				18.4				6.3											
LWDMW2D	21.8				2096				18.8				6.7											
BC1		18.9				242				16.6				6.9										
BC2		19.2				177				3.9				6.7										

Site	Parameter																							
	Temperature (°C)				Conductivity (µS/cm)				DO (% saturation)				pH				Turbidity (NTU)				Alkalinity (ppm)			
	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
ANZECC (2000) recommended range	n/a				125 -2200				85 - 110				6.5 - 8.5				6 - 50				n/a			
BC3		17.6				173				11.9				6.3										

4.3.4 Macroinvertebrate assessment

4.3.4.1 Invertebrate community overview

Invertebrate diversity was generally higher in spring than in autumn for all sites (**Table 16**). Bohena Creek had higher diversity than the Namoi/Narrabri Creek sites, with 38 families compared to 27. Only Chironmodae were present at all sites, though not on every occasion (**Appendix E**). Atyidae, Baetidae and Leptoceridae were widespread, occurring at all but one of the sites sampled (**Appendix E**). Hydropsychidae, Telephleidae and Protoneuridae occurred in the Namoi River but not in Bohena Creek.

The fauna at MW was depauperate in autumn, with only 4 and 5 taxa (**Table 16**). Diversity increased to 9 and 7 taxa in spring and there were at least two families of mayfly and one trichopteran family (**Appendix E**). NRDS had at least one family from all three orders in both autumn and spring. Atyidae shrimp and Corixidae water boatmen were the only taxa present at all of the permanent sites during sampling (**Appendix E**).

Sites at Bohena Creek averaged a higher invertebrate diversity than the Namoi sites and contained 11 families not present at any of the Namoi sites. Only two families of gastropod were collected during this surveys, and only at one site (BCUSD).

4.3.4.2 SIGNAL Scores

SIGNAL scores at Bohena Creek sites ranged between 2 and 4.6. The lowest score of 2 was from Teds Hole in spring 2014, and appears to be an exception to other survey periods at this site (**Table 16**). These scores are indicative of high to moderate levels of disturbance. The upstream and downstream sites scored the highest.

SIGNAL scores for Narrabri Creek and Namoi River were between 2.7 and 5.2 (**Table 16**). NRDS had the highest SIGNAL scores. SIGNAL scores for NCUS and Mollee Weir indicate that these sites are moderately disturbed.

4.3.4.3 AUSRIVAS

All sites in Namoi River and Narrabri Creek had O/E50 scores of between 0.17 and 0.69, placing them in either AUSRIVAS Bands B or C (**Table 16**). This indicates that sites were in poor condition and either significantly or severely impaired, with fewer of the expected taxa and lower water quality than modelled reference sites. All Bohena Creek sites had O/E50 scores between 0.17 and 0.61, and were also in Bands B and C.

Table 16: Summary table for macroinvertebrate assessment at Bohena Creek and Namoi River sites

Site Code	Autumn 2013				Spring 2013				Autumn 2014				Spring 2014			
			AUSRIVAS				AUSRIVAS				AUSRIVAS				AUSRIVAS	
	SIGNAL	Taxa Richness	O/E50	Band	SIGNAL	Taxa Richness	O/E50	Band	SIGNAL	Taxa Richness	O/E50	Band	SIGNAL	Taxa Richness	O/E50	Band
BCUS	4.53	16	0.61	B												
BCUSD	4.4	9	0.43	C	4.56	15	0.45	C	3.25	9	0.17	C				
BCD	4.4	4	0.26	C												
TH					3.82	10	0.36	C	4.2	9	outside model	outside model	2	4	0.18	C
BCDS	4.56	8	0.52	B												
BCS02									3.67	11	0.35	C	3.33	17	0.64	B
BCS07									3.45	10	outside model	outside model	3.13	7	outside model	outside model
BCS09									3.77	12	0.52	B	3.58	11	0.27	C
NCUS	2.8	4	0.26	C	4.64	10	0.45	C	3.85	8	0.35	C	3.09	5	0.45	C
MW	2.67	5	0.26	C	4.2	9	0.36	C	3	4	0.17	C	3.78	7	0.36	C
NRDS	4.93	14	0.69	B	5.15	12	0.36	C	3.53	15	0.61	B	4	8	0.36	C

4.3.5 Fish communities

Eleven fish species were collected during surveys (**Table 17, Appendix F**). Bohena Creek had four fewer species than the Namoi River (**Table 17**). NCUS had the highest fish diversity, with seven native and two exotic species. NRDS and MW had 8 and 7 species respectively; twice as many as the Bohena Creek sites of 2 to 4 species. The species collected from the Namoi River/Narrabri Creek and not Bohena Creek include *Tandanas tandanas* (Freshwater Catfish), *Melanotaenia fluviatilis* (Murray-Darling Rainbowfish), *Nematalosa erebi* (Bony Bream) and *Carassius auratus* (Goldfish). Only *Craterocephalus stercusmuscarum fulvus* (Unspeckled Hardyhead) was collected from Bohena Creek and not Namoi River/Narrabri Creek (**Table 17**).

Hypseleotris sp. (Carp Gudgeon) was the only species present at all sites. Plague Minnow was collected at all Bohena Creek sites and the upstream site on Narrabri Creek, and were probably at the two Namoi River/Narrabri Creek sites, though not collected during sampling. The other two exotic species, *Carassius auratus* (Goldfish) and *Cyprinus carpio* (Common Carp), are also likely to occur at all sites.

Table 17: Fish and turtle species collected during surveys.

Common Name	Scientific Name	NCUS				MW				NRDS				TH				BCS02				BCS07			
		Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
Murray Rainbowfish	*Melanotaenia fluviatilis*		8	8		1			2	1	7	16	12												
Australian Smelt	*Retropinna semoni*		56	50			8	180			2	120	43												
Golden Perch	*Macquaria ambigua*	2		1				1	1	2	1		2												
Spangled Perch	*Leiopotherapon unicolor*	1									1		1												
Freshwater Catfish	*Tandanus tandanus*				1					1															
Carp gudgeon	*Hypseleotris* sp.	3	2	2	26	5	3		14	5	2	230			7	300	14			32	86			150	206
Bony Bream	*Nematalosa erebi*		17	1	1	1	20	1	4		9		15												
Common Carp	*Cyprinus carpio**			32		1		102	1	1			1		1		2							1	3
Goldfish	*Carassius auratus**					1																			
Plague Minnow	*Gambusia holbrooki**	2													4	250				12				5	20
Unspeckled Hardyhead	*Craterocephalus stercusmuscarum fulvus*																							20	
Easternn Longneck Turtle	*Chelodina longicollis*							1					1											1	
Macquarie River Turtle	*Emydura macquarii macquarii*							3																	
Number of fish species per season		4	4	6	3	5	3	4	5	5	6	3	6	n/a	3	2	2	n/a	n/a	2	1	n/a	n/a	4	3
Total fish species per site		9				7				8				3				2				4			

Common Name	Scientific Name	BCS09				BCD				BCUS				BCUSD				BCDS			
		Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
Murray Rainbowfish	*Melanotaenia fluviatilis*																				
Australian Smelt	*Retropinna semoni*			18	12																
Golden Perch	*Macquaria ambigua*																				
Spangled Perch	*Leiopotherapon unicolor*					5															
Freshwater Catfish	*Tandanus tandanus*																				
Carp gudgeon	*Hypseleotris* sp.			256	315	5				12				14	16			2			
Bony Bream	*Nematalosa erebi*																				
Common Carp	*Cyprinus carpio**														4						
Goldfish	*Carassius auratus**																				
Plague Minnow	*Gambusia holbrooki**			12		4				5				5	14			2			
Unspeckled Hardyhead	*Craterocephalus stercusmuscarum fulvus*																				
Eastern Longneck Turtle	*Chelodina longicollis*																				
Macquarie River Turtle	*Emydura macquarii macquarii*																				
Number of fish species per season		n/a	n/a	3	2	3	DRY	DRY	DRY	2	DRY	DRY	DRY	2	3	DRY	DRY	2	DRY	DRY	DRY
Total fish species per site		4				3				2				3				2			

4.3.6 Stygofauna

Two shallow monitoring bores at Leewood, and three in the bed of Bohena Creek were sampled twice for stygofauna. Four production bores and five shallow pits were also sampled (see Table 4). Of the total of 19 samples taken, no stygofauna were found.

4.4 Overview of significant ecological components

4.4.1 Riparian habitat/vegetation

No threatened plant species were observed in the riparian zone at any of the survey sites.

Riparian vegetation at all Namoi River sites was generally in moderate condition and was well-connected to adjoining floodplain vegetation via a travelling stock reserve along the northern side of the river. The riparian zone made significant contributions to in-stream habitat; at all sites, logs, root balls, or other large woody debris was present in the channel. At MW and NRDS, woody roots extended into the river, providing habitat and bank stability, and at all three sites there was overhanging vegetation and channel shading. While *S. babylonica* was present on the banks of the river, there were also populations of *E. camaldulensis* of varying ages.

Riparian vegetation along Bohena Creek derives its main ecological value from its connectivity to the broader Pilliga Forest. Vegetation along the creek was in moderate condition, although played only a minor role in creating channel and in-stream habitat. Four of the Bohena Creek sites (all except BCD) had at least one side that was formed by a vegetated bank that adjoins the Pilliga Forest. These banks had sufficient woody vegetation to provide enough stability for the bank to develop a moderate steepness that extended into the water and gave a depth of 60 to 120 cm. Leaf litter and woody debris were present in low densities at all Bohena Creek Sites. At BCUS, riparian shrubs overhung the water and provided shelter and shade for the aquatic community.

Phragmites australis occurred at low to medium densities at all sites along Bohena Creek. This species has the potential to increase in density if water becomes more permanent (Gucker 2008). Densities appeared to be higher at the upstream and downstream ends of Teds Hole, BCS02 and BCS09, than at the other sites that dry out more frequently.

4.4.2 Water quality and aquatic habitat

The sandy bed of Bohena Creek has very little topographic variation, so remnant pools were shallow and relatively uniform. The main habitat feature present at these sites is the fringing vegetation provided by *P. australis*, which grows in low to medium densities. Overhanging and trailing vegetation is also present at some sites, as are small amounts of debris.

Dissolved oxygen concentrations in the Bohena Creek pools were generally outside of ANZECC/ARMCANZ (2000) guideline values. At most sites, concentration was low, but at BCUSD it was above the upper target value. Concentrations of DO that are above saturation level can be problematic and cause ‘gas bubble disease’ in fish, whereby bubbles begin to form in tissues and eventually block gill capillaries and kill the fish (Boulton and Brock 1999). The high DO concentrations at BCUSD were probably due to the high surface area and low volume of water in the shallow pool and the subsequent high rate of diffusion across the water membrane.

At BCUSD, turbidity more than doubled between the first and second sampling occasions. This is probably due to a combination of factors, primarily the reduced depth and extent of the pool, and the concentration of large, benthic-feeding Carp disturbing silt and sediment on the bottom. At least four Carp between 20 and 30 cm were present at the time of sampling in spring 2013, when the water was barely deep enough to submerge them entirely and all movement stirred up silt.

In the Namoi River, the main habitat features at the upstream and weir sites were deep pools and large woody debris. The NRDS site had greater habitat complexity than the two other sites. Here, there was a well-developed riffle leading into a deep pool and running beside a deeper channel overhung by trailing vegetation.

Turbidity at the Namoi sites was almost twice the upper ANZECC trigger value in autumn 2013 and four to eight times higher in spring 2013. The high turbidity at these sites is likely to be a contributing factor to the low dissolved oxygen concentrations, which were below the ANZECC target range for all sites in autumn and all sites in spring except NRDS. One of the main causal factors of the high turbidity was the large volume of sediment suspended in the water column. The high sediment load is likely to be caused by the re-suspension of silt washed into the river channel over the past decade or more from catchment-wide erosion and bank slump. The respiration of bacteria attached to suspended sediments can consume large amounts of oxygen in turbid water, so driving down oxygen concentrations (Boulton and Brock 1999). Coupled with this, very little sunlight is able to penetrate the turbid water, reducing photosynthetic contributions of oxygen. At low DO concentrations, fish and invertebrate respiration becomes increasingly impaired.

4.4.3 Aquatic invertebrates

The threatened *Notopala sublineata* (River Snail) occurs in slow-flowing water and is found on logs and large woody debris, rocks, and in softer sediments such as mud (NSW DPI 2007). The species has declined significantly and has not been collected for more than 15 years in natural environments (NSW DPI 2007). The likely reason for the decline in population is a reduction in natural periphyton that made up a large part of the species diet (NSW DPI 2007). This has been attributed to changes to natural flow regimes and a reduction in large woody debris and other solids substrata through removal or smothering with fine sediment (NSW DPI 2007). Populations remain in some artificial habitats such as irrigation pipelines, which have favourable conditions for periphyton. The species has previously been collected from near Mollee Weir, though not for more than thirty years (NSW DPI 2007) and it is unlikely that populations persist in the study area at either the Namoi River or Bohena Creek sites.

The invertebrate communities of Bohena Creek were usually more diverse than those in the Namoi River and Narrabri Creek. This is possibly because the waterholes were contracting and concentrating the fauna into smaller pools of surface water. An exception was BCD in autumn 2013. This pool was only small and had high densities of Spangled Perch and Plague Minnow, which kept invertebrate numbers low.

The depauperate invertebrate fauna at the Mollee Weir and Narrabri Creek upstream sites is due to a combination of factors. Both sites were in a reach of river that experiences daily fluctuations in water level because of the backing up effect from Mollee Weir. This meant that the edges where samples were collected from were relatively featureless, and apart from a few pieces of large woody debris, were essentially bare mud. Regular fluctuations of up to 30 cm, coupled with rapid drop-off into the water and high turbidity have made the edge unsuitable for submerged macrophytes as invertebrate habitat.

4.4.4 Stygofauna communities

Stygofauna are known to occur in the Namoi River alluvial aquifer. In a study conducted between 2007 and 2008, Korbel (2012) collected at least 7 stygofauna taxa from 15 monitoring bores near Wee Waa, approximately 50 km west-northwest (and downstream) of Narrabri. The taxa collected included Ostracoda, Cyclopoida, Harpacticoida, Amphipoda, Oligochaeta, and three genera of Bathynellaceae.

The Namoi River alluvial aquifer is not part of the immediate project area but is a potential source of colonisation for stygofauna. Thin sedimentary aquifers associated with Bohena, Cowallah and Bibblewindi Creeks extend south into the Pilliga and are potentially suitable habitat for stygofauna. It is possible that communities may be present in permanently saturated parts of these aquifers, especially if they have an occasional hydrological connection to the larger Namoi alluvium.

Stygofauna may also be present in the shallower sandstone aquifers present in the project area, such as the Pilliga Sandstone and Keelindi Beds, although this is unlikely. For these to be suitable for stygofauna, they would have to be fractured or weathered enough to allow stygofauna movement, have a sufficient flux of water and organic matter, and be well connected to a colonising aquifer such as the Namoi. The suitability of these rock aquifers as stygofauna habitat diminishes with depth from the surface because:

- Stygofauna rely on organic matter derived from the surface. Without a good hydrological connection to the surface, there is not likely to be enough organic matter or oxygen present.
- The space available for stygofauna movement is reduced significantly with increasing depth.
- With depth, there is an overall decline in water quality.

Stygofauna may also be present, although with decreasing likelihood with depth below ground from alluvium, in weathered sections of sandstone with high secondary porosity, and in the deeper colluvial sediments.

4.4.4.1 Rockdale stygofauna survey

Stygoecologia (2013) sampled four sites for stygofauna at the Rockwood property. Fauna collected during these surveys included mites and enchytreid worms. Ants were also collected from the bores, though in a partially decomposed state. The status of the oligochaete and mite as stygofauna needs to be made with caution. While some groups, mostly crustaceans such as bathynellids, amphipods, and isopods, are unambiguously groundwater obligates because of their aquatic ancestory and troglobitic morphological features, there are other taxa that are likely to be in groundwater accidentally. These are taxa that occur more commonly in the soil profile, but regularly fall into bores/wells and are collected during sampling and include worms and mites, and the larval stages of terrestrial insects. It is more likely that the worm and mite collected at Rockwood are soil fauna, rather than stygofauna. The presence of ants in the sampled bore indicate that it was open to the soil profile, and that other soil fauna could potentially fall into the bore. Soil fauna are not considered as significant as stygofauna because species are more widespread and have fewer incidences of short-range endemism.

4.4.5 Fish communities

Bohena Creek is an intermittent waterway, with a highly variable flow regime. In contrast, the Namoi River and reaches of Narrabri Creek experience a permanent, regulated flow regime, albeit with regular fluctuations. The permanence of water in the Namoi River and Narrabri Creek favours larger, long-lived species, but also offers suitable habitat for small-bodied species. Hence, a range of small and larger-bodied species were collected in the Namoi River and Narrabri Creek survey sites, but larger species were unusual in Bohena Creek. Larger fish are present in some of the deeper waterholes along Bohena Creek. Carp up to 40 cm were observed at the BCUSD site in March 2014, and at Black Duck Holes upstream of the Leewood release. Golden Perch between 23 and 30 cm were also collected at BCS002. Provided there is sufficient food, large species are able to survive in waterholes and disperse upstream in times of connected flow, using the deeper pools as stepping stones to facilitate movement further upstream.

Only rapidly dispersing species were collected from Bohena Creek at the sites sampled for this study. Plague Minnow, Carp Gudgeon, Common Carp and Spangled Perch are all highly dispersive species

(McDowall 1996). Spangled Perch can swim across flooded paddocks and along wheel ruts to waterholes (McDowall 1996). The Spangled Perch collected from the release site at Bohena Creek were all between 27 and 30 mm long so had not yet reached maturity, which occurs at 58 mm for males and 78 mm for females (Lintermans 2007). Most of these specimens had damaged fins from being continually 'pecked' by Plague Minnow and were in poor condition.

Many fish in the Namoi sites had parasitic isopods of the family Cirolanidae attached to their bodies, or had red welts where the isopods had once been. Isopods appeared to be present in higher numbers in autumn than in spring.

Of the three threatened fish species and populations considered likely in the area, only Freshwater Catfish was collected during sampling. Catfish are a benthic species that prefer slow-flowing streams and are relatively sedentary, with adults moving less than 5 km during their life (Lintermans 2007). Catfish numbers have declined in the Murray-Darling Basin over the last two decades, possibly due to cold-water pollution from dams, barriers to movement, changes to natural flow regimes, and elevated salinity (Lintermans 2007). Carp and Redfin may also have led partly to the decline.

Silver Perch numbers have declined in recent years because of the proliferation of barriers to upstream migration (Allen *et al*. 2003). This species prefers slow-flowing, turbid rivers and has previously been recorded from the Namoi River upstream and downstream of the release site. Murray Cod have also been collected from near the study site. Cod require deep pools with in-stream structure such as logs, rocks, and undercut banks (Lintermans 2007)

All the threatened fish species possible in the study area require deep pools and flowing water (Allen *et al*. 2003). While suitable habitat occurs in the Namoi River, Bohena Creek is dry along most of its length, and where pools do occur they do not generally exceed 1.6 m in depth, making it very unlikely that any threatened fish occur.

4.4.6 Reptiles and amphibians

A number of threatened reptiles and amphibians are known to occur in freshwater habitats in the Namoi River catchment. Bell's Turtle is listed as Vulnerable under both the NSW TSC Act and the Commonwealth EPBC Act. It occupies narrow sections of rivers in granite country, shallow pools in the upper reaches, or small tributaries of major rivers to the east of the study area. The pools are typically less than 3 m deep, with a sandy or rocky substrate, and patches of macrophytes (NSW OEH 2012a). This species is known only from the headwaters of the Namoi and Gwydir Rivers, and is considered threatened by changes in riverine condition and structure arising from land management practices and irrigation activities, predation of eggs by foxes, trampling and damage to river banks by livestock, and pollution and sedimentation of rivers (Namoi CMA, 2012). Bell's Turtle is considered unlikely to occur in the study area because there is no suitable habitat.

Of the four conservation significant amphibian species known to occur in the locality, only Sloane's Froglet is considered to have the potential to occur at the study areas (**Table 9**). This species is listed as Vulnerable under the TSC Act. It is a small, ground-dwelling frog, which was previously encountered throughout the floodplains of the Murray-Darling Basin. It breeds in ephemeral areas in grassland, woodland and disturbed habitats and forages in areas adjacent to breeding habitat, in natural or highly modified environments (OEH 2012d).

The floodplain north of NRDS and MW are potentially suitable for Sloane's Froglet, and the species has previously been detected in the Pilliga Outwash south of the Namoi (last record in 1996). However, a combination of several threats has contributed to an overall decline in the extent and abundance of the species, such that it is thought that only a moderately low number of mature individuals exist in its former range (OEH 2011). Specific threats to the species are:

- degradation of habitat quality through clearing and overgrazing
- changes in flooding regimes
- predation by the Plague Minnow
- climate change.

All frogs are sensitive to changed flow regimes and changed water quality, because they rely on specific aquatic habitat characteristics suitable for successful reproduction. Actions which alter the water chemistry or duration at frog breeding sites, may therefore affect frog population persistence in the landscape.

Frog responses to changes in water chemistry are well-documented. Although tolerance limits vary between species, most frogs are sensitive to salinity, chemicals (e.g. insecticides and herbicides), siltation, and changed water conditions which encourage introduced fish species (especially Plague Minnow).

5 Project water management

5.1 Overview of project water management

A total of 37.5 GL of produced water will be extracted over the assessment period and treated at the Leewood WMF. During peak water extraction, up to 10 ML/day of produced water is predicted to be treated at Leewood WMF although the Managed Release Study has assessed a peak production of 12 ML/d. From that assessment, it is estimated that approximately 7.2% of the treated water would be directed to Bohena Creek over the 25 year assessment period. This estimate is based on the deployment of an early release protocol, wherein release of treated water to Bohena Creek is initiated when flow in the creek equals or exceeds 100 ML/day at the Newell Highway.

During years 0 – 4 of the project, the median increase in total Bohena Creek flow volume is estimated to be 0.49%. This estimate is based on the rolling 4-year sum of release and streamflow during the assessment period 1995 to 2005 when streamflow data were recorded.

From year 5 onward, water extraction will decrease from previous years. As pond sizes and irrigation areas are designed to accommodate peak production years, the need to release will diminish.

Whilst it is possible that episodic release during streamflow events may marginally extend the period of time the creek would take to dry, the effect is considered too small to be measureable and this potential impact would diminish as water production reduces. Note that whilst the threshold triggering release of treated water to the creek is 100 ML/day, when flow occurs in the creek it commonly greatly exceeds 100 ML/day.

5.2 Managed release (quantity)

Total water extracted from the coal seam targets is estimated to be approximately 37.5 GL over the 25 year assessment period. The estimated water volumes would peak during the early years of the project (around the first two to four years) at approximately 10 megalitres per day and then gradually decline over the life of the project. The long-term average would be around four megalitres per day, which is equivalent to 1.5 gigalitres per year, over the 25-year assessment period.

The environmental impact assessment for the managed release activity has assumed the use of up to 12 ML of treated water per day. This ensures the peak production volumes are catered for and provides additional operational flexibility, given the estimated peak water production rate of approximately 10ML per day between years 2-4.

Releases of treated water to Bohena Creek will occur infrequently and only during periods when Bohena Creek is flowing with natural flows of ≥ 100 ML/day.

The episodic managed release scenario considered in this impact assessment is when the creek is flowing at greater than or equal to 100 ML/day measured at Newell Highway crossing (referred to as a ‘wet’ or flowing creek). It is assumed for this assessment that a flow of 100 ML/day will result in a continuous reach of water extending from the release location to the Namoi River.

If episodic releases occur only when Bohena Creek is flowing (natural flows of ≥ 100 ML/day), then the likelihood of ecologically significant or measurable change in surface water quantity is considered to be very low.

5.3 Treated water quality

Prior to release, dissolved oxygen will be raised (via a diffuser at the release location). Temperature is also expected to reflect ambient temperature.

A comparison of the treated water concentrations from the Hydranautics IMS Design modelling software output and ANZECC/ARMCANZ (2000) Guideline Trigger Values is presented in **Table 18**. Concentrations are mean and maximum concentrations. For several metals, reverse osmosis (RO) will reduce the mean concentrations to below the limit of resolution (LOR) and hence these metals are assumed to occur at levels below their respective LOR.

Treated water data are also compared to background concentrations in **Table 18**. Treated water measurements (mean and maximum) of pH, electrical conductivity, copper, alkalinity, and chloride exceed the background levels in Bohena Creek. Additionally background data exceed default trigger values for, turbidity, phosphorus, aluminium, and chromium in Bohena Creek waters.

Table 18: Expected chemistry of water released from Leewood WMF

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems*'	Bohena Creek background (80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed default trigger?
pH		6.5-8.0	7.43	7.10	9.2	MAX	MAX			
EC	uS/cm	125-2,200	197	357	645		MEAN/MAX		224	No
TDS	mg/L		184 115 [d]	232 [c]	419 [c]		MEAN/MAX		170	
Turbidity	NTU	6.0-50.0	59.2	<0.5	<1.0	MEAN/MAX	MEAN/MAX	YES		
Boron	mg/L	1.8 [a]	-	0.12	0.68				0.09	No
Sodium	mg/L		18 [f]	77	140				28.7	
Magnesium	mg/L		7 [f]	0.01	0.01				5.928	
Aluminium	mg/L	0.055	1.95	<0.001	0.01			YES		
Silica	µg/L SiO2		16220	23.3	27.3					
Potassium	mg/L		2.8 [f]	0.8	1.0					

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems*'	Bohena Creek background (80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed default trigger?
Calcium	mg/L		6.8 [f]	0.01	0.01					
Chromium (III+VI)	mg/L	0.001	0.004	<0.001	0.001			YES		
Manganese	mg/L	1.9	0.248	<0.001	0.001					
Iron	mg/L		7.742	<0.001	0.005					
Cobalt	mg/L		0.004	<0.001	-					
Nickel	mg/L	0.011	0.006	<0.001	0.000					
Copper	mg/L	0.0014	0.001	<0.001	0.002	MEAN/MAX	MAX		0.0012	No
Zinc	mg/L	0.008	0.003	<0.001	0.003					
Arsenic	mg/L	0.013	-	<0.001	0.001					
Selenium	mg/L	0.005	-	<0.001	0.001					
Molybdenum	mg/L		-	<0.001	0.000					
Cadmium	mg/L	0.0002	-	<0.001	0.00056	MEAN/MAX			0.00010	No

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems*'	Bohena Creek background (80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed default trigger?
Barium	mg/L		0.055 [f]	<0.001	0.027					
Mercury	mg/L	0.00006	-	0.0000067	0.0002	MEAN/MAX	MEAN/MAX		0.000065	Yes [g]
Lead	mg/L	0.0034	-	<0.001	0.000					
Uranium	µg/L		-	-	0.003					
Alkalinity (Carbonate as CaCO3)	mg/L		-	139	-		MEAN			
Alkalinity (total) as CaCO3	mg/L		52	139	193		MEAN/MAX			
Ammonia as N	µg/L	900	20	15	50					
Nitrate (as N)	mg/L		0.03	-	-					
Nitrogen (Total Oxidised)	mg/L	0.04	0.04	-	-					
Nitrogen (Total)	µg/L	500	800	-	-					
Sulphate	mg/L		-	0.003	0.532					
Chloride	mg/L		29	15	83		MAX		33.6	

Constituent	Units	ANZECC/ARMCANZ (2000) default trigger value for '*slightly to moderately disturbed systems'*	Bohena Creek background (80th percentile)	Treated water Mean [e]	Treated water Max. [e]	Does treated water exceed default trigger?	Does treated water exceed background?	Is 80th percentile background > default trigger value?	Mixed Water Max. [b]	Does mixed water Max. exceed default trigger?
Fluoride	mg/L	0.46 [a]	-	0.08	0.16				0.061	No
Phosphorus	mg/L	0.05	0.094	0.010	<0.01			YES		

Notes:

1. Blank cells and cells with '-' indicate value is not available or could not be calculated because it was not detected.
2. 80th percentile calculations use 0.5 x LOD
3. Max = Maximum

[a] Site-specific Boron and Fluoride Protective Concentrations developed in the DTA were used in place of ANZECC/ARMCANZ (2000) Guideline Trigger Values

[b] With 10:1 background dilution (surface water:treated water). Calculation uses mean background concentrations.

[c] Calculated

[d] Measured at @180°C

[e] Based on post chlorination treated water quality projections.

[f] Based on filtered measurements.

[g] Projections for treated water mean and maximum values are based on conservative estimate of mercury (approximately 4 times actual recorded produced water concentrations). Actual values are likely to be less.

6 Impact assessment

Managed release will occur in the reach presented in the Managed Release Study. The locations where aquatic data were collected are considered to give an appropriate representation of the Bohena Creek receiving environment and are thus suitable to use as a basis for impact assessment. Releases to Bohena Creek are informed by the release scheme protocol described in the Managed Release Study.

Release to a flowing stream (natural flow ≥ 100 ML/day)

Episodic release will only occur when Bohena Creek is flowing and the natural creek flow is equal to, or greater than, 100 ML/d at the Newell Highway gauging station. At this flow level, it is likely that the Newell Highway bridge will be connected to the Namoi with continuous surface flow and there will be negligible infiltration, so all of the released treated water will mix with natural flow and continue to the Namoi River. Infiltration is assumed to be negligible because groundwater in the alluvium would be likely to have become saturated before overland flow commenced. As release occurs during periods of natural flow and is stopped again when flow drops below 100 ML/d, the natural flow regime is unlikely to be altered.

Release to Bohena Creek during natural flow periods will not prolong the period of connectivity. However, during periods of release, natural flow will be supplemented by up to 12.0 ML/day from the Leewood WMF. This could mean that the 100 ML/day trigger on the receding limb of the flow period is not reached for a brief period (< 0.5 d) after flow would have dropped to this level naturally. This extra period of flow is very unlikely to result in significant ecological consequences to Bohena Creek.

6.1 Flow dependent ecological thresholds in intermittent streams

6.1.1 Flow and intermittent stream ecology

Organisms living in intermittent streams and the ecological processes that they perform are naturally dependent on a variable hydrological regime. Life cycle cues can be triggered by the presence or absence of surface water, and a significant change to the stream hydrology can alter the ecological balance of the ecosystem. The components of a flow regime that are important to aquatic ecology in intermittent streams are (McGregor et al 2011):

- Duration of the flow period – the amount of time that surface water persists.
- Timing of the flow period – the time of year that surface water is present.
- Variability of the flow period – rate of rise in water level, and frequency of return of wet periods.
- Predictability of flow - whether flow periods occur at the same time throughout the year, or are random.
- Rate of rise and fall - the speed at which water level increases when flow commences, or drops in the falling stages of flow.

As release will only occur when the bed is saturated during periods of natural flow, there will be no addition in the frequency or duration of bed saturation. Groundwater levels will fluctuate as they would under natural conditions, so the timing of thresholds described below are unlikely to differ from what they are under the current intermittent regime.

Under the current hydrological conditions, Bohena Creek experiences long periods of drying where the only surface water expression occurs in isolated pools that are deep enough to avoid drying under most drought conditions because they are connected to alluvial groundwater. These pools become connected through surface flow following high rainfall events, allowing aquatic biota to disperse between deeper holes. In intermittent streams, changes in water level trigger different responses in the ecological community. It is possible to examine threshold responses in intermittent stream ecology by looking at water level in relation to depth below or above the stream bed.

6.1.2 Impact thresholds - how different water levels affect ecological processes

Water level in aquifer becomes accessible to herbaceous plants

The first threshold occurs when water level reaches a distance below the stream bed that is within useful reach of aquatic plants. Species that are not aquatic specialists, but terrestrial plants that have taken up residence in the dry creek bed, may die if their roots are sensitive to water-logging. Early plant colonisers, such as grasses and the noxious weed *Xanthium occidentale* (Noogoora Burr) become easily established in sandy creek beds, but die out when water level reaches the surface.

Phragmites australis is one species likely to increase in density once water level comes within 75 cm of the surface. This species can spread through rhizome growth, and can reach problematic densities under extended periods of growth (Gucker 2008). At Teds Hole and the waterholes upstream and downstream of the Newell Highway Bridge, *P. australis* has formed large beds that extend across the creek bed, effectively forming a wall of vegetation. This prevents native fringing aquatic species from establishing, and also restricts the movement of native fauna wishing to access the water. At high densities, *P. australis* can also become a fire hazard or a hydraulic barrier during periods of flooding that can channel water from the creek out onto the floodplain. Regular drying is one method of controlling densities of *P. australis* (Sainty and Jacobs 2003), and lowering the water table below 50 cm has been used to reduce the spread of new growth (Gucker 2008).

The formation of isolated pools

The next threshold is reached when the water level breaks the surface of the creek bed and creates pools of standing water. At this point, aquatic invertebrates begin to hatch from eggs deposited by previous generations when the last surface flow was in recession. Likewise, seeds from aquatic plants sprout and begin to grow, and microbial biofilms on sediments begin their break-down of organic matter. At this point, water is expressed as a series of waterholes that attract terrestrial fauna such as kangaroos, wallabies and Feral Pigs. After several weeks, vegetation, algae, and invertebrate populations become established, and waterholes become suitable habitat for frogs and tadpoles. Insects with adult flying stages, such as dragonflies, beetles, and midges are able to disburse between waterholes.

Under the current hydrological regime, Bohena Creek is dry for much of its length, although a series of semi-permanent waterholes persist that act as ‘refuge islands’ for aquatic flora and fauna. Only the waterholes at Teds Hole and upstream of the Newell Highway have been visited, but these have depths of 1.6 and 2 m (measured June 2014) so are likely to be semi-permanent. Other waterholes occur further downstream at irregular intervals along Bohena Creek all the way to Mollee Weir. The deepest of these visited in June 2014 had a depth exceeding 2.5 m.

Given that the project will establish a water management scheme that ensures episodic releases only, no additional pools will be created, other than those formed by natural flows.

Isolated pools become connected by surface flow

Continued increases in the water level result in a third threshold, when isolated pools start linking up and aquatic fauna can move between them. This is a key threshold for the migration of fish. Native species such as Spangled Perch and Carp Gudgeon are among the earliest fish to move up recently established hydrological pathways (McDowell, 1996). Unfortunately so too are the exotic Plague Minnow and Carp. The rapidity of fish dispersal along Bohena Creek will depend on how well the colonising species, initially restricted to refuge pools, are distributed throughout the landscape. The waterholes along Bohena Creek are all likely to have Spangled Perch, Carp, Plague Minnow, and Carp Gudgeon, and these species will move between waterholes once they are linked by surface flow. The nearest waterhole to the release point is Teds Hole, 1.6 km downstream.

The project will establish a water management scheme that results in episodic releases only when there is already flow in the creek and isolated pools are all connected. It is therefore unlikely that the release option will increase the frequency of links between waterholes downstream of the Newell Highway and other waterholes upstream to as far as the BCUS sampling location.

There is continuous flow in Bohena Creek that links the Leewood release site to the Namoi River

A fourth threshold occurs once there is continuous flow in Bohena Creek that links it to the Namoi River. At this threshold, Bohena Creek (from the release point) becomes connected to the larger, regional gene pool of the Namoi, with species able to move upstream and downstream between the two systems.

Given that the project will establish a water management scheme that results in episodic releases to an already-flowing creek only, a continuous flow that connects the release location to the Namoi River will already be likely from natural flows.

Increases in flash flooding and flow duration

Under natural conditions, water level in the aquifer below Bohena Creek increases in response to rainfall. The infiltration of runoff into the aquifer gives the creek a buffer against sudden rises in flow. However, once the bed is saturated, surface water level rises rapidly, causing scouring of bed sediments and erosion of banks. Rainfall runoff modelling indicates Bohena Creek may be expected to flow when rainfall in the local catchment exceeds 100-110 mm in a given month, achieving flows of at least 100 ML/day approximately 15% of the time. The increase in water level has been modelled and is small.

The Managed Release Study indicates that release to an already flowing creek would not increase surface water level a significant amount, and is unlikely to increase the impact of flooding.

Another main contrast between water entering Bohena Creek via natural spates and that which enters from the proposed release to Bohena Creek is likely difference in turbidity. With rain-generated flow events, most of the water concentrated in the channel is a result of overland flow and contains turbid water laden with dust, silt particles and any associated nutrients or coarse organic matter. Treated water coming from the Leewood WMF will have a low turbidity, so will not add external silt to the overall budget in Bohena Creek. With appropriate design the release location can mimic turbidity expected from rainfall-runoff if needed.

It is also important to consider the duration of flow periods that may link up the Bohena Creek waterholes. It is difficult to judge from existing records, since they are taken from a single gauge near the Newell Highway Bridge, how long continuous flow persists in other parts of the creek. Bohena Creek flows approximately 15% of the time, which equates to an average of 7.8 weeks of flow each year, although the creek sometimes does not experience continuous surface flow for several years. It is thus the variability in flow permanence that is the overriding influence on the aquatic ecological community of

Bohena Creek. Wetting periods follow no seasonal patterns and can occur throughout the year. Most of the aquatic species in Bohena Creek are adapted to patterns of flow, recession, and drying, with the latter period being as important to ecosystem function as the period of wetting.

The importance of drying

Dry periods allow aquatic ecosystems to ‘reset’ themselves. Fish die off during these natural drying events. Some invertebrates fly away, while others, such as copepods and ostracods, lay desiccation-resistant eggs before the last bit of water dries up. Yabbies seek refuge in burrows that trap water. Aquatic plants drop seeds to wait for re-wetting and then die once the water level is too low. At a smaller scale, aquatic microbial activity stops or slows in the absence of water, and air is able to circulate in the upper sediment layers. Dry periods allow the aquatic components of intermittent streams to effectively shut down, and in their absence, terrestrial processes slowly start to dominate.

Drying is a partially effective way of killing off the exotic species Carp and Plague Minnow (Lintermans 2007, Pyke 2008). However, drying will only remove these species temporarily if no preventative measures are taken to stop recolonisation once flow re-commences. In Bohena Creek both of these species will retreat to permanent waterholes during periods of drying.

If the bed sediments dry out completely and groundwater level drops beneath 75 cm, then the domineering species *Phragmites australis* may cease its spread and eventually die back (Gucker 2008). Sporadic periods of dieback are important for controlling the growth of *P. australis*, as it prevents the species from completely blocking the channel and becoming so dense that other fringing aquatic plants are unable to grow (Sainty and Jacobs 2003). As the project will establish a water management scheme that results in episodic releases only when streamflows are ≥100 ML/day, the drying cycles will be retained, so it is unlikely that *P. australis* densities will increase significantly over the next 25 years unless they do so in response to natural conditions.

When stream beds dry out, they also become useful for terrestrial fauna, acting as a highway for rapid dispersal. Emus move regularly along the dry bed of Bohena Creek, dropping seed-laden scats. Kangaroos, goannas, and other large fauna regularly move along the edge of the sandy channel, as do feral foxes, goats, and pigs.

The proposed episodic release does not affect the frequency, duration or intensity of natural periods of drying.

6.1.3 Impacts due to increased volumes of release water

The potential risks associated with releasing to the existing waterway will be influenced by the quality and quantity of water delivered, as well as the timing, duration, frequency and magnitude of the release compared to the natural flow regime of the receiving waterway.

There are unlikely to be any major ecological impacts as a result of the proposed release to Bohena Creek during periods of flow.

6.1.4 Impacts due to changed water chemistry and physical attributes

In intermittent waterways, the concentrations of some dissolved chemicals fluctuate widely through the wetting and drying phases (Williams 2006). For example, as the volume of water in isolated pools decreases, concentrations of orthophosphate, sulphate, salts and other ions increase. With re-filling of pools, concentrations generally decrease with dilution. Fluctuations in water chemistry can be important triggers for biological responses that prepare organisms for drying, with increased concentrations leading some taxa to lay eggs or enter diapause (Williams 2006). The addition of more water with chemical signatures that differ to that of the natural waters in Bohena Creek may remove the trigger for some aquatic taxa such as copepods and chironomids to prepare for drying. This is unlikely to be significant in reaches of the creek that remain permanent, since the need for diapause will become obsolete.

For episodic release to a flowing Bohena Creek, the chemical signature of the treated water will be diluted by the natural creek water that generated flow in the creek. This natural creek water will comprise rainfall runoff and shallow alluvial groundwater. At peak release, up to 12 ML/day of water could be released from Leewood WMF. If this is released into a natural flow of at least 100 ML/day, there will be a dilution factor of at least 8 or greater. As most of the chemicals in the release water will be within the ANZECC guidelines albeit slightly above background concentrations, it will not change the chemistry of water in the creek significantly.

At Bohena Creek, background pH is close to neutral. Intermittent streams often experience a wide fluctuation in pH as they shift from continuously flowing and well-connected waterways to isolated pools (Williams 2006). The treated water is expected to have an average pH close to neutral so will not lead to changes in the pH of Bohena Creek.

Electrical conductivity of the treated water is expected to fall within the range of the ANZECC target values, but will be higher than EC in Bohena Creek (62-275 μS/cm), its aquifer (173-242 μS/cm) and the Namoi River (385-392 μS/cm). However, release to Bohena Creek during flow periods will dilute EC and reduce the impact of this to aquatic ecology.

Turbidity of the treated water will be extremely low most of the time; much lower than ANZECC trigger values, and lower than the levels measured in the Namoi River and Bohena Creek. Treated water will be released only when there is rainfall-generated flow in Bohena Creek, and the addition of this water will not significantly change the turbidity of Bohena Creek.

Other major variables that need to be considered are the differences in temperature and dissolved oxygen between the treated and receiving waters. Temperature of treated water will be approximately 25 to 30 degrees, much warmer than the winter minimums currently experienced, and dissolved oxygen concentration of water coming up from the production wells will be close to zero. Both of these variables are important to most aquatic life (Crook and Gillanders 2013, King *et al.* 2013), so a significant increase or decrease in either temperature or dissolved oxygen could impact on aquatic ecology. However, as the release will only occur in periods of surface flow, the differences between temperature in the treated water and that in Bohena Creek will be reduced. Furthermore, thorough and rapid mixing of treated water with creek flow close to the discharge location will ensure no significant difference is apparent.

Groundwater contains very little or no dissolved oxygen, and generally occurs at concentrations too low to support surface-dwelling aquatic species (Strayer 1994). Low dissolved oxygen concentrations in rivers can lead to the death of aquatic organisms, as well as suppressed growth (Koehn and Kennard 2013). Without mitigation the dissolved oxygen concentration of water entering the creek is likely to be extremely low. Dissolved oxygen concentration in discharged water should be as near as possible to that of Bohena Creek prior to release to reduce the chance of hypoxia. Dissolved oxygen concentration in Bohena Creek will be close to saturation during periods of flow because the water will be moving, and because much of the water will already be oxygenated from recently falling as rain. Treated water released from Leewood WMF will be diluted when it enters Bohena Creek during periods of flow.

6.1.5 Post-project impacts

While the Leewood WMF is operational, releases would only occur during flow periods, retaining the intermittent flow regime. This means there are unlikely to be any long-term impacts to ecology once the WMF ceases operation.

6.2 Impacts from crossings and infrastructure

Road and pipe crossings of Bohena Creek and other drainage lines in the project area have the potential to obstruct fish passage, damage riparian vegetation, and cause compaction or erosion of the creek bank and bed. Where possible, existing road crossings should be used to prevent the need for further vegetation removal. Any constructed road crossing of Bohena Creek, such as a causeway, low bridge, or culvert, could provide a barrier for fish migration during flow periods. If new crossings are needed, they should be designed in accordance with *The NSW Fish Passage Requirements for Waterway Crossings* (NSW DPI 2003). Under the *Guidelines for Riparian Corridors on Waterfront Land* (NSW DPI 2012), streams with a Strahler Order of 4 and above need a culvert or a bridge for road crossings. However, Bohena Creek is dry for most of the time, so unless there is a lot of traffic, or wet-weather crossings are needed, level crossings similar to those already in place in the project area would have a smaller impact on the creek ecosystem.

Pipelines crossing Bohena Creek and other drainage lines in the project area may create barriers to the upstream migration of fish during periods of flow if they are above the creek bed. However, if they are buried in the bed of Bohena Creek, they are unlikely to cause any problems to fish migration. Pipes should be buried during dry periods when the water level of the Bohena Creek alluvium is deeper than 70 cm below the creek bed. This will remove the chance of impacts to any stygofauna in the area.

The *Guidelines for Riparian Corridors on Waterfront Land* (NSW DPI 2012) provide procedures for conducting controlled activities adjacent to rivers. It gives minimum riparian zone widths that are based on Strahler Stream Order. Under the Strahler system of calculating stream order, Bohena Creek is aa sixth order stream. This means that any roads, pipelines or powerlines running alongside the creek need to be set back at least 40 m (NSW DPI 2012). Other infrastructure, such as wells and buildings should also be separated by the creek by a riparian zone at least 40 m wide.

6.3 Tests of significance and impacts to threatened species

6.3.1 Fish and invertebrates

All fish species that were collected or observed during sampling are common in the Namoi River catchment except for the Eel-tailed Catfish. The Murray-Darling Basin population of this species is listed as threatened under the FM Act. There are records for Eel-tailed Catfish from the last decade in several waterways throughout the Namoi River catchment. Prior to this survey, the most recent in the Namoi River is from 2009 at sites upstream and downstream of Mollee Weir (NSW DPI 2013).

Although Eel-tailed Catfish occur in suitable habitat throughout the Murray-Darling Basin, most riverine populations have declined significantly over the last thirty years (Lintermans 2007). The decline is variously attributed to competition with introduced Common Carp and *Perca fluviatilis* (Redfin), cold-water pollution below dams, barriers to movement, changes to natural flow regimes, and elevated salinity levels (Lintermans 2007). No catfish are likely to occur in Bohena Creek because it lacks suitable habitat, so there are unlikely to be any impacts from the release to this species.

Other threatened species which occur in the Namoi River and tributaries, but weren't detected during this survey, are Murray Cod and Silver Perch. Murray Cod is a large-bodied, long-lived, territorial species, known to occur in a wide range of habitats in the Murray-Darling Basin (McDowall 1996). The last reported records for Murray Cod in the Namoi River are from 2009, both upstream and downstream of the Mollee Weir (NSW DPI 2013). Silver Perch are a moderate to large-bodied species, and occur in similar habitats to the Murray Cod. This species was last reported from the Namoi River near the study site in 2005 (NSW DPI 2013). Both species have experienced significant declines in distribution and abundance in the Murray-Darling Basin, owing to changed flow and temperature regimes from river regulation, cold-water releases from dams, degradation of in-stream habitats (i.e. loss of riparian vegetation, sedimentation, barriers to passage, decline in water quality), and competition from introduced species (NSW DPI 2005). The proposed release to Bohena Creek will not result in any of the impacting factors known to have contribute to declines in these species, so will not cause reductions in their populations.

The presence of Murray-Darling Rainbowfish at all three sites along the Namoi River is also significant. Although the species is not considered threatened, it was previously widespread throughout the Murray-Darling Basin, but is now uncommon (Lintermans 2007). Like Murray Cod and Silver Perch, threats to the Murray-Darling Rainbowfish are predation by introduced species, loss of habitat and cold-water pollution (Lintermans 2007). Because of its size, it is also possible that this species will be vulnerable to fin-pecking by Plague Minnow. The release of water to Bohena Creek will have no impact on this species.

As per **Table 8** and **Table 9**, EPA Act and EPBC Act tests of significance were conducted for the following species and populations:

- Murray-Darling Basin population of *Tandanus tandanus* (Freshwater Catfish)
- *Notopala sublineata* (River Snail)
- *Bidyanus bidyanus* (Silver Perch)
- *Maccullochella peelii peelii* (Murray Cod)

The completed tests are at **Appendix G** and **Appendix H**.

The tests for concluded that the proposed release will have no or negligible impacts on these species because none occur in Bohena Creek.

6.3.2 Riparian vegetation communities

The potential impacts of the Leewood release to the riparian vegetation community of Bohena Creek are negligible. This is because release will not occur until the creek is already flowing with a volume of at least 100 ML/d, so any weed species whose propagules are spread by water will have already been distributed by natural flows.

Other impacts may occur where pipes or roads need to cross drainage lines. In these cases, some vegetation may need to be cleared if there are no existing tracks. While existing crossings will be utilised where possible, the exact locations of crossing sites are not known at this stage and additional crossings are likely to be required. Prior to the removal of riparian vegetation, searches should be made for threatened plant species and endangered ecological communities to minimise impacts.

6.3.3 Potential impacts to stygofauna communities

No stygofauna were detected in any samples collected from the Bohena Creek alluvial aquifer, but as with any sampling exercise, there remains a small chance that some species occur in the deeper parts that are permanently saturated. The proposed release to Bohena Creek is unlikely to have a significant impact on stygofauna communities because, at the time of discharge Bohena Creek will be flowing and the alluvial aquifer will be saturated. Only a small proportion of the water released to flowing Bohena Creek will enter the aquifer.

Operations potentially create the following risks to stygofauna:

- impacting suitable habitat during drilling
- impacts to groundwater levels or water quality associated with trans-boundary flow between aquifers due to improper drilling and/or completion techniques

- Depressurisation of underlying aquifers that alters the physical structure of stygofauna habitat and subsequently changes groundwater levels or quality.

The proposed project does not include wells that require drilling through the Namoi alluvial aquifer and this significantly reduces the potential for impact to stygofauna. A maximum drawdown of 0.5 m has been predicted from numerical modelling in the Groundwater Impact Assessment (CDM Smith, 2016) for the Namoi River alluvial aquifer. This is unlikely to have an impact on stygofauna communities, which are likely to be resilient to such small fluctuations in the water table. Stygofauna living in alluvial aquifers have evolved under conditions where the water table fluctuates naturally, and are able to move up and down with the water table provided the change in water level is not too extreme.

Provided drilling, operation and closure activities are undertaken in accordance with the relevant guidelines and legislation, the proposed project activities are very unlikely to pose a significant threat to any known or potential stygofauna habitat.

Pipe crossings will also pose no significant threat to stygofauna, as burial will occur in dry periods when the groundwater table is below the depth of excavation.

6.4 Summary

The selection of an episodic managed release scheme (and mitigation measures outlined in the Managed Release Study) will ensure impacts to aquatic ecosystem components can be avoided. Episodic releases to a flowing creek (with natural flows of than 100 ML/day or greater) would result in almost negligible impact to the aquatic ecological community because it will cause no major change to the hydrological regime, and will allow for the dilution of released water. Mitigation measures are discussed in **Section 7**.

7 Mitigation measures

This section describes mitigation measures for aquatic ecology related impacts from releasing to a flowing creek (with natural flows greater than 100 ML/day), as described in **Section 6**. Information used to describe potential impacts is limited to that drawn from information contained in preceding sections of this report.

Table 19 provides a list of suggested measures to avoid, manage and mitigate potential impacts on aquatic ecosystems arising from episodic release to Bohena Creek. It also includes an assessment of the potential for residual impacts once the suggested mitigation has been implemented. The two main mitigation measures listed in the table are to amend temperature and dissolved oxygen concentration of water prior to discharge. However, the extent to which this is necessary is uncertain, and will depend on the flow moving past the discharge point at the time of release. At its lowest, 100 ML/d will be flowing in Bohena Creek when water is released from Leewood, and this water should have a high DO concentration. Depending on the rate of release, the amount of water in the creek should be sufficient to minimise or negate the temperature or DO differential. Even larger natural flow volumes will have a greater capacity to absorb the released water, and so make the amending of DO concentration and temperature unnecessary.

Guidelines in Queensland suggest that the ecology of appropriate flow-dependent assets (i.e. species or ecological processes) should be used to establish management targets for treated coal seam gas (CSG) water releases in intermittent creeks (McGregor et al. 2011). By this, the guidelines suggest the careful selection of species whose biology is in some way influenced by flow, and whose population dynamics are likely to be affected by the managed water release (McGregor et al. 2011). While, from a conservation perspective, it may be preferable to focus release management on the needs of threatened species, the effectiveness of this is not always measurable because of their rarity. Instead, using species that are relatively common and that show responses to flow should form the basis of monitoring. The biology of the selected species also needs to be known in a sufficient amount of detail so that the impacts for different flow scenarios can be predicted (McGregor et al. 2011).

Consideration was given to finding a biological indicator that could be used to assess ecological changes caused by the managed release. However, at periods when water is released to Bohena Creek, there will be at least 100ML/d of natural flow in the system, and flow-sensitive taxa will already be mobilised by the natural flow. It is unlikely that changes in any potential indicators (e.g. Spangled Perch, Carp Gudgeon, Carp, overall fish diversity, and *Phragmites australis* density) could be attributed to the portion of flow contributed by managed release. No biological indicators could be identified that are sensitive enough to distinguish between natural flows from the portion of flow contributed by the managed release.

Table 19: Suggested mitigation measures

Risk/issue	Potential impacts	Mitigation options	Residual impacts
Treated water for release has higher temperature than receiving environment.	More stable water temperature may favour exotic species such as Plague Minnow. Warmer winter temperatures can	Heat transfer from gathering lines to 'Leewood WMF'. Heat transfer from 'Leewood WMF' ponds.	LOW - as treated water is likely to be an equivalent or slightly lower temperature to that of the receiving environment.

Risk/issue	Potential impacts	Mitigation options	Residual impacts
	increase breeding success in this exotic species.	Heat transfer through pipeline from WMF to release point. Thorough and effective mixing through diffuser at discharge location.	
Treated water for release has lower dissolved oxygen concentration than the receiving environment.	Input of low-oxygen water can result in fish-kills and the loss of some animals.	Aeration in the Leewood ponds and spraying at the discharge point will increase the DO concentration prior to discharge. However, this is unlikely to be necessary because water in the creek will already be turbulent and have a high DO concentration. Thorough and effective mixing through diffuser at discharge location.	LOW – water in the creek is already likely to be turbulent and have a high DO concentration, so released water will soon equilibrate.
Road and pipe crossings blocking fish passage	Fish are not able to migrate upstream during flow periods.	Use existing road crossings where possible or construct crossings that are similar to existing or that are compliant with the NSW DPI guidelines for waterway crossings. Bury pipelines at least 70 cm below the bed of Bohena Creek.	LOW – fish will be able to move upstream provided roads and pipes create no barrier to passage.
Damage to riparian zone vegetation	Riparian vegetation is removed, increasing silt and nutrient concentrations in Bohena Creek.	Refer to the Guidelines for Riparian Corridors on Waterfront Land and ensure that infrastructure is set back at least 30 m for third order streams and 40 m for fourth order and greater.	LOW

8 Conclusions

8.1 Conclusions

This aquatic ecology and stygofauna assessment collected samples from the Namoi River and tributaries in the area impacted by the project. Rivers and creeks in the area are currently impacted by agricultural activities and river regulation. All of the smaller creeks are ephemeral, and are in poor to good ecological condition.

None of the species collected from Bohena Creek are listed as threatened, nor are any threatened aquatic species likely to occur in Bohena Creek in the area of potential influence for the proposed managed release. Eel-tailed Catfish are present in the Namoi and were collected downstream of Mollee Weir. Catfish are not likely to use Bohena Creek because it is mostly dry and the adults are relatively sedentary, so unlikely to move upstream in periods of flow. The isolated pools have insufficient habitat for them to be used as breeding habitats. Similarly, release to Bohena Creek is unlikely to have any impact on Eel-tailed Catfish populations in the Namoi River because of the distance between the Leewood site and the Namoi River confluence.

Release to Bohena Creek only when there is a flow considerably reduces the potential impact to Bohena Creek aquatic ecology because it still allows for long periods of no flow and maintains the current intermittent flow regime.

During periods of flow, many species in intermittent streams are in a state of dynamism. For example, some invertebrate species drift downstream, while fish move upstream. Water chemistry during these periods is also different to what it is when the pools are isolated. As the temporary periods of flow constitute natural events that stimulate many ecological processes, the ecological community of Bohena Creek should tolerate the addition of water from the Leewood WMF in the volumes proposed under the episodic release scenario and with the chemistry expected.

Sampling has not found any stygofauna in the alluvium of Bohena Creek, nor are extensive stygofauna communities likely because of the poor development of the aquifer and the frequency with which the aquifer dries. However, if stygofauna were to occur in the aquifer, the managed release would have negligible impact to the community because the release will only occur when the aquifer is saturated. Also, the thorough and rapid mixing of treated water released to the creek would ensure no change to groundwater chemistry in the alluvial aquifer. The adoption of field protocols for pipe crossings of any drainage lines will ensure that no impacts to potential stygofauna populations or habitat are realised through project operation.

8.2 Recommendations

The surveys reported in this assessment aimed to assess baseline ecological condition in Bohena Creek, the Namoi River, and some of the larger tributaries. An important gap in our understanding is what the baseline ecological communities of Bohena Creek, and other ephemeral creeks, are like when surface flow continues for an extended period of time. This is because all sampling to date has occurred during a period of drying.

When the Leewood WMF becomes operational, sampling should occur before and following a number of episodic releases to assess whether there are changes to the aquatic ecology. Sites should be routinely monitored in autumn and spring to determine whether release is altering aquatic ecosystems. It will be difficult to isolate the impacts attributable to release water from those that occur from natural flows, but comparisons between upstream and downstream sites will facilitate this. Continual monitoring is particularly important if there is an unexpected and prolonged persistence of water in the creek channel.

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Appendix A: Aquatic site photos

The scale of the aerial imagery is 1:10,000 (i.e. 1 cm = 100 m) and the source of the imagery is ArcGIS 10.1 Basemap.

Sites for mid-Namoi Catchment Assessment. The scale of the aerial imagery is 1:10,000 (i.e. 1 cm = 100 m) and the source of the imagery is ArcGIS 10.1 Basemap.

Upstream

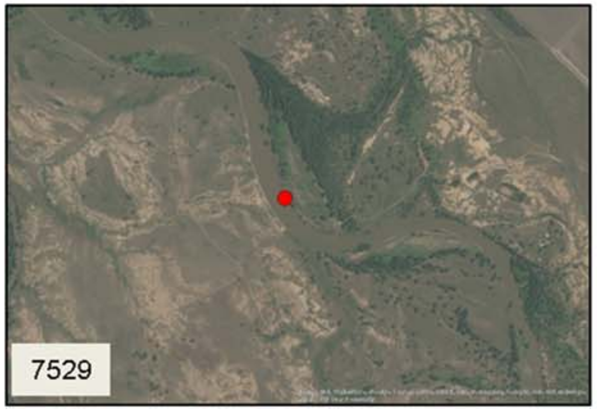
Downstream

	Upstream	Downstream
		
		

Upstream

Downstream

Upstream | Downstream



Upstream

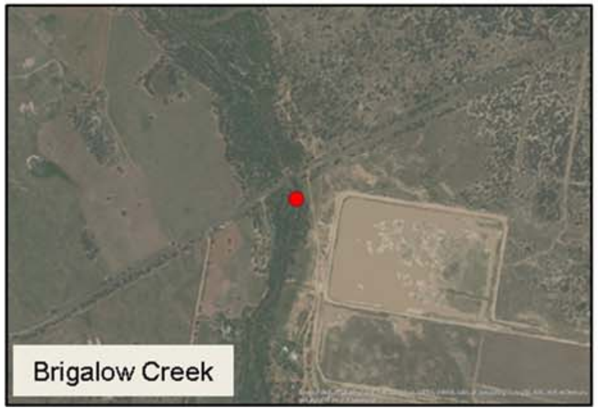
Downstream

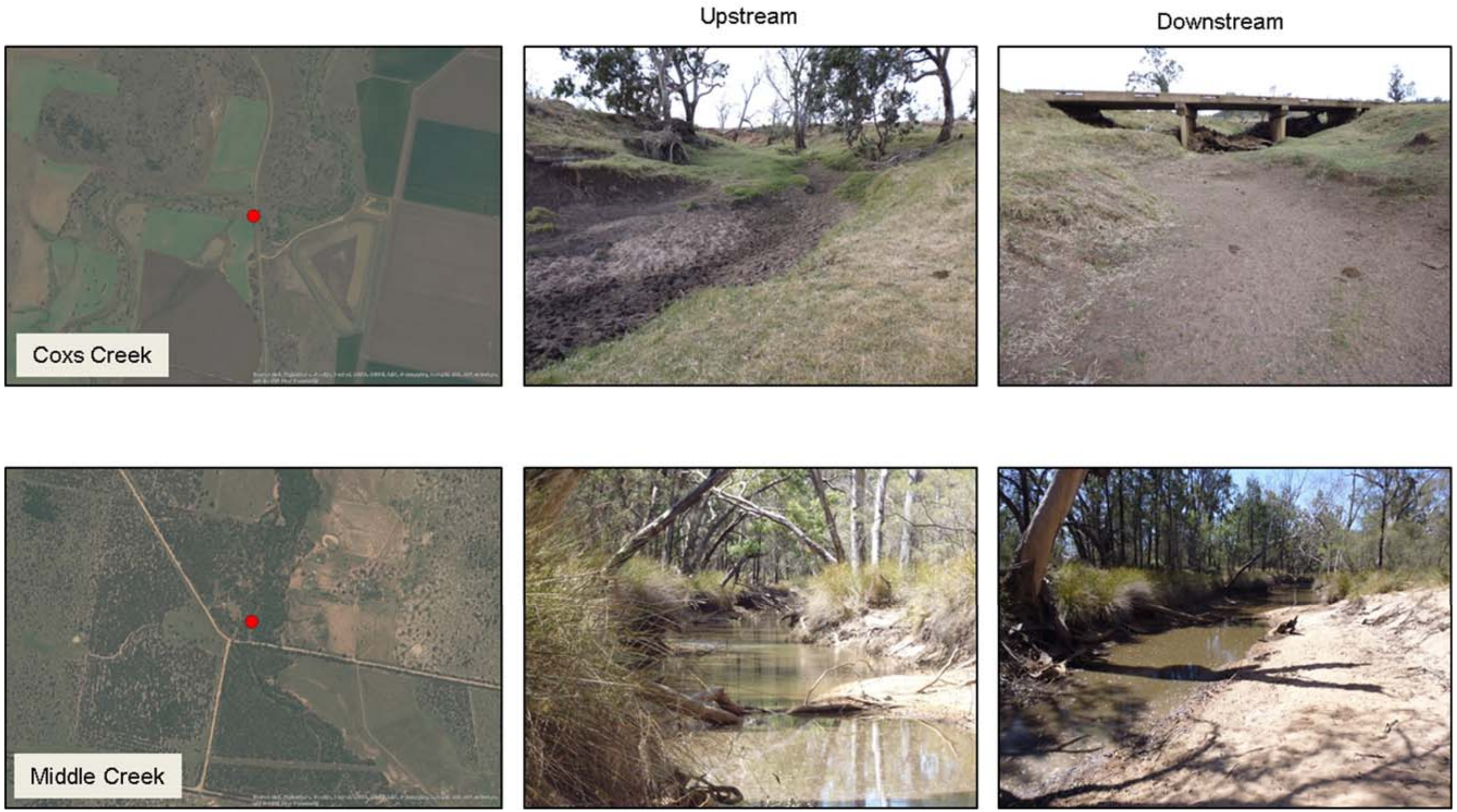
Upstream

Downstream

Upstream

Downstream




Upstream
Downstream
Coxs Creek
Middle Creek

Upstream | Downstream

Sites for the Bohena Creek Study:


SITE MW - Mollee Weir site looking downstream in autumn (left) and spring (right)


SITE MW - Mollee Weir site looking upstream in autumn (left) and spring (right)


SITE NRDS - Namoi River downstream of Mollee Weir looking downstream in autumn (left) and spring (right)

SITE NRDS - Namoi River downstream of Mollee Weir, looking upstream in autumn (left) and spring (right)

SITE NCUS - Narrabri Creek facing upstream in autumn (left) and spring (right)

SITE NCUS - Narrabri Creek facing downstream in autumn (left) and spring (right)

SITE BCUSD - Bohena Creek upstream of the proposed release site looking downstream in autumn (left) and spring (right)

SITE BCUSD - Bohena Creek upstream of the proposed release site looking upstream in autumn (left) and spring (right)

SITE BCUS - Bohena Creek upstream site, looking downstream in autumn (left) and spring (right)

SITE BCUS - Bohena Creek upstream release site, looking upstream in autumn (left) and spring (right)

SITE BCD - Bohena Creek near the proposed release site in autumn (left) and spring (right)

SITE BCDS - Bohena Creek downstream of the proposed release site in autumn looking upstream (left) and downstream (right)

SITE BCS02 – Bohena Creek near the Newell Highway bridge looking upstream (left) and downstream (right). Photos taken in October 2014.

SITE BCS07 – Bohena Creek waterhole looking upstream (left) and downstream (right), in October 2014.

SITE BCS09 – Bohena Creek waterhole upstream of Culgoora Rd looking upstream (left) and downstream (right) in October 2014.


TEDS HOLE- Bohena Creek looking upstream (left) and downstream (right) in October 2014.

Appendix B: Scoring and weighting of site attributes

Site Attribute	Site Attribute Score (see notes below)				Weighting for site attribute score
	0	1	2	3	
Native Plant Species Richness	0	>0 – <50% of benchmark	50–<100% of benchmark	≥ benchmark	25
Native Over-storey Cover (%)	0–10% or >200% of benchmark	>10–<50% or >150–200% of benchmark	50–<100% or >100–150% of benchmark	within benchmark	10
Native Mid-storey Cover (%)	0–10% or >200% of benchmark	>10–<50% or >150–200% of benchmark	50–<100% or >100–150% of benchmark	within benchmark	10
Native Ground Cover-grasses (%)	0–10% or >200% of benchmark	>10–<50% or >150–200% of benchmark	50–<100% or >100–150% of benchmark	within benchmark	2.5
Native Ground Cover-shrubs (%)	0–10% or >200% of benchmark	>10–<50% or >150–200% of benchmark	50–<100% or >100–150% of benchmark	within benchmark	2.5
Native Ground Cover-other (%)	0– 10% or >200% of benchmark	>10–<50% or >150–200% of benchmark	50–<100% or >100–150% of benchmark	within benchmark	2.5
Exotic Plant Cover (%)	>66%	>33–66%	>5–33%	0–5%	5
Number of Trees with Hollows	0 (unless benchmark includes 0)	>0–<50% of benchmark	50–<100% of benchmark	≥ benchmark	20
Proportion of over-storey species occurring as regeneration	0	>0–<50%	50–<100%	1	12.5
Total Length of Fallen Logs (m)	0–10% of benchmark	>10–<50% of benchmark	50–<100% of benchmark	≥ benchmark	10

Note: The term ‘within benchmark’ means a measurement that is within (and including) the range of measurement identified as the benchmark for that vegetation type. The term ‘<benchmark’ means a measurement that is less than the minimum measurement in the benchmark range. The term ‘>benchmark’ means a measurement that is greater than the maximum measurement in the benchmark range.

Appendix C: Riparian plant species list

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
1. Gymnosperms										
Cupressaceae		*Callitris glaucophylla*	White Cypress-pine	+			2			
2. Dicotyledons										
Amaranthaceae		*Alternanthera denticulata*	Common Joyweed	+	+	r		1	r	
Amaranthaceae	Y	*Alternanthera pungens*	Khaki Weed							r
Amaranthaceae	Y	*Amaranthus* sp.						r		
Amaranthaceae	Y	*Amaranthus* sp.						r		
Apiaceae	Y	*Daucus carota*	Wild Carrot				r	r		
Apocynaceae	Y	*Gomphocarpus fruticosus*	Narrow-leaved Cotton Bush						r	r
Asteraceae		Unidentified Asteraceae								+
Asteraceae	Y	*Aster subulatus*	Wild Aster					r	+	
Asteraceae	Y	*Bidens pilosa*	Farmer's Friend					+	1	+
Asteraceae	Y	*Bidens subalternans*	Greater Beggar's Ticks	r	2	+	3	+	1	5
Asteraceae		*Calotis cuneifolia*	Purple Burr-daisy	r						
Asteraceae		*Centipeda minima*	Spreading Sneezeweed			+	r			

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Asteraceae		*Chrysocephalum apiculatum*	Common Everlasting, Yellow Buttons	r		r				
Asteraceae	Y	*Cirsium vulgare*	Spear Thistle						+	+
Asteraceae	Y	*Conyza bonariensis*	Flaxleaf Fleabane	+	r	+	r	1	1	
Asteraceae		*Epaltes australis*	Spreading Nut-heads	1	+	1	+			
Asteraceae		*Pseudognaphalium luteoalbum*	Jersey Cudweed	+	r	+	r			
Asteraceae	Y	*Sonchus oleraceus*	Common Sow-thistle, Milk-thistle					r	r	
Asteraceae		*Tagetes minuta*	Stinking Roger						r	
Asteraceae		*Vittadinia cuneata* var. *cuneata*	Fuzzweed				1			
Asteraceae	Y	*Xanthium occidentale*	Noogoora Burr				r	1	1	+
Brassicaceae	Y	Unidentified Brassicaceae								r
Brassicaceae	Y	*Lepidium africanum*	Common Peppercress					r	+	
Cactaceae	Y	*Opuntia stricta*	Prickly Pear, Common Pest Pear	r			r			+
Campanulaceae		*Wahlenbergia* sp. (unidentified)	Australian Bluebell			r				
Chenopodiaceae		*Atriplex semibaccata*	Creeping Saltbush							r
Chenopodiaceae		*Chenopodium* sp.						r		
Chenopodiaceae		*Einadia hastata*		r						r

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Chenopodiaceae		*Einadia nutans*	Climbing Saltbush		r		r	r		+
Chenopodiaceae		*Einadia trigonos*	Fishweed				+			
Chenopodiaceae		*Sclerolaena* sp.								r
Clusiaceae		*Hypericum gramineum*	Small St Johns-wort	+	r	r	+			
Euphorbiaceae	Y	*Ricinus communis*	Castor Oil Plant					2		
Fabaceae Caesalpinioideae		*Senna barclayana*	Smooth Senna						+	
Fabaceae Faboideae		*Crotalaria mitchellii*	Yellow Rattlepod	r						
Fabaceae Faboideae		*Glycine canescens*	Silky Glycine	+		r	r			
Fabaceae Faboideae		*Medicago* sp.	Medic						r	r
Fabaceae Faboideae	Y	*Vicia* sp.	Vetch					r	+	+
Fabaceae Mimosoideae		*Acacia deanei* subsp. *deanei*	Green Wattle, Deane's Wattle	r		1	1			
Fabaceae Mimosoideae		*Acacia* sp.		r		r				
Fabaceae Mimosoideae	Y	*Cachiella farnesiana*	Mimosa Bush							r
Fumariaceae	Y	*Fumaria* sp.						r		
Haloragaceae		*Haloragis heterophylla*	Raspwort			r				
Malvaceae		*Malvastrum coromandelianum*	Prickly Malvastrum						r	

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Malvaceae	Y	*Sida rhombifolia*	Paddy's Lucerne					+	1	+
Malvaceae		*Sida* sp. (unidentified)								+
Myrtaceae		*Callistemon linearis*	Narrow-leaved Bottlebrush	2		2				
Myrtaceae		*Eucalyptus blakelyi*	Blakely's Red Gum	1	2	1	2			
Myrtaceae		*Eucalyptus camaldulensis*	River Red Gum					3	3	2
Myrtaceae		*Leptospermum polygalifolium*	Tantoon			+				
Nyctaginaceae		*Boerhavia* sp.	Tarvine							+
Oxalidaceae		*Oxalis perennans*	Oxalis					r	r	+
Polygonaceae		*Persicaria* sp.		+	+			r		
Polygonaceae		*Polygonum aviculare*	Wireweed						r	
Polygonaceae		*Rumex brownii*	Slender Dock		+		+	1		+
Polygonaceae	Y	*Rumex crispus*	Curled Dock					1	r	
Polygonaceae		*Rumex* sp.						+		
Rubiaceae	Y	*Galium aparine*	Goosegrass					1		
Rutaceae		*Geijera parviflora*	Wilga							r
Salicaceae	Y	*Salix babylonica*	Weeping Willow					2	2	
Solanaceae		*Lycium ferocissimum*	African Boxthorn						2	+

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Solanaceae	Y	*Solanum nigrum*	Black-berry Nightshade					r		
Urticaceae		*Urtica incisa*	Stinging Nettle, Scrub Nettle					r		
Verbenaceae		*Verbena quadrangularis*						1		r
Verbenaceae	Y	*Glandularia aristigera*	Mayne's Pest, Moss Verbena		1	+	1			
Verbenaceae	Y	*Lippia nodiflora*	Lippia						1	
4. Monocotyledons										
Alliaceae	Y	*Nothoscordum gracile*	Onion Weed						r	
Amaryllidaceae		*Crinum flaccidum*	Darling Lily						+	
Commelinaceae		*Commelina cyanea*	Blue Spiderwort	r			r			
Commelinaceae		*Commelina ensifolia*	Scurvy Grass					1	+	
Cyperaceae		*Carex* sp.			1					
Cyperaceae		*Cyperus exaltatus*		+	1			+		
Cyperaceae		*Cyperus gracilis*	Slender Sedge				r			r
Cyperaceae		*Cyperus* sp.						+		
Juncaceae		*Juncus* sp.	Rush	+	2	1	+			
Lomandraceae		*Lomandra leucocephala subsp. leucocephala*	Woolly-head Mat-rush		+					

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Lomandraceae		*Lomandra longifolia*	Spiny-headed Mat-rush, Honey Reed, Spike Mat-rush			r	2			
Poaceae		*Aristida jerichoensis* var. *jerichoensis*	Jericho Wiregrass				r			
Poaceae		*Aristida ramosa*	Purple Wiregrass					1	r	
Poaceae		*Aristida* sp. *warburgii?*	Wiregrass							2
Poaceae		*Arundinella nepalensis*	Reedgrass	r	1	+	+			
Poaceae		*Austrostipa* sp.	Speargrass							+
Poaceae		*Austrostipa verticillata*	Slender Bamboo Grass		+		+			
Poaceae		*Bothriochloa decipiens*	Redleg Grass, Pitted Bluegrass						+	2
Poaceae		*Bothriochloa ewartiana*	Desert Bluegrass						r	r
Poaceae	Y	*Bromus catharticus*	Prairie Grass					4	r	
Poaceae	Y	*Chloris gayana*	Rhodes Grass					r		
Poaceae		*Cymbopogon refractus*	Barbed Wire Grass	+	r		+			
Poaceae	Y	*Cynodon dactylon*	Barbed Wire Grass	r		+	+	3	5	1
Poaceae		*Dactylis glomerata*	Cocksfoot							r
Poaceae		*Dichanthium sericeum*	Silky Blue-grass					r	r	1
Poaceae		*Digitaria brownii*	Cotton Panic Grass		r					

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Poaceae		*Digitaria divaricatissima*	Umbrella Grass				r			
Poaceae	Y	*Digitaria sanguinalis*	Summer Grass						r	
Poaceae		*Echinochloa colona*	Awnless Barnyard Grass					+	r	
Poaceae		*Enteropogon acicularis*	Curly Windmill Grass					+		+
Poaceae	Y	*Eragrostis curvula*	African Lovegrass	+		+				
Poaceae		*Eragrostis* sp.	Love Grass							r
Poaceae		*Eragrostis* sp. 2	Love Grass	1						
Poaceae		*Eriochloa pseudoacrotricha*	Early Spring Grass					1	1	
Poaceae		*Imperata cylindrica*	Blady Grass	3	5	3	3			
Poaceae		*Microlaena stipoides*	Meadow Rice-grass, Weeping Grass				r			
Poaceae		*Panicum sp.*						1	1	
Poaceae		*Paspalidium gracile*	Slender Panic					1	1	1
Poaceae		*Paspalidium* sp.						+		+
Poaceae	Y	*Paspalum dilatatum*	Paspalum					r	+	
Poaceae		*Paspalum* sp.							1	1
Poaceae		*Phragmites australis*	Common Reed		1	2				

Family	Exotic	Species	Common Name	BCDS	BCD	BCUSD	BCUS	NRDS	MW	NCUS
Poaceae	Y	*Setaria parviflora*			r		r	r	+	
Poaceae		*Sporobolus coromandelianus*	Small Dropseed							r
Poaceae		*Themeda australis*	Kangaroo Grass				r			

Appendix D: Threatened species habitat preferences

Common Name	Scientific Name	Habitat Description
PLANTS		
Coolabah Bertya	*Bertya opponens*	Ranges from stony mallee ridges and cypress pine forest on red soils.
Lobed Bluegrass	*Bothriochloa biloba*	Commonly found on clay soils.
Ooline	*Cadellia pentastylis*	Ooline occurs in low- to medium-nutrient soils of sandy clay or clayey consistencies, with a typical soil profile having a sandy loam surface layer, grading from light clay to medium clay with depth.
	Cyperus conicus	The species grows in open woodland on sandy soil. In central Australia, it grows near waterholes and on the banks of streams in sandy soils. In QLD the species is usually found on heavy soils. It has been recorded from *Callitris* forest in the Pilliga area, growing in sandy soil with *Cyperus gracilis, C. squarrosus* and *C. fulvus*.
Bluegrass	*Dichanthium setosum*	Associated with heavy basaltic black soils. Often found in moderately disturbed areas such as cleared woodland, grassy roadside remnants and highly disturbed pasture.
Finger Panic Grass	*Digitaria porrecta*	Habitat includes native grassland, woodlands or open forest with a grassy understorey, on richer soils.
Pine Donkey Orchid	*Diuris tricolor*	Grows in sclerophyll forest among grass, often with native Cypress Pine (*Callitris* sp.). It is found in sandy soils, either on flats or small rises. Also recorded from a red earth soil in a Bimble Box community in western NSW. Disturbance regimes are not known, although the species is usually recorded from disturbed habitat

Common Name	Scientific Name	Habitat Description
Square Raspwort	*Haloragis exalata subsp. exalata*	Protected and shaded damp situations in riparian habitats.
Belson's Panic	*Homopholis belsonii*	Habitat and ecology poorly known. Grows in dry woodland (e.g. Belah) on poor soils.
Spiny Peppercress	*Lepidium aschersonii*	Found on ridges of gilgai clays dominated by *Acacia harpophylla* (Brigalow), with *Austrodanthonia* and/or *Austrostipa* species in the understorey. The species grows as a component of the ground flora, in grey loamy clays. Vegetation structure varies from open to dense Brigalow, with sparse grassy understorey and occasional heavy litter.
Winged Peppercress	*Lepidium monoplocoides*	Known to occur on seasonally moist to waterlogged sites, on heavy fertile soils. In the Pilliga, it has been found in White Cypress Pine-Bulloak-ironbark woodland of the Pilliga area of the Brigalow Belt South Bioregion vegetation and associated with gilgais.
Large-leafed Monotaxis	*Monotaxis macrophylla*	Grows on rocky ridges and hillsides. There is a great diversity in the associated vegetation within NSW (less though in Queensland), encompassing coastal heath, arid shrubland, forests and montane heath from almost sea level to 1300 m altitude.
	Philotheca ericifolia	Grows chiefly in dry sclerophyll forest and heath on damp sandy flats and gullies
Native Milkwort	*Polygala linariifolia*	Occurs in sandy soils in dry eucalypt forest and woodland with a sparse understorey. The species has been recorded from the Inverell and Torrington districts growing in dark sandy loam on granite in shrubby forest of *Eucalyptus caleyi, Eucalyptus dealbata* and *Callitris*, and in yellow podsolic soil on granite in layered open forest.
Scant Pomaderris	*Pomaderris queenslandica*	The species is found in moist eucalypt forest or sheltered woodlands with a shrubby understorey, and occasionally along creeks.

Common Name	Scientific Name	Habitat Description
Greenhood Orchid	*Pterostylis cobarensis*	The Greenhood Orchid is found in Eucalypt woodlands, open mallee or *Callitris* shrublands on low stony ridges and slopes in skeletal sandy-loam soils
	Rulingia procumbens	It grows in sandy sites, often along roadsides. Recorded in *Eucalyptus dealbata* and *E. sideroxylon* communities, *Melaleuca uncinata* scrub, under mallee eucalypts with a *Calytrix tetragona* understorey, and in a recently burnt Ironbark and *Callitris* area. It also occurs in *E. fibrosa* subsp. *nubila, E. dealbata, E. albens* and *Callitris glaucophylla* woodlands north of Dubbo
Shrub Sida	*Sida rohlenae*	It occurs in flood-out areas, creek banks and at the base of rocky hills. NSW specimens have been found along roadsides in hard red loam to sandy-loam soils.
Velvet Thread-petal	*Stenopetalum velutinum*	*Stenopetalum velutinum* is currently distributed in Queensland, Western Australia, South Australia, and the Northern Territory. It is presumed extinct in NSW.
Slender Darling Pea	*Swainsona murrayana*	The species has been collected from clay-based soils, ranging from grey, red and brown cracking clays to red-brown earths and loams. It grows in a variety of vegetation types including bladder saltbush, black box and grassland communities on level plains, floodplains and depressions and is often found with Maireana species.
Austral Toadflax	*Thesium australe*	Austral Toadflax occurs in grassland or grassy woodland and often found in damp sites in association with *Themeda australis* (Kangaroo Grass).
	Tylophora linearis	Grows in dry scrub and open forest. Recorded from low-altitude sedimentary flats in dry woodlands of *Eucalyptus fibrosa*, *E. sideroxylon*, *E. albens*, *Callitris endlicheri*, *C. glaucophylla* and *Allocasuarina luehmannii*.

Common Name	Scientific Name	Habitat Description
INVERTEBRATES		
River Snail	*Notopala sublineata*	Flowing rivers, found attached to logs and rocks, or crawling in the mud (NSW DPI 2007). River Snail was once common and widespread in the Murray-Darling river system, but has undergone a rapid decline such that it is now considered virtually extinct in their natural range (NSW DPI 2007).
FISH and REPTILES		
Murray-Darling Basin population of Eel-tailed Catfish	*Tandanus tandanus*	A relatively sedentary species of slow-flowing streams and lake habitats. Widespread throughout the Murray-Darling Basin, but generally in the lower, slow-flowing rivers (Lintermans 2007).
Silver Perch	*Bidyanus bidyanus*	Fast-flowing, open waters in lowland, turbid and slow-flowing rivers (Lintermans 2007). Originally present throughout most of the Murray-Darling drainage system, except upper reaches, they have now declined to low numbers or disappeared from most of their former range (NSW DPI 2005).
Murray Cod	*Maccullochella peelii peelii*	A wide range of warm water habitats, ranging from clear, rocky streams to slow-flowing turbid rivers and billabongs in the Murray-Darling Basin (Anon. 2003). Favours deeper water around boulders, logs, undercut banks and overhanging vegetation (Allen et al. 2003). A wide range of warm water habitats, ranging from clear, rocky streams to slow-flowing turbid rivers and billabongs in the Murray-Darling Basin (Anon. 2003). Favours deeper water around boulders, logs, undercut banks and overhanging vegetation (Allen et al. 2003).
Bell’s Turtle	*Elseya belli*	Narrow sections of rivers in granite country, in shallow pools in upper reaches or small tributaries of major rivers. The pools are typically less than 3 m deep, where there is a sandy or rocky substrate, and patches of macrophytes (NSW OEH 2012a).

Common Name	Scientific Name	Habitat Description
AMPHIBIANS		
Booroolong Frog	*Litoria booroolongensis*	Permanent streams with fringing vegetation cover such as ferns, sedges or grasses. Adults occur on or near cobble banks and other rock structures along the stream (NSW OEH 2012b).
Davies' Tree Frog	*Litoria daviesae*	All records for the species are from permanently flowing streams and adjacent riparian vegetation at elevations above 400 m. Its habitat is restricted to the region from Carrai Plateau to the Barrington Tops area of the Great Divide (NSW OEH 2012c).
Sloane's Froglet	*Crinia sloanei*	Breeding habitat is ephemeral areas in grassland, woodland and disturbed habitats. Foraging habitat is areas adjacent to breeding habitat, in natural or highly modified environments (NSW OEH 2012d).
Tusked Frog population in the Nandewar and New England Tableland Bioregions	*Adelotus brevis*	Rainforests, wet forests, flooded grassland and pasture, usually near creeks, ditches and ponds hidden amongst vegetation or debris (NSW OEH 2012e). The species was once found throughout the New England Tableland and North West Slopes, but has declined throughout this area, and is now considered very rare in the region (NSW OEH 2012e).

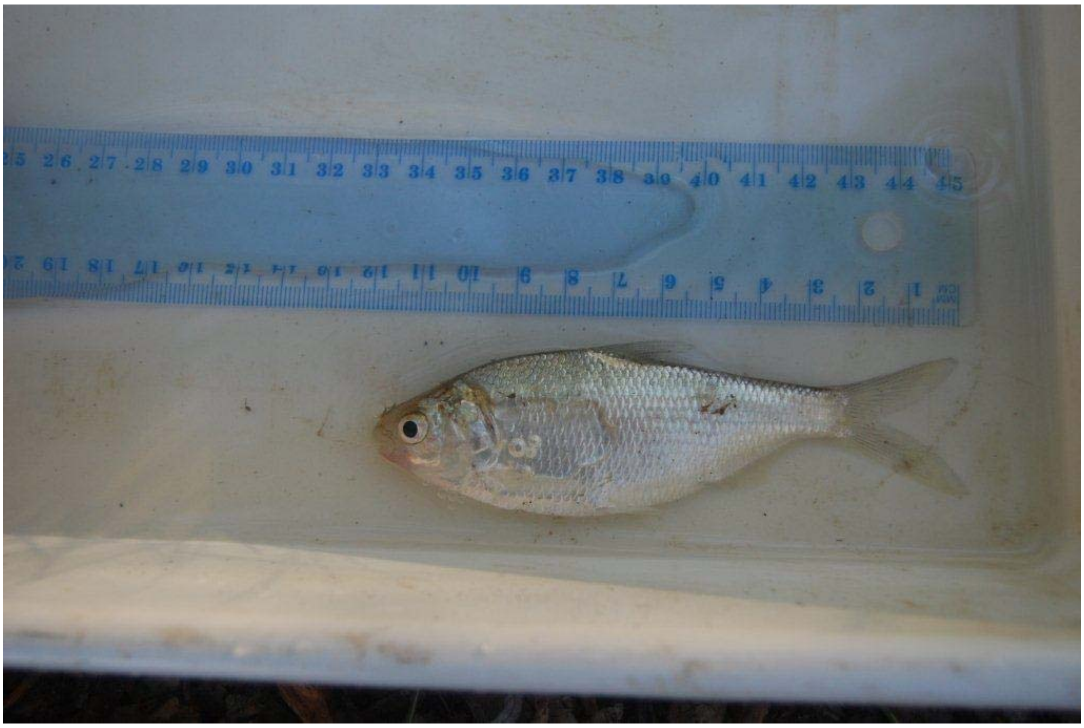
Appendix E: Macroinvertebrate taxa collected at each site

Order	Family	SIGNAL Score	NCUS				MW				NRDS				BCUS				BCUSD				BCD				TH				BCDS				BCS02				BCS07				BCS09			
			Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14	Aut13	Spr13	Aut14	Spr14
Acarina		6									X		X		X				X	X	X		X						X								X	X							X	X
Coleoptera																																														
	Chrysomelidae	2																											X																	
	Curculionidae	2																																											X	
	Hydrochidae	4											X		X				X	X								X									X	X				X			X	X
	Hydraenidae	3							X																			X									X	X			X					
	Hydrophilidae	2			X								X							X	X																X	X			X				X	X
	Dytiscidae	2											X								X		X							X											X	X				
Isopoda																																														
	Cirolanidae	2	X		X						X		X																																	
Decapoda																																														
	Atyidae	3	X	X	X	X	X	X	X	X	X	X	X	X	X				X									X	X	X	X				X		X	X			X	X			X	X
	Parastacidae	4													X					X																	X	X			X				X	X
	Palaemonidae					X	X							X	X																															X
Diptera																																														
	Ceratopogonidae	4									X	X			X				X	X									X								X	X				X			X	X
	Chironomidae	4		X	X	X	X	X	X		X	X	X	X	X				X	X	X		X					X	X		X						X	X			X	X			X	X
	Culicidae	1											X								X																X									
	Dixidae	7			X															X	X								X																	
	Simuliidae	5										X																																		
	Tabanidae	3																		X																										
	Tipulidae									X																																X				
Ephemoptera																																														
	Baetidae	5		X		X		X		X	X	X	X	X	X				X	X								X	X	X	X						X	X							X	
	Caenidae	4		X	X			X			X	X	X																		X										X					X
	Leptophlebidae	8		X	X						X	X	X	X														X																		
Gastropoda																																														
	Physidae	1																	X																											
	Ancylidae	4																		X																										
Hemiptera																																														
	Corixidae	2	X	X			X	X	X	X	X	X	X	X	X				X	X	X								X	X								X			X	X			X	X
	Galastocoridae	5																										X									X									
	Gerridae	4	X					X		X	X	X	X																																X	
	Nepidae	3																		X																		X								
	Notonectidae	1		X			X	X		X				X	X					X								X			X							X								
	Veliidae	3													X					X																		X								
	Hydrometridae	3													X																							X								
Odonata																																														
	Gomphidae	5																			X																				X					
	Aeshnidae	4													X													X																		
	Libellulidae	4						X																														X								
	Protoneuridae	4									X	X																																		
	Hemicordulidae	5													X																X															
	Lestidae	1											X								X																									
	Oxygastridae	5																													X															
	Isostictidae	5													X																															
	Telephleidae	9								X																																				
Oligochaeta		2		X	X						X																	X																		
Trichoptera																																														
	Hydropsychidae	6		X							X	X		X																																
	Leptoceridae	6		X				X			X	X	X		X				X	X			X						X		X							X			X				X	X
	Ecnomidae	4																																				X								
Number of families			4	10	8	4	5	9	4	7	14	12	15	8	16				9	15	9		4					10	9	4	8						11	17			10	7			12	11
Average SIGNAL score			2.8	4.6	3.8	3.1	2.67	4.2	3	3.8	4.93	5.15	3.5	4	4.53				4.4	4.56	3.3		4.4					3.82	4.2	2	4.56						3.7	3.3			3.45	3.13			3.8	3.58

Order	Family	SIGNAL Score	7511			7517			7518			7519			7529			7531			7533			7534			7537			7538			Brigalow Creek			Cox's Creek			Middle Creek			Sandy Creek			Spring Creek			Ted's Hole		
			Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14
Acarina		6	X	X					X	X			X													X		X				X	X						X		X		X		X				X	
Ostracoda										X			X			X									X			X									X						X						X	X
Chironomidae																																																		
	Tanypodinae		X		X	X											X			X	X							X		X			X		X	X	X		X	X						X			X	
Cladocera							X	X		X			X			X			X						X			X						X			X	X		X						X			X	
Coleoptera																																																		
	Chrysomelidae	2											X																					X									X						X	
	Curculionidae	2																																																
	Hydrochidae	4	X	X	X						X							X		X										X		X	X		X				X		X				X		X			
	Hydraenidae	3	X	X					X	X	X		X		X						X				X	X			X		X	X				X	X		X	X			X		X		X			X
	Hydrophilidae	2		X	X	X					X		X								X			X								X		X	X		X	X	X	X	X		X			X	X			
	Gyrinidae	4											X																																	X				
	Dytiscidae	2			X				X		X									X				X		X			X				X			X		X	X		X				X		X			X
	Elmidae	7																								X			X								X													
	Noteridae	4									X																																				X			
	Spercheidae																																		X																
Copepoda				X			X	X		X	X		X			X			X	X		X			X	X		X	X		X	X		X	X		X	X		X	X		X			X	X			X
Decapoda																																																		
	Atyidae	3				X	X	X	X	X	X					X	X	X	X	X	X				X					X	X	X				X	X	X	X	X	X				X	X	X		X	X
	Parastacidae	4		X	X	X					X													X																			X				X			
	Palaemonidae	4					X										X		X						X						X	X															X			
Diptera																																																		
	Ceratopogonidae	4	X		X								X			X					X					X		X	X	X			X	X					X	X	X								X	
	Chironomidae	4	X	X	X		X	X		X	X		X			X	X		X	X		X				X		X	X	X	X		X	X	X	X	X	X	X	X	X		X		X	X			X	
	Culicidae	1																																X																
	Dixidae	7					X		X	X			X			X						X						X					X	X			X		X	X						X			X	
	Orthocladiinae	4		X		X							X			X	X		X	X	X	X				X		X		X	X			X	X		X			X	X					X				
	Simuliidae	5																						X																										
	Tabanidae	3																																					X											
	Tipulidae	5	X					X			X															X			X				X					X												
	Muscidae	1																								X							X					X												
Ephemoptera																																																		
	Baetidae	5				X		X			X		X				X	X	X	X	X					X		X	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X			X	
	Caenidae	4																	X	X		X									X			X		X	X													
	Leptophlebidae	8						X								X	X		X	X								X				X				X							X							
Gastropoda																																																		
	Physidae	1								X			X											X													X													
	Ancylidae	4	X																														X						X	X					X					
	Planorbidae	2		X																																														

Order	Family	SIGNAL Score	7511			7517			7518			7519			7529			7531			7533			7534			7537			7538			Brigalow Creek			Cox's Creek			Middle Creek			Sandy Creek			Spring Creek			Ted's Hole		
			Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14	Spr13	Aut14	Spr14
Hemiptera																																																		
	Corixidae	2	X	X	X	X	X	X		X	X		X		X	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X				X	X	X		X	X
	Galastocoridae	5																																																	
	Gerridae	4								X					X						X				X									X					X	X										
	Nepidae	3																																											X					
	Notonectidae	1			X						X		X		X	X				X	X					X		X	X			X	X	X	X	X	X	X	X		X		X		X		X			
	Veliidae	3					X						X															X		X	X		X			X					X		X				X			
	Hydrometridae	3								X																		X						X																
	Pleidae	2		X						X																								X																
	Saldidae	1																																				X												
Hirundinae																																																		
	Glossiphonidae	1																																																		
	Hirudinea	1		X																													X																	
Hydrozoa																																																		
	Hydridae	2																	X									X						X																
Isopoda																																																		
	Cirolanidae	2				X	X	X								X		X	X		X	X			X					X	X																X			
Odonata																																																		
	Gomphidae	5	X										X				X																				X													
	Aeshnidae	4											X																								X													
	Libellulidae	4																																																
	Protoneuridae	4																																																
	Hemicordulidae	5	X							X			X											X				X						X		X	X	X	X	X										
	Lestidae	1																																																
	Oxygastridae	5																																																
	Isostictidae	5																																																
	Telephleidae	9																																																
	Coenagrionidae	2											X																				X				X													
	Platycnemidae																																		X															
Oligochaeta		2		X													X		X														X	X		X			X	X					X					
Platyhelminthes																																																		
	Temnocephalidae																								X																								X	
Trichoptera																																																		
	Hydropsychidae	6																																																
	Leptoceridae	6	X			X		X								X		X			X							X					X		X	X	X	X	X		X				X				X	
	Ecnomidae	4																																																
	Philorheithridae	8																											X																					
Veneroida																																																		
	Spheriidae			X						X																					X						X			X										
Number of families			14	15	10	11	10	11	7	16	14	n/a	22	n/a	6	14	11	8	14	13	14	8	n/a	9	11	14	n/a	19	12	12	13	12	20	20	12	16	22	15	21	18	15	n/a	13	n/a	15	12	14	n/a	14	7
Average SIGNAL score			3.8	3.2	2.9	3.8	3.4	3.6	4.2	3.7	2.8	n/a	3.5	n/a	2.5	4	3.1	3.7	3.5	3.5	3.3	3.7	n/a	2.7	3.3	3.4	n/a	4.1	3.4	3.5	3.5	3.6	3.5	3.2	3	3.6	3.7	2.7	3.6	3.8	3.3	n/a	3.7	n/a	3.4	3.8	2.6	n/a	4.3	2

Appendix F: Photos of fish species collected during surveys



***Nematalosa erebi* (Bony Bream) – Mollee Weir**

***Tandanus tandanus* (Eel-tailed Catfish) – Namoi River Downstream**

Leiopotherapon unicolor **(Spangled Perch) – Bohena Creek at Release**

Hypseleotris **sp. (Carp Gudgeon) – Mollee Weir**

Carassius auratus **(Goldfish) – Mollee Weir**

Macquaria ambigua ambigua **(Golden Perch) – Narrabri Creek Upstream**

Cyprinus carpio **(Common Carp) – Namoi River Downstream**

Melanotaenia fluviatilis **(Murray-Darling Rainbowfish) – Namoi River Downstream**

Appendix G: Assessment of significance (EPA Act 1979)

The following seven-part tests describe the nature and severity of any potential impacts arising during construction and operation of the proposed development on those threatened species considered ‘known’, ‘likely’ or ‘possible’ to occur in the type of habitat represented both at and in the locality of the subject site.

Groups of species with similar ecological and habitat requirements or life-cycle patterns have been assessed within a single seven-part test.

Murray-Darling Basin population of Eel-tailed Catfish – *Tandanus tandanus*

in the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Not applicable, Eel-tailed catfish is not an endangered species.

in the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction

The Eel-tailed Catfish is a benthic species that prefers slow-flowing streams and lake habitats. They build nests from pebbles and gravel with coarser material in the centre. Spawning takes place in the spring and summer months when water temperatures are 20 - 24°C. The species is primarily an opportunistic carnivore, feeding on shrimp, yabbies, freshwater prawns, with aquatic invertebrates and small fish also important (Lintermans 2007).

Eel-tailed catfish are likely only to occur in the Namoi River and not Bohena Creek.

The predicted impacts of the project are unlikely to put a local population at risk because the amount of sedimentation that occurs will be negligible compared to the current high sediment load of the river. Mollee Weir will act as a barrier downstream of the release site to intercept any sediment.

in the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

> **is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or**
>
> **is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction.**

Not applicable.

in relation to the habitat of a threatened species, population or ecological community:

> **the extent to which habitat is likely to be removed or modified as a result of the action proposed, and**

The release of treated water proposed for this project is unlikely to remove or modify catfish habitat.

> **whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and**

This project will not create any barriers to catfish movement, nor will it fragment the population.

> **the importance of the habitat to be removed, modified, fragmented or isolated to the long term survival of the species, population or ecological community in the locality,**

No habitat is proposed for removal in this project

whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly),

No critical habitat has been declared for this species.

whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan,

The objectives of the recovery plan for the Eel-tailed Catfish include:

- Protect and enhance existing populations of Eel-tailed Catfish.
- Prevent further decline in the distribution and abundance of Eel-tailed Catfish.
- Restore populations throughout the species' distribution within the Murray Darling Basin.

The recovery plan outlines actions that encompass conservation status, priority protection, population assessment, population monitoring, community awareness, river regulation, research, weir removal, introduced species, water quality, habitat components, diseases, aquaculture industry, translocations and genetic implications, and fishing (Clunie & Koehn 2001). The components that are applicable to this project relate to water quality, particularly sedimentation and habitat and are outlined in the following table.

<table>
<tr><th>Recovery Action</th><th>Relevance to project</th></tr>
<tr><td>Investigate the tolerance of all life history stages of Eel-tailed Catfish to suspended and deposited sediment levels</td><td rowspan="2">It is not clear how or if sediment levels impact upon Eel-tailed catfish, however it is suspected that when sediments settle they could pose a threat to demersal eggs and, as they are benthic feeders, smother their food source. The large volume of sand and sediment already present in the Namoi River at this site suggests that the catfish are adapted to current levels. The proposed release is unlikely to increase sediment loads.</td></tr>
<tr><td>Determine whether there is a correlation between the distribution and abundance of Eel-tailed Catfish and sediment levels</td></tr>
</table>

whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

Threats to this population include river regulation, changes to temperature regimes, barriers, introduced species, water quality, and degradation of riparian vegetation, removal of woody debris, aquatic vegetation, diseases, aquaculture, commercial fishing, and recreational fishing (Clunie & Koehn 2001).

Conclusion

On the basis of the above considerations, it is not likely that the project will result in a significant effect on the survival of the Murray-Darling Basin population of Eel-tailed Catfish – *Tandanus tandanus*.

Silver Perch – *Bidyanus bidyanus*

in the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Silver Perch is listed as a vulnerable species under Schedule 5 of the *Fisheries Management Act 1994*. The species prefers fast-flowing waters, especially where there is rapids, although have been stocked in impoundments (NSW DPI 2006). The species is unlikely to be in Bohena Creek, and if it occurs in the Namoi River at Mollee Weir, this may be a result of stocking. Downstream of the weir there is suitable habitat, but none of the impacts expected from the proposed release will affect these fish.

in the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction

Not applicable

in the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

> **is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or**
>
> **is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction.**

Not applicable.

in relation to the habitat of a threatened species, population or ecological community:

> **the extent to which habitat is likely to be removed or modified as a result of the action proposed, and**

The release of treated water proposed for this project is unlikely to remove or modify Silver Perch habitat.

> **whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and**

This project will not create any barriers to Silver Perch movement, nor will it fragment any known populations.

> **the importance of the habitat to be removed, modified, fragmented or isolated to the long term survival of the species, population or ecological community in the locality,**

No habitat is proposed for removal in this project

whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly),

No critical habitat will be altered for this species.

whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan,

The relevant objectives of the recovery plan for the Silver Perch include (NSW DPI 2006):

- Protect and enhance remaining natural populations
- Ameliorate the impacts of known major threats
- Increase scientific knowledge of ecology

No natural populations are known form the area where release will occur. If they are present, then the release of treated upstream of Mollee Weir is unlikely to threaten the species.

whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

Threats to this species include increased mortality in weir pools caused by lack of water circulation, spawning failures from cold water dam releases, predation by and competition with introduced species, barriers to migration (NSW DPI 2006). All of these threatening conditions already exist at Mollee Weir and in the Namoi upstream and downstream of the site. The proposed action does not pose a threatening process to this species.

Conclusion

On the basis of the above considerations, it is not likely that the proposed release will result in a significant effect on the survival of Silver Perch, which are unlikely to occur in Bohena Creek.

River Snail – *Notopala sublineata*

in the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction.

Notopala sublineata is listed as an endangered species in NSW. It is virtually extinct in NSW, but populations persist in irrigation pipelines in the Murray Darling Basin (NSW DPI 2007). The species is threatened by weir building, the degradation of riparian vegetation, the removal of large woody debris, and the introduction of fish (NSW DPI 2007). Neither the release point in Bohena Creek nor the pool at Mollee Weir are suitable habitat for this species, so the proposed release will not have any impact.

in the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction

Not applicable.

in the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

> **is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or**
>
> **is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction.**

Not applicable.

in relation to the habitat of a threatened species, population or ecological community:

> **the extent to which habitat is likely to be removed or modified as a result of the action proposed, and**

The release of treated water proposed for this project is unlikely to remove or modify River Snail habitat.

> **whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and**

This project will not create any barriers to River Snail movement, nor will it fragment the population.

> **the importance of the habitat to be removed, modified, fragmented or isolated to the long term survival of the species, population or ecological community in the locality,**

No habitat is proposed for removal in this project

whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly),

No critical habitat has been declared for this species.

whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan,
This project is consistent with the objectives of the recovery plan, as it poses none of the threats known to adversely impact on the species.

whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

Threats to this species include:

- removal of large woody debris
- river regulation
- removal from artificial habitat
- sedimentation
- disturbance by Carp.

The proposed release at Bohena Creek will result in none of these key threatening processes occurring.

Conclusion

The proposed release to Bohena Creek is unlikely to impose a significant effect on the River Snail because it is unlikely to occur in Bohena Creek.

Appendix H: Assessment of significance (EPBC Act MNES)

Those species consider either ‘known’, ‘likely’ or ‘possible’ in any one of the sections are included in the following assessments of significance. No critically endangered and endangered species or ecological communities, or migratory species, are considered likely to be affected by the project, so these assessments are not applied.

Murray Cod *(Maccullochella peelii)*

Criterion 1: lead to a long-term decrease in the size of an important population of a species

The proposed works will not lead to a long-term decrease in the size of an important population of the species.

Criterion 2: reduce the area of occupancy of an important population

The Namoi River has been identified as habitat for an important Murray Cod population. Cod may be present in Mollee Weir, but not in Bohena Creek. The proposed release will not reduce the amount of suitable cod habitat available in the Namoi River.

Criterion 3: fragment an existing important population into two or more populations

The project will not fragment an existing important population into two or more parts. There are natural barriers to migration upstream and downstream of the site, such as sand slugs, but the frequency of these is unlikely to increase as a result of the project. The main impediment to cod movement in the area is Mollee Weir, downstream of release.

Criterion 4: adversely affect habitat critical to the survival of a species

The proposed release will not adversely affect habitat critical to the survival of the species.

Criterion 5: disrupt the breeding cycle of an important population

The proposed works will not disrupt the breeding cycle of an important population if temperature of released water is similar to that of receiving water in spring and summer during peak breeding season. Murray Cod migrate upstream to spawn (up to 120 km) which takes place in the spring and summer months when water temperatures exceed 15 °C. Eggs are large and adhesive and usually deposited on hard surfaces such as rocks, logs, or clay banks. After hatching, larvae drift downstream for 5 – 7 days (Lintermans 2007).

Criterion 6: modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline

The proposed works will not modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline.

Criterion 7: result in invasive species that are harmful to a vulnerable species becoming established in the vulnerable species’ habitat

The proposed works will not result in the establishment of an invasive species that is harmful to the Murray Cod.

Criterion 8: introduce disease that may cause the species to decline

The proposed works will not introduce disease that may cause the species to decline.

Criterion 9: interfere substantially with the recovery of this species

The proposed works will not interfere substantially with the recovery of this species.

Conclusion of EPBC Act Assessment

It is unlikely that a release of water, as proposed for this project, will significantly impact on the Murray Cod.

Silver Perch (*Bidyanus bidyanus*)

Silver Perch prefers fast-flowing waters, especially where there is rapids, although have been stocked in impoundments (NSW DPI 2006). The species is unlikely to be in Bohena Creek, and if it occurs in the Namoi River at Mollee Weir, this may be a result of stocking. Downstream of the weir there is suitable habitat, but none of the impacts expected from the proposed release will affect these fish.

Criterion 1: lead to a long-term decrease in the size of a population

The proposed works will not lead to a long-term decrease in the size of a population of the Silver Perch.

Criterion 2: reduce the area of occupancy of the species

The Namoi River has been identified as potential habitat for a Silver Perch population, however the only known significant natural population of Silver Perch in NSW is confined to the Murray River on the border of Victoria (NSW DPI 2006). Silver Perch may be present in Mollee Weir, but not in Bohena Creek. The proposed release will not reduce the amount of suitable Silver Perch habitat available in the Namoi River.

Criterion 3: fragment an existing population into two or more populations

The project will not fragment an existing population into two or more populations. There are natural barriers to migration upstream and downstream of the site, such as sand slugs, but the frequency of these is unlikely to increase as a result of the project. The main impediment to Silver Perch movement in the area is Mollee Weir, downstream of release.

Criterion 4: adversely affect habitat critical to the survival of a species

The proposed release will not adversely affect habitat critical to the survival of the species.

Criterion 5: disrupt the breeding cycle of a population

The proposed works will not disrupt the breeding cycle of an population if temperature of released water is similar to that of receiving water in spring and summer during peak breeding season. In addition, no breeding habitat for Silver Perch occurs within the vicinity of the project. Silver Perch migrate upstream in spring and summer to spawn and can travel extensive distances. Silver Perch eggs are semi-pelagic and will sink to the bottom in absence of current, which is typically a gravelly or rock rubble substrate.

Criterion 6: modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline

The proposed works will not modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline.

Criterion 7: result in invasive species that are harmful to a critically endangered species becoming established in the critically endangered species' habitat

The proposed works will not result in the establishment of an invasive species that is harmful to the Silver Perch.

Criterion 8: introduce disease that may cause the species to decline

The proposed works will not introduce disease that may cause the species to decline.

Criterion 9: interfere substantially with the recovery of the species

The proposed works will not interfere substantially with the recovery of this species.

Conclusion of EPBC Act Assessment

It is unlikely that a release of water, as proposed for this project, will significantly impact on the Silver Perch.

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Appendix D Fluvial Geomorphology Engineering Impact Assessment

Managed Release Study: Bohena Creek – Fluvial Geomorphology Engineering Impact Assessment

Narrabri Gas Project

Prepared for
Santos NSW (Eastern) Pty Ltd

September 2016

This report should be cited as ‘Eco Logical Australia 2016. *Managed Release Study: Bohena Creek: Fluvial Geomorphology Engineering Impact Report*. Reference 2640_005. Prepared for Santos NSW Eastern Pty Ltd.’

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Contents

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Abbreviations

Abbreviation	Description
ANZECC	Australian and New Zealand Environment Conservation Council
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BSAL	Biophysical Strategic Agricultural Land
CAP	Catchment Action Plan

Abbreviation	Description
CMA	Catchment Management Authority
CSG	Coal Seam Gas
DPI Water	Department of Primary Industries – Office of Water, formerly NSW Office of Water
DTA	Direct Toxicity Assessment
DTIRE	Department of Trade Investment Resources and Energy
EPBC	Environment Protection and Biodiversity Conservation Act
EPA	Environment Protection Act
EP&A	Environment Planning and Assessment Act
ERA	Ecological Risk Assessment
EPL	Environment Protection Licence
FM Act	Fisheries Management Act
GDE	Groundwater Dependent Ecosystem
GIA	Groundwater Impact Assessment
GL	Giga Litres
LGA	Local Government Area
MAR	Managed Aquifer Recharge
MDB	Murray Darling Basin
ML	Mega Litres
MNES	Matters of National Environmental Significance
MRS	Managed Release Study
NEPM	National Environment Protection Measures
NSW	New South Wales
OEH	Office of Environment and Heritage
PAL	Petroleum Assessment Lease
PEL	Petroleum Exploration Licence
POEO Act	Protection of Environment Operations Act
PO Act	Petroleum (Onshore) Act
PWMP	Produced Water Management Plan
PWMS	Produced Water Management Strategy
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SEPP	State Environment Protection Policy
SSD	State Significant Development

Abbreviation	Description
SSI	State Significant Infrastructure
SWD	Surface Water Discharge
TDS	Total Dissolved Solids
TJ	Terra Joules
TSC Act	Threatened Species Conservation Act
TSS	Total Suspended Solids
WSP	Water Sharing Plan
WMF	Water Management Facility
WMP	Water Management Plan

Executive summary

Managed release which is the focus of this report will be required episodically to maintain water management system operational reliability. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water when Bohena Creek is flowing at more than 100 ML/day.

This Fluvial Geomorphology Impact Assessment forms part of the Managed Release Study (MRS) which investigates potential impacts associated with the managed release scheme and documents how impacts can be avoided, managed and mitigated.

E1 Purpose

The purpose of this geomorphology assessment is to:

- Characterise the existing geomorphological environment; and
- Determine impacts of:
    - River geomorphology on the design and function of a proposed managed release structure; and
    - Proposed managed release on the geomorphology of Bohena Creek.

E2 Scope

The geomorphology assessment:

- Reviewed available existing information;
- Documented existing condition;
- Described existing channel morphology and geomorphological processes;
- Reviewed historical channel change;
- Investigated sediment transport;
- Identified potential impacts of the geomorphology on the design and function of the managed release structure;
- Identified potential impacts of managed release on the geomorphology of the channels; and
- Provides a conceptual design of release infrastructure.

E3 Key Findings

The following potential geomorphological impacts attributed to managed release were identified:

During construction

- Direct loss of bank side and habitat through the installation of the managed release structure.

During operation

- Flow from the managed release structure has the potential to scour bed and banks;
- Potential for scour/erosion around the managed release structure caused by lateral channel change;
- Burial of managed release structure by sediment from upstream and blockage of structure by large woody debris from upstream; and
- Development of a scour pool in the channel bed at the managed release structure location.

In order to manage and mitigate the above potential impacts the following should be implemented:

- Position the outlet on a straight section of channel, away from areas of erosion and deposition and in an area of frequent flow; and
- Place outlet structure low in the channel (as near to the lowest point in a channel cress-section) to limit scour potential to the channel bed and banks, plus provide additional erosion control measures.

1 Introduction

1.1 Background

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

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

To enable gas extraction, the depressurisation of coal seams is required. The project would thus involve the extraction of produced water from coal seams that would be treated at the Leewood Water Management Facility (WMF). As part of the Project EIS, treated water would be beneficially used for drilling, dust suppression, and irrigation, with releases to Bohena Creek occurring infrequently.

Managed release which is the focus of this report is required from time-to-time to maintain water management system operational reliability. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water, typically during prolonged periods of wet weather when Bohena Creek is flowing (natural flows ≥ 100 ML/day). The Managed Release Study (MRS) is based on a proposed 25-year assessment period.

The MRS identifies and evaluates the potential impacts on the receiving environment related to the managed release of treated water to Bohena Creek. The report documents how Santos would avoid, manage and/or mitigate unacceptable impacts.

This Fluvial Geomorphology Impact Assessment forms part of the Managed Release Study.

1.2 Study area

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

The selected site being considered for managed release is at **Bohena Creek** approximately 2 km from the Leewood Water Management Facility (WMF) (Figure 1-1 and Figure 1-2).

To gain a wider context and understanding of the fluvial geomorphology of this site a study area has been defined, covering approximately 4 km up and downstream of the selected location.

1.3 Purpose

CH2M HILL and Eco Logical Australia (ELA) were commissioned by Santos to undertake a geomorphological survey of the proposed managed release location and to document potential impacts of the geomorphology on the managed release structure, as well as the impacts of the managed release on the geomorphology (including sediment regime and drainage patterns) of Bohena Creek.

1.4 Scope

This report reviews and documents the existing geomorphological information of the Namoi catchment to provide an overview of catchment conditions. It then outlines the existing channel morphology and geomorphological processes within the study area and reviews historical channel change. Based on this understanding, the potential impacts of the geomorphology on the design and function of the managed release structure and the impacts of the treated water managed release on the geomorphology of the channels at Bohena Creek.

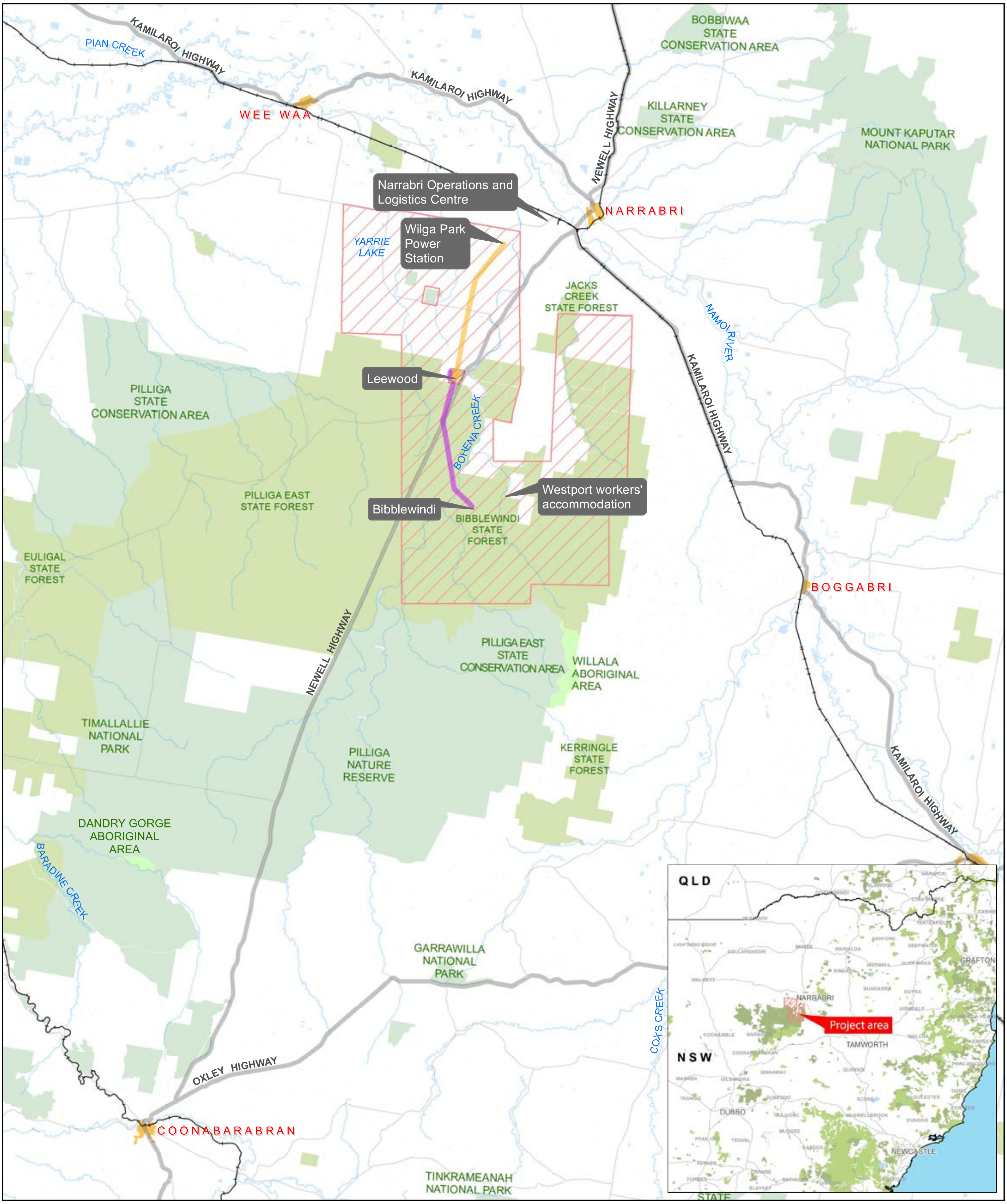
Specifically, this report determines impacts of:

- River geomorphology on the design and function of a proposed managed release structure; and
- Proposed managed release on the geomorphology of the Bohena Creek.

1.5 Available information

The following reports have been reviewed to provide an overview of geomorphology for the Namoi catchment, with a focus on the Lower Namoi sub-catchment and the Bohena Creek catchment:

- **Thoms et al (1999),** Environmental Scan of the Namoi River Valley, Department of Land and Water Conservation and the Namoi River Management Committee.
- **Lampert and Short (2004),** Namoi River Styles Report. River Styles, Indicative Geomorphic Condition and Geomorphic Priorities for River Conservation and Rehabilitation in the Namoi Catchment, North-West, NSW.
- **Schlumberger (2011),** Namoi Catchment Water Study Independent Expert Phase 2 Report IINSW09/19 50371/P2-R1). Prepared for Department of Trade and Investment, Regional Infrastructure and Services, New South Wales.
- **Australian Government (2012),** Environmental Water Delivery, Namoi River.
- **Eco Logical Australia (2016),** Bohena Creek Managed Release Study.
- **GHD (2016),** Narrabri Gas Project – Environmental Impact Statement –Appendix H Hydrology and Geomorphology.



LEGEND

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

0 5 10 20
Kilometers

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

N

Narrabri Gas Project
EIS Technical Appendix

Job Number 21-22463
Revision A
Date 12 Mar 2015

Regional context
and location of key infrastructure

Figure 1-1

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

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

Figure 1-2: Overview of Bohena Creek Managed release Location

2 Namoi River catchment & Bohena Creek subcatchment

2.1 Namoi River Catchment Characteristics

2.1.1 Geology

The total length of the Namoi River is approximately 400 km, draining a total catchment area of 42,000 km^2. The Namoi catchment is considered one of the Murray-Darling Basin's major sub-catchments in New South Wales.

The Namoi catchment is bound on its eastern margin by the Great Diving Range, where the majority of the rivers rise. Headwater areas comprise the deeply incised and uplifted New England Range, which is formed by the Silurian-age New England granite batholith. The granites and associated metamorphic rocks have been deformed into basins that are in-filled by Devonian to Carboniferous age volcanic tuffs and lavas, and sedimentary shales and limestones that form the rugged foothills and lower-lying plains of the eastern half of the catchment. More recent volcanic activity during the Tertiary period deposited more lavas that are up to 150m thick and which form the characteristic rugged and elevated topography of the Nandewar and Liverpool Ranges in the central part of the catchment.

A distinct boundary east of Narrabri separates the eastern and western regions of the catchment. This boundary corresponds to a north-south line of folding and faulting that separates the high relief uplands of the east from the low angle alluvial plain of the west. This alluvial plain consists of alternating beds of gravel, sand and silt-clay sediments up to 150m thick that are underlain by the Jurassic to Cretaceous rocks of the Great Artesian Basin.

2.1.2 Landscape units

The catchment has been divided into 7 landscape units by Lampert and Short (2004) with a summary of the characteristics in Table 2 1 and their locations in . More details of each unit can be found in Lampert and Short (2004). The Bohena Creek proposed managed release point is located in the alluvium-dominated Pilliga outwash unit (refer Table 2-1).

The Namoi catchment can also be split into 5 sub-catchments, with major tributaries including Cox's Creek, the Mooki, Peel, Manilla and McDonald Rivers, and the Pian, Narrabri, Baradine and Bohena Creeks joining below Boggabri (Figure 2-2). The study area falls within the Lower Namoi (detailed later in this section).

Table 2-1 Summary of landscape units

Landscape units	Landscape character	Geology	Relief	Elevation mAHD	Valley widths
Uplands	Rolling to steep granite and meta-sediment uplands	Dominantly granites with metasediments and some volcanic occupying the upper Macdonald catchment	up to 500 m	>800	5-1000m
Rugged Meta-sediments	Moderate to steep Meta-sediment escarpment, ranges and foothills and associated valleys	Dominantly meta-sediments with some granite in the Moonbi area	200-600m	400-100	<500m
Rugged volcanic	Moderate to steep volcanic escarpment, ranges and foothills and associate valleys	Volcanics	200-650m	500-100	<500m
Middle to Lower Peel	Gently undulating to rolling hills on meta-sediments	Meta-sediments	50-150m	300 -700	<2000m
Pilliga/ Pilliga Outwash	Low lying plateau dissected with relatively shallow valleys with gently sloping outwash plain	Sandstones and conglomerates, with outwash composed of alluvial sediments.	<150m	200-600	<500m
Liverpool Plains	Flat, low lying plains with outlying hills and ranges	Alluvial plains with outlying hills and ranges composed of dominantly sandstones and volcanics	<400m	200-600	Up to 10 Km
Lowland plain	Flat, low lying alluvial plains	Alluvial plains	<10m	130-200	Up to 75Km

Notes:

- Refer Figure 2.1 for landscape unit locations.
- Table adapted from Lampert and Short (2004)

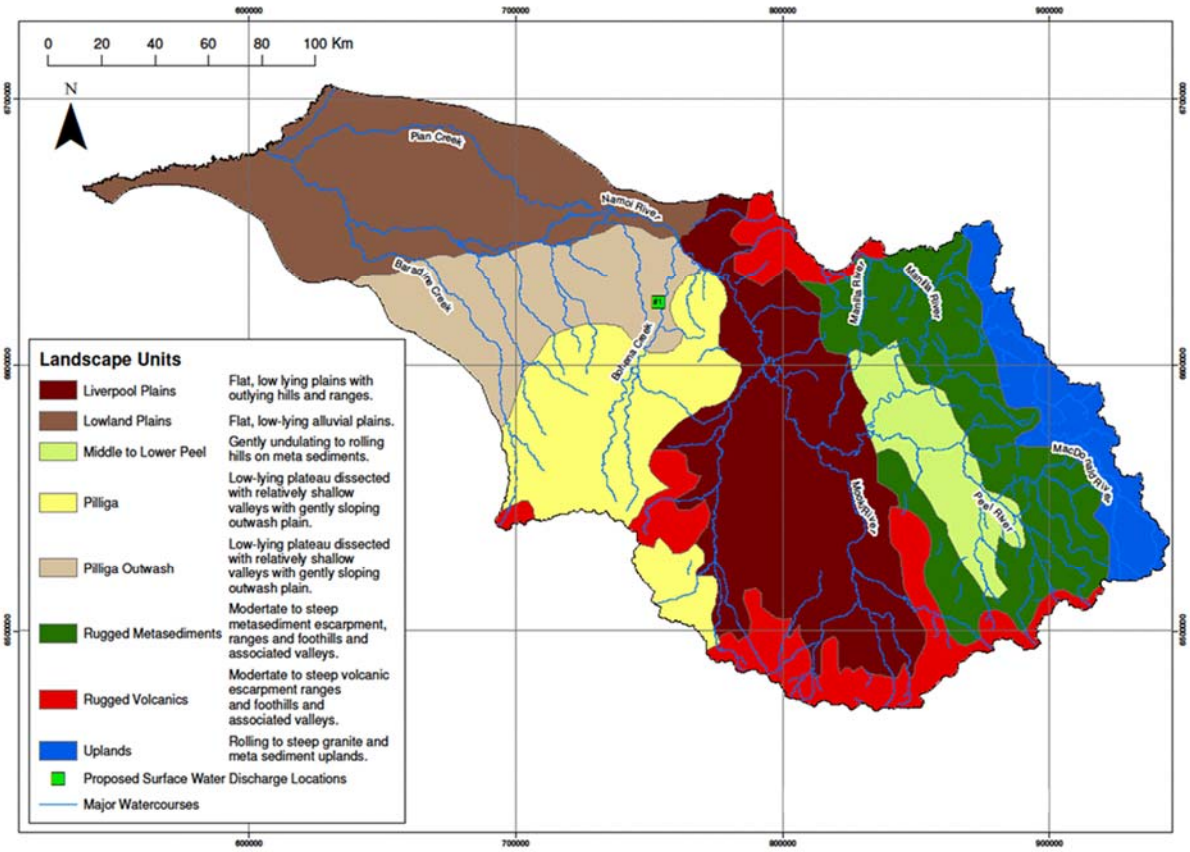

Figure 2-1: Distribution of landscape units within the Namoi Catchment

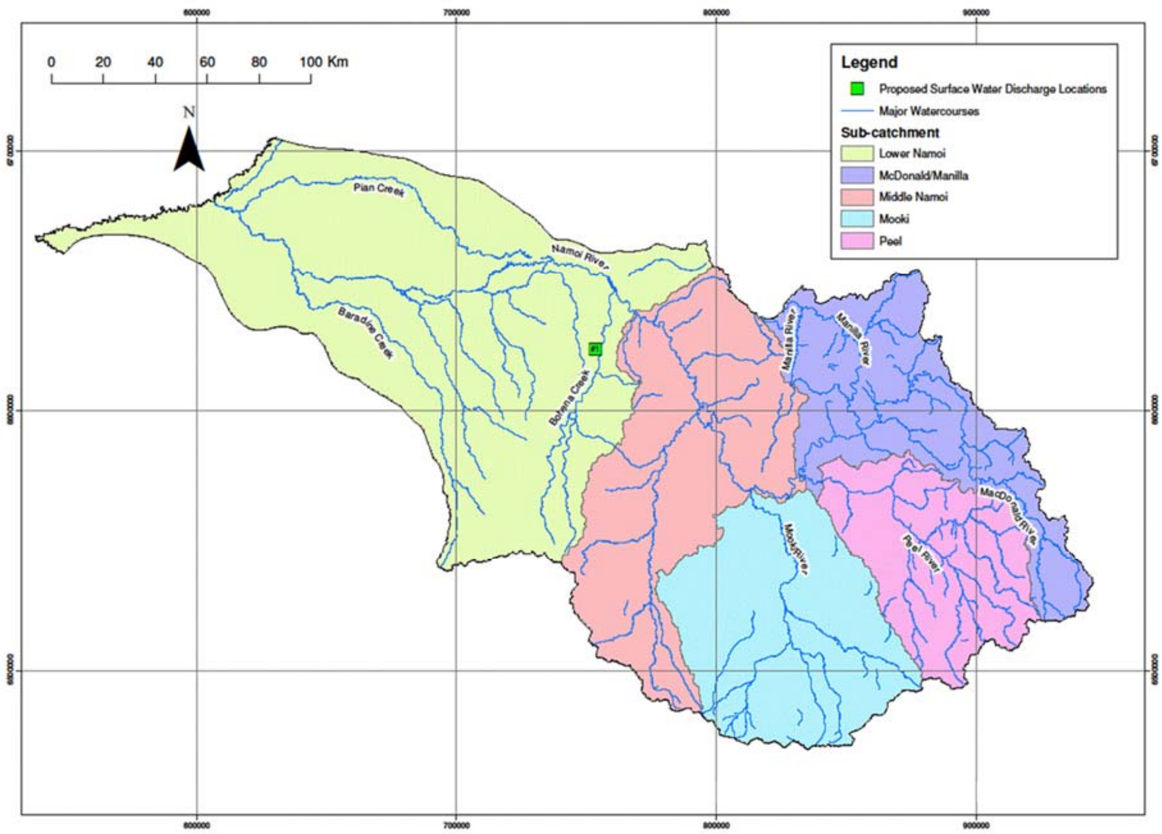

Figure 2-2: **Sub-catchments within the Namoi Catchment**

2.1.3 Land use and vegetation cover

Land use and vegetation cover has altered overtime, leading to changed hydrological fluvial geomorphology of channels within the catchment. Prior to European settlement, a complex array of vegetation was present within the Namoi catchment. Over time, vegetation has been thinned for cropping and grazing, leaving only thin and discontinuous corridors of riparian vegetation. Vegetation removal has caused an increase in the surface runoff volume and change to discharge peaks in the catchment (time of runoff hydrograph concentration), as well as increasing the energy of the channel, reducing channel stability and increasing sediment transport. Currently approximately 50% of the catchment is used for grazing, with 23% for cropping, and the remaining used for timber, mining, or urban area (Lampert and Short, 2004). It should also be noted that in the past sand and gravel extraction from river areas was also undertaken and was uncontrolled. Sand and gravel extraction, however, now requires a permit and is limited to areas that will not affect the stability of the channel (Lampert and Short, 2004). In the study area land use is predominately grazing and cropping.

2.1.4 Climate

Daily temperature and annual evaporation both increase across the catchment in a westerly direction, with average annual rainfall decreasing from east to west across the catchment (Figure 2-3). This leaves the study area with a higher temperature and lower level of rainfall than much of the catchment. Rainfall occurs in all months of the year but on average 40% more rain falls in summer months than in winter months. Summer rainfall is typically of high intensity and short duration commonly resulting in summer flooding (Lampert and Short, 2004).

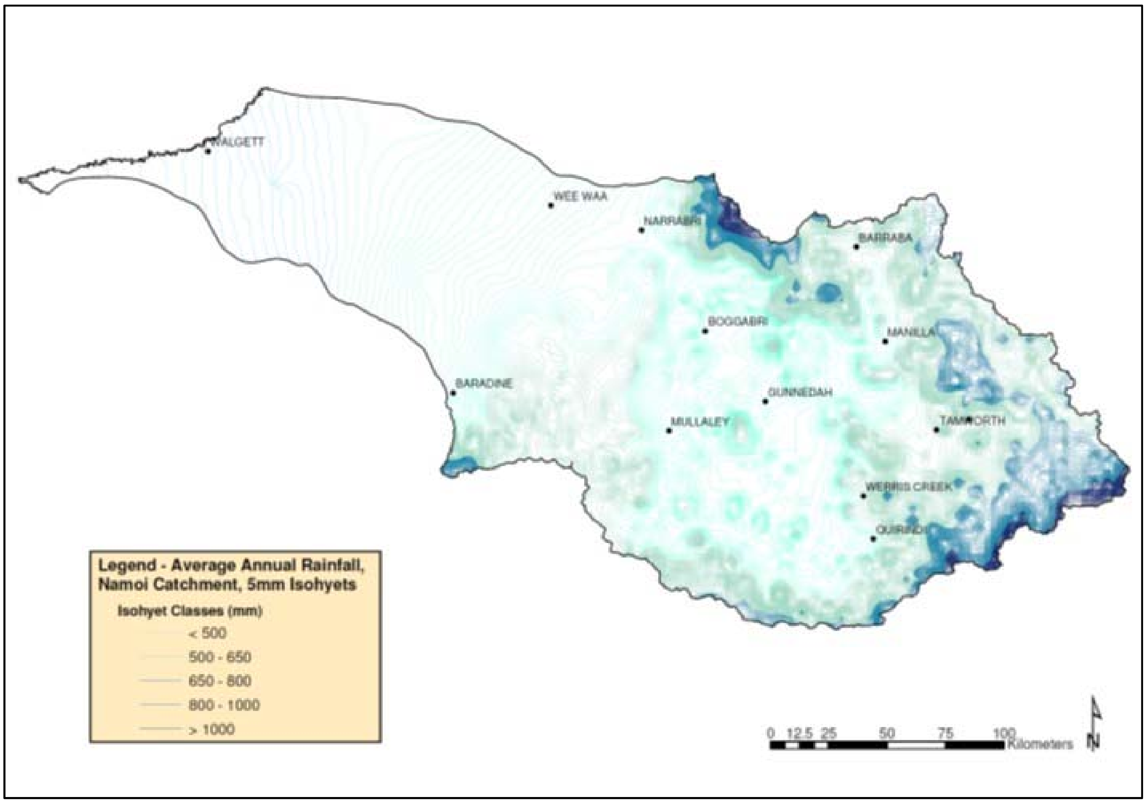

Figure 2-3 Average annual rainfall (Lampert and Short, 2004)

2.1.5 Flows and channel types

Mollee Weir, located downstream of Bohena Creek and Namoi River confluence backs up water into a Weir pool several kilometres long along Namoi River (Australian Government, 2012). Mollee weir was installed in the 1970s. Flows within the channels of the Namoi catchment are often discontinuous, with Figure 2-5 showing the distribution of perennial (streams flowing >90% of days), intermittent (streams flowing 10%-90% of days) and ephemeral (streams flowing <10% of days).

Thoms *et al* (1999) has classified the character of the main channels of the catchment into zones, with site #2 in the anabranch zone. A summary of the zones and their character is provided in Figure 2-4 and Table 2-2.

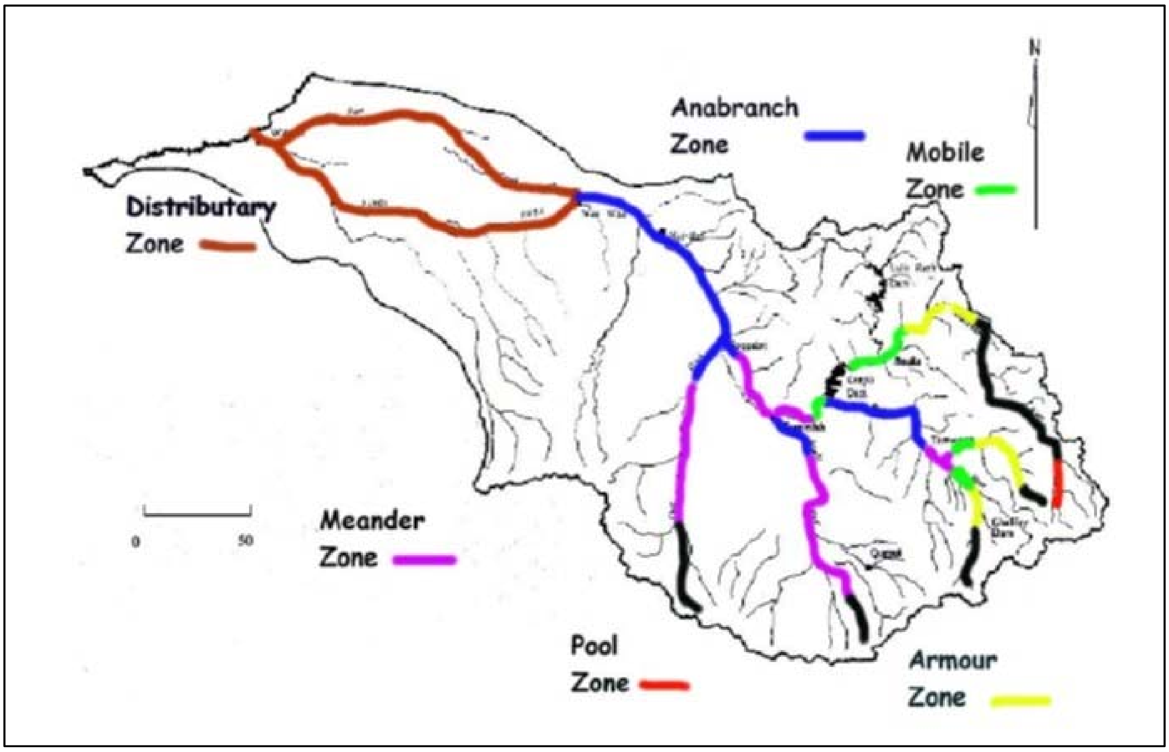

Figure 2-4: Morphological channels zones based on Thoms et al (1999).

(Black bold lines are constrained zones.)

Table 2-2 Morphological Zones in the Namoi Catchment, from Thoms et al (1999)

River Zone	River	Character
Pool	MacDonald	Stable channel Deep pools are important habitat for local species.
Constrained	MacDonald, Cockburn Peel, Mooki, Cox's	Stable channel Sediment supply area. Plunge pools and runs are important habitat for local species.
Armoured	MacDonald Cockburn, Peel	Relatively stable channel but can become active and unstable. Temporary sediment stores within the channel. The gravel bed/bars are important habitat for local species.
Mobile	MacDonald, Cockburn, Peel	Very active channel and bed sediment – sediment transfer area with numerous temporary sediment stores. The sandy gravel deposits are important habitat for local species.
Meander	Namoi, Cockburn Peel, Mooki, Cox's	Active channel in which bank erosion is common. Sediment transfer area with some sediment stores. Floodplain functioning increases in importance to the river system
Anabranch	Namoi, Peel, Mooki, Cox's	Main channel is relatively stable but can experience bank erosion. River system is multi-channelled during floods. Secondary channels may erode if they become the main flow path. Both the main and anabranch channels are important habitat. Floodplain functioning important to the river system.
Distributary	Namoi	Multi channelled - secondary channels are the dominant habitat area. The condition of the floodplain vital to river functioning.

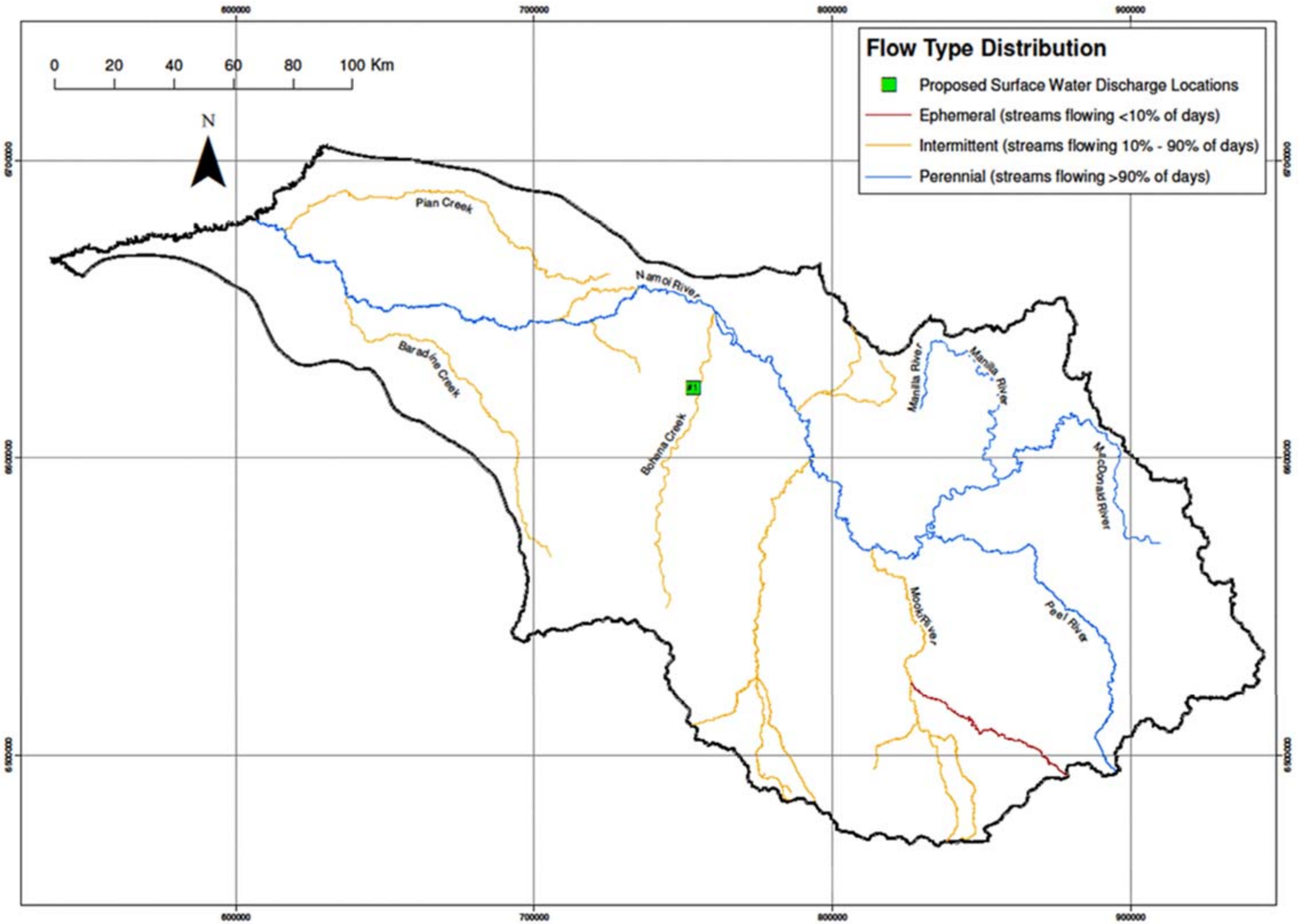

Figure 2-5: Distribution of flow types within the Namoi Catchment

2.1.6 Bohena Creek Sub-catchment

The study area is located within the Bohena Creek sub-catchment. The Bohena creek is an intermittent channel flowing approximately 15% of time with its catchment falling within the Pilliga and Pilliga outwash plain units (Figure 2-1 and Table 2-1). The Pilliga unit (in the upstream part of the catchment) is a densely forested and dissected Pilliga sandstone plateau. It is a denundational landscape of rolling to steep hills with local relief of up to 150 metres. Valley floor widths are generally narrow but can be up to 500m wide. The steep slopes and shallow regolith/soils combine to give high runoff rates and highly variable, peaky discharges (Lampert and Short, 2004).

The Pilliga Outwash (where the proposed Bohena Creek release point is located) is an aggradational landscape, with deposition of sediments sourced from the erosion of the Pilliga Sandstone plateau. It is a low lying landscape of undulating alluvial sediments, where local relief does not exceed 10m. It is traversed by numerous drainage lines; many being abandoned palaeo-channels reflecting changes in climatic conditions during the Quaternary period. Most sediment within the streams of this area is derived from upstream sources or as a result of reworking of the broad outwash plain.

3 Geomorphological Site Conditions

3.1 Methodology

Mapping of key features has been undertaken for the Bohena Creek within the study area. This has been based on a combination of the aerial imagery and surface elevation data and was ground-truthed in areas accessible and safe for site visits to be performed (Figure 1-1, Figure 1-2 and Figure 3-1). As well as ground-truthing the mapping, site visits also involved observation and recording of the existing form and geomorphological processes including a photographic record of the sites (Appendix A).

ISIS flood modelling (Eco Logical Australia, 2016 after CH2M Hill) has been used to obtain an estimate of average channel velocity for Bohena Creek during 1:5 and 1:100 year flow events. These results have been plotted on a Hjulstrom curve which has been used to comment on potential sediment transport.

Historical analysis of planform change has been undertaken for the study area using aerial imagery from 1956 and 2011, and cadastral data for 2008.

These mapping, site observations and historical analyses were then combined with desk study review to inform impact assessments.

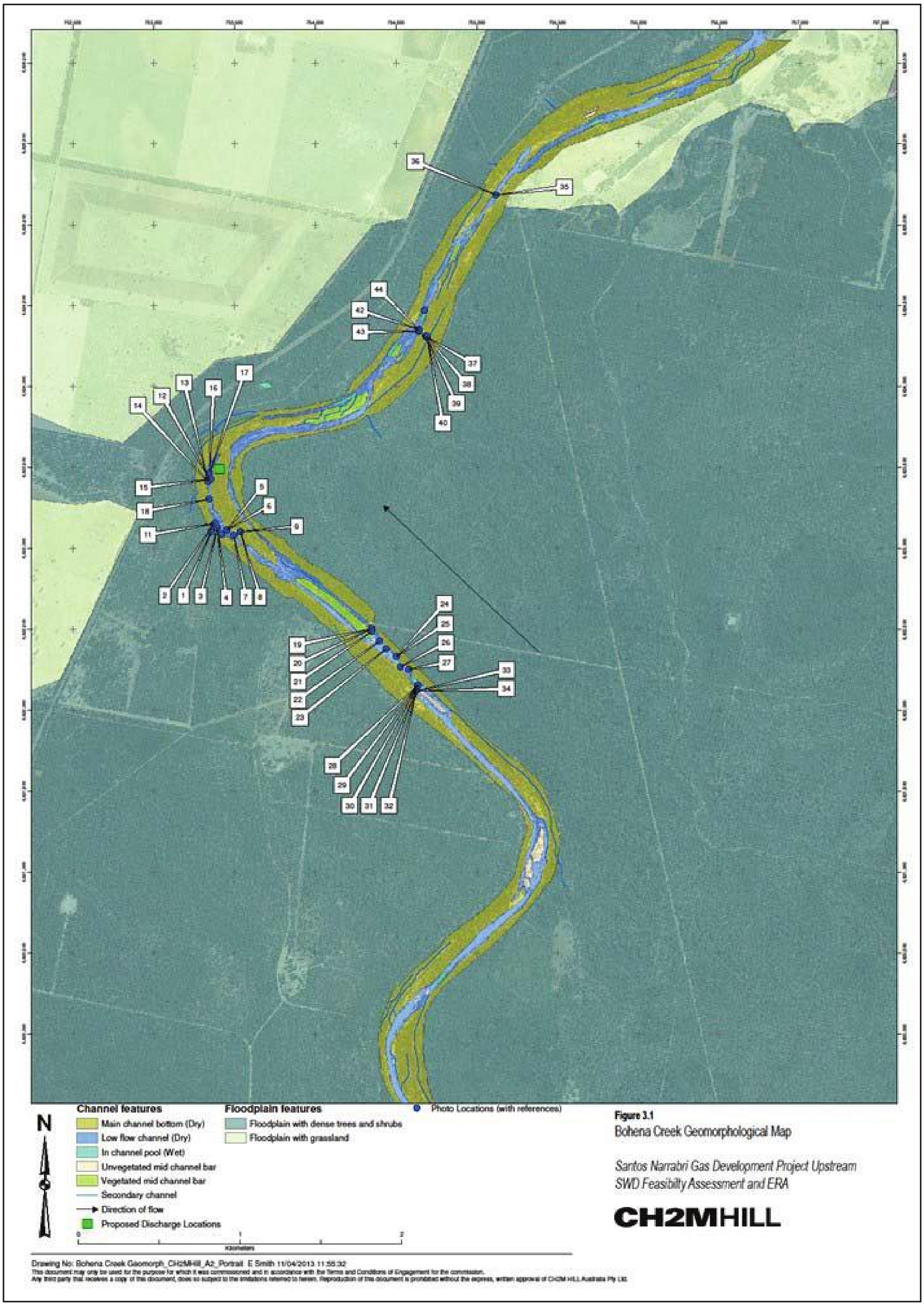

Figure 3-1 Geomorphological mapping of Bohena Creek

3.2 Site analysis

3.2.1 Site observations

Bohena Creek lies within a geomorphologically relatively unconfined, but densely forested valley in the Pilliga forest (Figure 3-1 and Appendix A, Photograph 1). The creek is characterised by a low gradient and wide (approximately 200 to 300m) channel that at the time of field survey did not have surface flow. This channel has well defined banks that are often vegetated and formed from sand and organic material. The channel bed is formed from medium to coarse sand with localised deposits of fine gravels (**Appendix A**, Photographs 7, 14, 21 and 40). The channel bed is generally densely vegetated by low scrub (**Appendix A**, Photographs 12, 17 and 41). Within the main channel are a series of well-defined low flow channels (Figure 3-1 and Photograph 32) that take a range of forms including mobile sand sheets (**Appendix A**, Photographs 27 and 28), a series of ponds linked with a poorly defined channel (**Appendix A**, Photographs 4, 11, 26, 29, 37, 39 and 41), or a series of depressions between sand bars and splays.

Vegetation of the channel bed and banks is locally stabilising the channel and often preventing the formation of a continuous low flow channel. Sand bars have developed in the main channel. Where these mid channel bars are above the level of flow they are well vegetated and appear stable under current high flows (**Appendix A**, Photograph 9). Where mid channel bars are partially vegetated or unvegetated they are mobile, and expected to be reworked under moderate to high flow events when the sand is entrained and transported (**Appendix A**, Photographs 23 and 33). The reworking of the sand leads to the formation of low flow channels with a mobile bed. These have the potential to be laterally mobile within the main channel under high flow conditions. The isolated ponds present within the channel represent the deepest pool morphology of the channel bed, and the presence of water suggests that the water table is at this elevation.

3.2.2 Flow and sediment transport

Bohena Creek is an intermittent channel that flows approximately 15% of the time (Figure 3-2). Velocity outputs from the flood modelling suggest a maximum velocity of 1.16 m/s during a 1:5 year event and 1.84 m/s during a 1:100 year event at the proposed managed release location, with similar velocities experienced upstream and downstream during both events, suggesting that these values are representative for the study area. When plotted on the Hjulstrom curve (Figure 3-3) it suggests that the size of sands and gravels that are present in the channel should be expected to be transported and eroded during both the 1:5 and 1:100 year events. This confirms that the unvegetated sediments within the channel bed and bars noted during the site visits are likely to be entrained and mobilised under typical flow events.

It should be noted that the estimated velocities are the maximum values for the modelled flood events and have been calculated as cross sectional averages. This means that in some locations during flow events such as the channel thalweg (centre of the channel) velocity will be increased, and along the bed and banks velocity would be reduced. Localised erosion and deposition is therefore possible along bank areas.

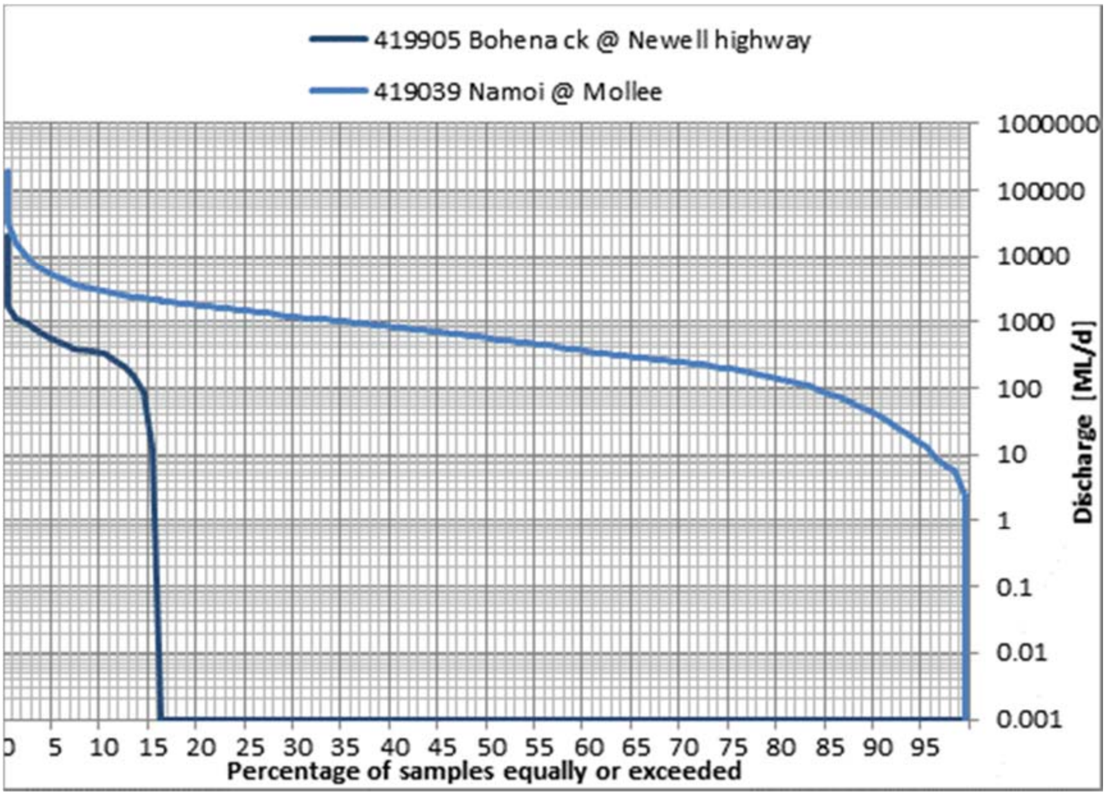

Figure 3-2 Flow duration curves for Bohena Creek and Namoi River

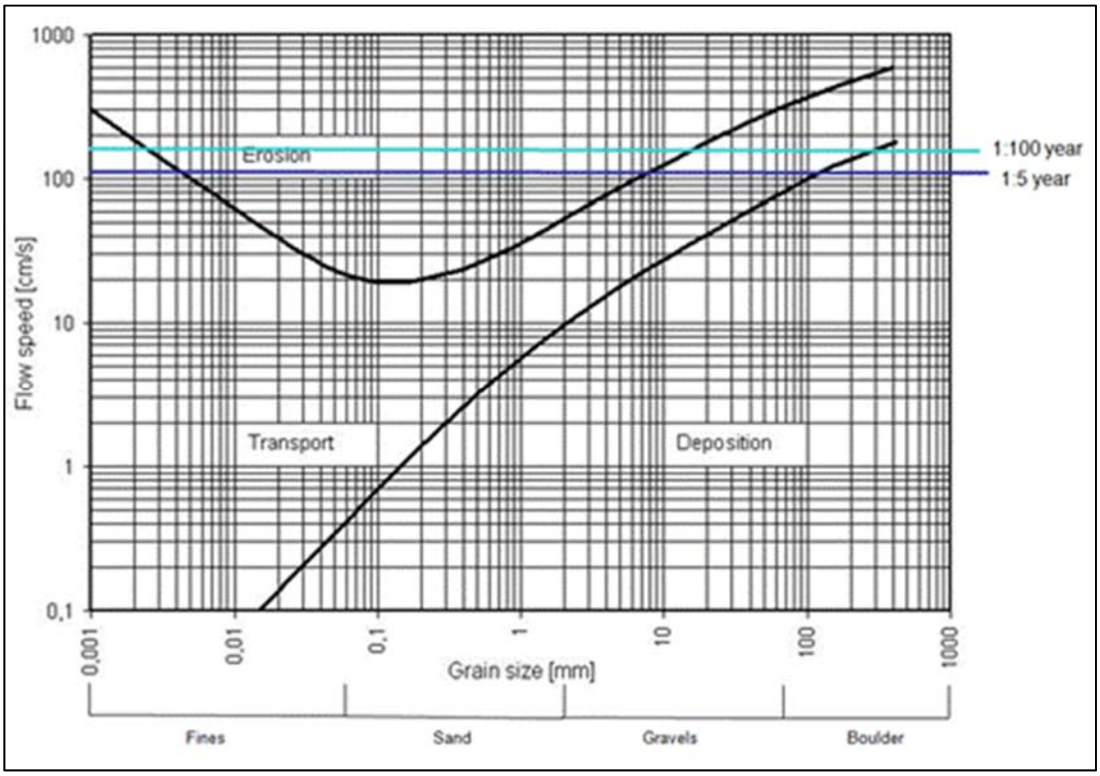

Figure 3-3 Bohena Creek Hjulstrom curve

Note: Bankfull velocity is plotted for the proposed managed release location (Hydraulic Model Section BC7600)

3.2.3 Historical change

There has been no significant change in the position of the main channel corridor within the study area of the Bohena Creek since 1956 (Figure 3-4), and the low flow channels also appear to have been relatively stable over this period. It is noted, however, both the low flow channels and bedforms within the channel are highly mobile during flood events when there is enough energy to mobilise the sand.

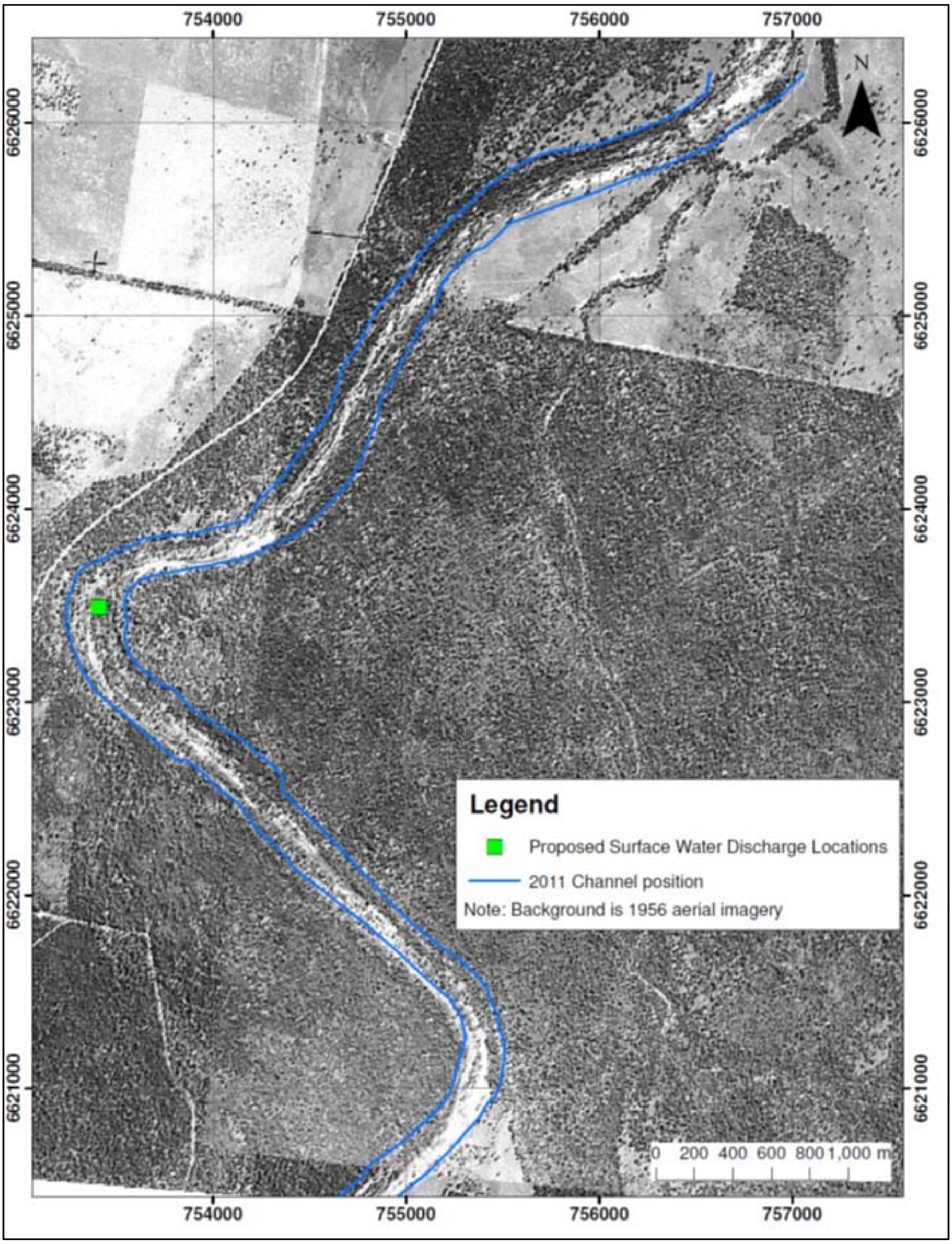

Figure 3-4 Historical change on Bohena Creek

3.2.4 Summary

The Bohena Creek is an intermittent channel that flows through a forested catchment, runs sub-parallel with the western outcrop margin of the Orallo Formation (which overlies the Pilliga Sandstone). Within the study area the channel is braided, within a wide and stable planform. The braided channel is composed of mobile sand bars (high points in the channel bed) and a series of ponds (low points in the channel bed) creating low flow channels. In-channel sediments are highly mobile under high flow condition.

4 Managed Release, Impacts & Mitigation

4.1 Managed Release Scheme Water Management

Water produced by the Narrabri Gas Project will be transmitted from wellhead via water pipes to the centralised water treatment and distribution facility known as the Leewood WMF. Treated water release would be transported via a pipeline to the proposed outlet location in Bohena Creek from where it will be released according to the episodic release protocol to a flowing creek (refer Eco Logical Australia, 2016).

4.2 Bohena Creek Flow Scenarios Considered

As described in the MRS (Eco Logical Australia, 2016), beneficial use of water for drilling and irrigation are considered the main priorities for treated water re-use. However, managed release will be important during periods of extended wet weather during which the capacity to beneficially use treated water for irrigation will be constrained (refer Eco Logical Australia, 2016).

Assessments of episodic release in this report are based on results from MRS studies (Eco Logical Australia, 2016) and are considered from a scenario-based modelling point to enable a better understanding of surface hydrology and surface-water groundwater interaction associated with natural flows and possible managed release scenarios. The modelled episodic release scenario is presented in Table 4-1.

Table 4-1 Bohena Creek Treated Water Release Scenario

Release scenario modelled	Release type	Fraction of production curve treated [a] and released	Scenario rationale	Peak. release rate (ML/day)
N1	None	-	Representative of a natural flow event. To understand model predicative capability, reliability. To understand natural creek wetting and drying patterns response.	No release
37GLI01-W	Episodic	Variable [a]	To understand the impacts of episodic release based on the 37.5 GL water curve over 25 years assuming discharge occurs only when the creek is flowing	[a]

Notes:

[a] The Leewood WMF treated water recovery rate is estimated to be a maximum 95% of the production curve (produced water curve).

5 Impact Assessment

This section identifies:

- the potential impacts of the geomorphology on a future release structure (in terms of siting considerations) and identifies possible design measures to mitigate these potential impacts; and
- the potential impacts of the release on the geomorphological processes and morphological response of the Bohena Creek.

As part of this impact assessment, an assessment of the likelihood and magnitude has been made for each potential impact. These are outlined below.

Likelihood

- Unlikely – impact could occur but is unlikely
- Likely – impact likely to occur
- Very likely – impact very likely to occur

Magnitude

- Local – Will only impact in the vicinity of the release point (up to 100m)
- Reach – Will have an impact on a reach scale (100m to 1km)
- Multi-reach – Will have an impact on many reaches (1km +)

5.1 Localised geomorphological impacts relating to the release structure

Table 5-1 outlines the possible impacts that ongoing geomorphological processes may have on the proposed managed release structure and provides guidance as to how these impacts may be mitigated to ensure that the likelihood of occurrence is reduced to the 'unlikely' category.

Table 5-1 Potential Impacts of geomorphological processes on the managed release structure

Phase	Impact	Likelihood and Scale	Mitigation
Operation	Managed release has the potential to scour bed and banks	Unlikely	Consider release at multiple locations in Bohena Creek to disperse flow along the creek to match Bohena Creek Soil infiltration characteristics Install suitable bank and bed protection. Keep the release structure low in the channel and discharge at low flow level Keep the release structure flush with the channel banks Consider the alignment during design to minimise scour to the channel bed and banks.
Operation	Potential for scour/erosion around the managed release structure caused by lateral channel change	Very likely, local negative impact due to movement of sand bars	Consider location of the managed release structure on the straighter section of channel, away from the meander bend – during periods of active channel flow erosion/scour on the outside of this bend it likely.

Phase	Impact	Likelihood and Scale	Mitigation
			Design so that the movement of sand bars within the channel does not impact on release performance.
Operation	Burial of managed release structure by sediment from upstream and blockage of managed release structure by Large Woody Debris from upstream	Very likely, local negative impact due to movement of sand bars	Design so that burial of the managed release structure by sand bars within the channel does not impact on release performance. Consider a trash screen and regular clearance to reduce debris entering and blocking the managed release structure.

5.2 Potential Geomorphological Impacts on Bohena Creek

The potential impacts of managed release on the geomorphological processes and morphological response on the Bohena Creek have been considered and are outlined in Table 5-2, along with possible mitigation measures, where appropriate.

Table 5-2: Potential impacts of the managed release on the geomorphological conditions

Phase	Impact	Likelihood and scale	Mitigation
Construction	Direct loss of bank side and habitat through the installation of the release structure.	Unlikely, Local negative impact	Provision of habitat offset, where required.
Operation	Development of a scour pool in the channel bed at the release location	Very likely, Local negative impact	Keep the managed release structure low in the channel
Operation	Release structure could encourage sedimentation around it	Unlikely, Local negative impact if mitigation is considered	Consider stilling pool at site to dissipate energy
Operation	Increased sediment entrainment and transport resulting in increased sediment loads entering the Namoi River	Unlikely. It is noted that predicted flows will be shallow (magnitude and scale of this impact will decrease in line with declining episodic release volumes).	Regular monitoring of the channel downstream of the managed release location. Downstream monitoring at the Namoi. Provision of erosion protection at outfall location.

6 Release infrastructure design considerations

6.1 Design considerations

The design for the storage, transmission and outlet infrastructure may encompass the following:

- At the produced water pond (prior to treatment):
    - site pond so as to maximise wind movement across the surface;
    - maximise hydraulic retention time;
    - utilise mechanical agitation to promote aeration and heat loss/temperature equilibrium; and
    - use materials that have high conductive capacity (such as metallic transfer pipes, where practicable).

- At the pipe outlet structure:
    - A diffuser secured on top of rip-rap within the main low flow channel or channels;
    - A geo-textile filter fabric laid under the riprap apron and keyed into the surrounding soil to prevent erosion; and
    - The grade of the pipe at the outfall location should be as low as possible, which minimises the extent of outfall protection required and potential for erosion1. The pipe invert level should be as close to the channel invert as reasonably practicable (given flooding, physical and other constraints). Erosion potential will be reduced by aligning the pipe outlet to the channel and direction of flow.

- At the outlet structure, downstream of the diffuser outlet:
    - The riprap apron should continue with to form a shallow pool (on downstream end), to reduce velocity and erosion, encourage aeration and temperature equilibrium and protect the pipeline outlet. Riprap is designed to create a flexible lining that adjusts to settlement, traps sediment and reduces flow velocities. It is usually less expensive and easier to construct than a concrete apron or energy dissipater[2]; and
    - If determined to be appropriate, the flowpath where discharge waters would pool (immediately downstream) of the outlet structure may be lined with rip rap to prevent erosion[3].

- Buried release pipes/structures (*e.g*. as proposed at Bohena Creek):
    - These structures would need to be protected against blinding of the outlets to prevent clogging and major remedial maintenance;
    - Release infrastructure would need to be located to prevent undermining by intermittent surface flows, especially in flood conditions; and
    - Provision of additional aeration and temperature equilibrium at the discharge location would be problematic. Such provision would need to be made upstream of the actual

---

[1] U.S. Army Corps of Engineers, Hydraulic Design of Energy Dissipaters for Culverts and Channels, HEC 14, September, 1993, Metric Version

[2] Maine Erosion and Sediment Control, 2003. Source: http://www.maine.gov/dep/blwq/docstand/escbmps/escsectione3.pdf

[3] Further guidance on Rip-Rip and erosion control can be found in "The Blue Book" Managing Urban Stormwater, Soils and Cond Construction: Volume 1, 4th Edition.

discharge structure, e.g. discharge from the transfer pipe though a rip rap chute and subsequent flow into a buried discharge pipe/structure.

- Additional measures as outlined in Eco Logical Australia (2016) to minimise impacts on flooding, fluvial geomorphology and aquatic ecology should also be incorporated. These include:
  - Regular inspections of creek to ensure there are no surface pools forming due to clogging of sand or debris mounding in creek causing water to pool;
  - Keep the outfall low in the channel and discharge at low flow level;
  - Consider the alignment during design to minimise scour to the channel bed and banks;
  - Locate outfall on straighter section of channel;
  - Design so that the movement of sand bars within the channel does not impact on outfall performance;
  - Consider a trash screen and regular clearance to reduce debris entering and blocking the outfall;
  - Release at multiple locations in Bohena Creek to disperse flow along the creek to match Bohena Creek Soil infiltration characteristics; and
  - Simulate natural drying of creek bed by implementing an episodic release regime to facilitate natural drying of the creek bed.

6.2 Maintenance

Regular inspections and maintenance, especially after flood events, should be undertaken to ensure outfall structure integrity.

Key tasks for maintenance include:

- Inspection and testing of storages and pipelines;
- Plant/macrophyte maintenance (as required);
- Inspect outlet protection for erosion, sedimentation, scour or undercutting;
- Inspect flowpaths to receiving waters for erosion issues;
- Repair or replace riprap and geo-fabric as necessary to handle design flows; and
- Remove trash, debris, grass, or sediment.

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Appendix A – Photographs

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Photo 4

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Appendix E Mixing Zone Study

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MEMORANDUM

TO	Santos
FROM	Eco Logical Australia
DATE	9th September 2016
SUBJECT	**Bohena Creek Managed Release – Mixing Zone Study**
VERSION	**1**

Updated 13/11/2013

This document has been updated by Eco Logical Australia from final draft material originally prepared by CH2M Hill Australia Pty Ltd for Santos, with support and contributions from Eco Logical Australia Pty Ltd and Acqua Della Vita Pty Ltd, and based on data supplied by Santos.

Introduction

The Proponent is proposing to develop natural gas in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri. Santos has elected to proceed only with episodic release to Bohena Creek which is defined as infrequent release of treated water, typically during prolonged periods of wet weather when Bohena Creek is flowing (natural flows ≥ 100 ML/day). Bohena Creek is reported to be intermittent, flowing approximately 15 % of the time (Eco Logical Australia, 2016a). Santos requested mixing zone modelling be conducted for the intermittent Bohena Creek under two release scenarios (mean and maximum treated water quality).

Technical Methodology

Model Objectives

The objective of this study is to use a mixing zone model to determine the dilution ratio and concentrations of key water quality parameters after the produced water discharge mixes with river flow in Bohena Creek. Then these model-predicted mixed concentrations are then compared with suggested trigger levels listed in the Ecological Risk Assessment report (Eco Logical Australia, 2016b).

Description of CORMIX Model

This study used the CORMIX modelling package. CORMIX is recognized by the ANZECC Guidelines (2000) as a peer-reviewed model for mixing zone modelling analysis. It is also recognized by the United States Environmental Protection Agency as suitable for the analysis and prediction of point-source discharge plumes into various water bodies. CORMIX has been applied internationally, including in Australia.

CORMIX is an empirical model based on experimentally derived curve-fit equations that predict the dilution ratio of water quality parameters and that verify the accuracy of theoretical models. The CORMIX system's major emphasis is on the prediction of geometry and dilution characteristics of the initial mixing zone so that compliance with acute and chronic regulatory constraints may be evaluated. The system can also predict the behaviour of the discharge plume at larger distances. In general, CORMIX is suitable for calculating mixing and dilution for a number of different discharge conditions, such as open channel discharges, single pipe discharges, and multiple discharges to rivers, lakes and estuarine systems.

There are three primary modules within the CORMIX modelling system: CORMIX1 (for submerged, single port discharges), CORMIX2 (for submerged discharges with multi-port diffusers) and CORMIX3 (for surface discharges). CORMIX2 analyses unidirectional, staged, and alternating designs of multiport diffusers and allows for alignment of the diffuser structure within the ambient water body and for arrangement and orientation of the individual ports.

The CORMIX modelling system does not carry out detailed hydrodynamic calculations using the geometry of the discharge location, nor does it explicitly account for tidally-driven currents. It uses a simplified representation of the physical conditions at the discharge location to approximate the fundamental behaviour of the plume.

Modelling Methodology

The CORMIX modelling methodology was divided into three main steps as follows:

(a) The CORMIX model was first used to calculate a dilution ratio after the released produced water mixes with river flow in the Bohena Creek;

(b) A mass balance approach was then used to apply this dilution ratio to estimate the concentration of water quality parameters after mixing; and

(c) The concentrations of water quality parameters after mixing were then compared against suggested trigger values for these water quality parameters.

The two model scenarios in this study are listed in Table 1. There are a total of 10 water quality parameters for each scenario in the study. All of them are conservative pollutants.

Table 1 – Summary of Model Scenarios in this Study

Creek flow (ML/day)	Receiving water quality	Treated water quality	Release rate (ML/day)
Constant 100	Mean Concentration	Mean Concentration	12
Constant 100	Mean Concentration	Max Concentration	12

CORMIX Model Results

The CORMIX model input parameters for proposed produced water discharge scenario to Bohena Creek was listed in Table 2.

Diffuser configuration is described as follows. The length of the diffuser is 45 meters. The diffuser is in parallel to ambient flow and laid out in the middle of channel of the Bohena Creek. The diffuser is placed close to the bottom of the creek and the height of diffuser port is about 0.1 meter. The number of diffuser ports is three per meter (for a total of 133 ports along 45-meter diffuser). The diameter of diffuser port is 0.015 meter. The vertical discharge angle of diffuser port is 45 degrees.

The model-predicted dilution ratio at the edge of near-field region with above multi-port diffuser configuration is 9.8. Figure 1 plots dilution ratio with downstream distance.

A mass balance approach was used to apply this dilution ratio to estimate the concentration of water quality parameters after mixing. Table 3 lists the estimated concentrations for these 10 water quality parameters. Furthermore, comparison to suggested trigger values for these 10 water quality parameter under two model scenarios ("mean treated water quality" and "maximum treated water quality") are also shown in Table 3.

The preliminary results from this analysis are:

- Under "mean treated water quality" scenario, the concentrations of all 10 water quality parameters are below the suggested trigger values.

- Under "max treated water quality" scenario, the concentrations of chloride and mercury after mixing are slightly higher than suggested trigger values. In the case of mercury, the half of the limit of detection is used as river background concentration, given a lack of field sampling data. All other water quality parameters are below the suggested trigger values.

Table 2- CORMIX Model Inputs of Proposed Produced Water Discharge Scenario to Bohena Creek

Model Input Parameters	Value in Metric Units	Source of Data / Information
DISCHARGE PARAMETERS		
Effluent flow rate	12 ML/day	Eco Logical Australia, 2016a [1]
Temperature	Ambient – 30°C used for modelling	Eco Logical Australia, 2016a [1]
Effluent concentration	100%	For model setup use
AMBIENT PARAMETERS		
Ambient flow rate	100 ML/day	Eco Logical Australia, 2016a [1]
Temperature	13°C (Average)	Eco Logical Australia, 2016a [1]
Cross-section	Bounded	CH2M HILL estimate
Stratification Type	Uniform	CH2M HILL estimate
Bottom channel width	5 m	CH2M HILL estimate
Average channel depth	0.406 m	CH2M HILL estimate
Side channel slope	1 to 4	CH2M HILL estimate
Manning's coefficient	0.035	CH2M HILL estimate
Wind Speed	15 km/h	Website[2]
DIFFUSER CONFIGURATION		
Diffuser length	45 m	CH2M HILL estimate
Distance from the near shore to the first diffuser port	2.5 m	CH2M HILL estimate
Distance from the near shore to the last diffuser port	2.5 m	CH2M HILL estimate
Total number of diffuser ports	133	CH2M HILL estimate
Height of diffuser port	0.1 m	CH2M HILL estimate
Diameter of diffuser port	0.015 m	CH2M HILL estimate
Vertical discharge angle of diffuser port	45 degree	CH2M HILL estimate

Notes:

(1) Eco Logical Australia, 2016a. Narrabri Gas Project, Managed Release Study (Bohena Creek).

(2) http://wind.willyweather.com.au/nsw/new-england-and-north-west-slopes/narrabri.html.

Table 3 - Comparison of Estimated Water Quality Concentrations with Suggested Trigger Values

Constituent	Units	Treated water Mean	Treated water Max.	LOD	No. of background detections above LOD	Mean waterway background conc.	Mean Background Conc. (use LOD/2 if no detects or insufficient data)	Conc. after mixing (with treated water Mean)	Conc. after mixing (with treated water Max)	Adopted Trigger Value	Mixed treated water mean > trigger value?	Mixed treated water max > trigger value?
-												
Electrical conductivity	uS/cm	357	645	1	17	176	176	194.5	223.9	350	No	No
Total Dissolved Solids (TDS)	mg/L	232	419	1	13	142	142	151.2	170.3	-	-	-
Sodium (Filtered)	mg/L	77	140	1	17	16	16	22.2	28.7	-	-	-
Copper	mg/L	0.0005	0.0024	0.001	3	0.0011	0.0011	0.0010	0.0012	0.0014	No	No
Cadmium	mg/L	0.0005	0.00056	0.0001	0	ND	0.00005	0.00010	0.00010	0.00020	No	No
Mercury	mg/L	0.0000067	0.00020	0.0001	0	ND	0.00005	0.000046	0.000065	0.00006	No	Yes
Alkalinity (Carbonate as CaCO3)	mg/L CaCO3	139	-	1	1	ID	0.5	14.6	-	-	-	-
Chloride	mg/L	15	83	1	17	28	28	26.7	33.6	29.0	No	Yes
Boron	mg/L	0.12	0.68	0.05	0	ND	0.025	0.0	0.09	1.8	No	No
Fluoride	mg/L	0.08	0.16	0.1	0	ND	0.05	0.1	0.06	0.460	No	No
Notes												
<	Cells shown shaded with ‘<’ use a value half that shown in the cell for mixing calculations. For example a treated water mean of “<0.001” would result in the value 0.0005 being used in calculations.											

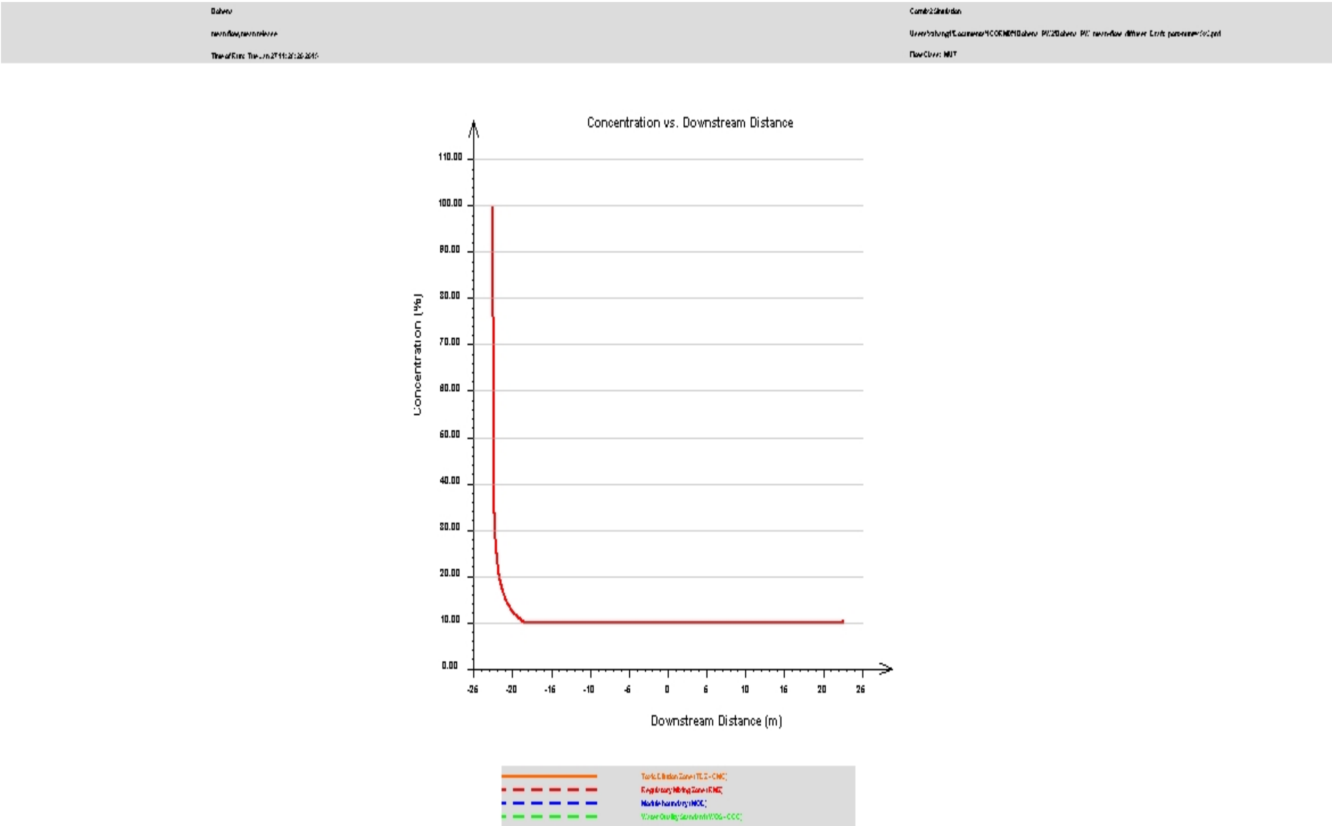

Figure 1 Model concentration versus downstream distance

Summary and Conclusions

This technical memo presented CORMIX modelling results of dilution ratio and estimated water quality parameter concentrations after the released produced water mixes with river flow in Bohena Creek. The model-predicted dilution ratio at the edge of near-field region using a multi-port diffuser is 9.8 to 1.

The estimated concentrations of 10 water quality parameters after mixing were compared against suggested trigger values. Under “mean treated water quality” scenario, the concentrations of all 10 water quality parameters are below the suggested trigger values. Under “max treated water quality” scenario, the concentrations chloride and mercury after mixing are slightly higher than suggested trigger values.

With respect to mercury, it is noted that mean and maximum treated water projection values are based on conservative estimate of mercury (approximately 4 times actual recorded values). Further evaluation of river background concentrations and data used for water treatment plant design (e,g, produced water data) is recommended. This would primarily involve additional testing with a higher resolution of detection for mercury.

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