Prepared for

Santos NSW (Eastern) Pty Ltd

Referral of Proposed Action: Water Resources Assessment

Energy NSW Coal Seam Gas Exploration and Appraisal Program



FINAL

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CH2MHILL®

CH2M HILL Australia Pty Ltd
Level 19, 215 Adelaide Street
BRISBANE QLD 4000
Phone 07 3169 2900
Fax 07 3169 2999

DOCUMENT CONTROL SHEET

CH2M HILL Australia Pty Limited

Level 19, 215 Adelaide Street
BRISBANE QLD 4000

Telephone: 07 3169 2900
Fax: 07 3169 2999

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Project Leader: Dr Paul Wilkinson

REPORT DETAILS

Title:	**Referral of Proposed Action: Water Resources Assessment**
Author:	**CH2M HILL**
Client:	**Santos NSW (Eastern) Pty Ltd**
Client Contact:	**Peter Mitchley**
Client Reference:	**Energy NSW Coal Seam Gas Exploration and Appraisal Program, Referral of Proposed Action: Water Resources Assessment Gunnedah Basin NSW**
***Synopsis*:**	This report presents an assessment of impacts of construction and operation of the Energy NSW Coal Seam Gas Exploration and Appraisal Program, Gunnedah Basin, NSW, on water resources as a Matter of National Environmental Significance (MNES).

Executive Summary

The federal government announced in March 2013 that it proposes to make an amendment to the *Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth)* to include 'Water Resources' as a Matter of National Environmental Significance (MNES) in relation to large coal mining and coal seam gas developments. This means that proposed developments which are likely to have a significant impact on water resources will require federal assessment and approval to ensure the protection of water resources. This Water Resources MNES Impact Assessment has been undertaken on the basis that the Bill will be legislated in the coming months.

This report considers the (significance of) potential impacts to water resources as a result of the construction and operation of pilot activities as part of the Energy NSW Coal Seam Gas Exploration and Appraisal Program (the Program) within the Gunnedah Basin, NSW.

A risk assessment process, as follows, was undertaken to predict the significance of potential impacts to water resources as a result of the Program:

- The potential water resources which could be impacted by the Program activities, and the sensitivity of these water resources, were identified;
- The potential risks and significance of associated impacts to water resources as a result of the Program were identified; and
- Mitigation and monitoring measures to be applied as a component of the Program were identified in order to reduce the risk of significant impacts occurring to water resources.

The main outcomes of the risk assessment were as follows:

- **No significant impacts** with very high or high likelihood of occurrence have been identified.
- The majority of potential impacts identified can be classed as typical construction type impacts following improper site practices, and can be mitigated by adopting best practice site environmental processes and monitoring, as is currently planned. Following successful implementation of mitigation and management measures including maintaining best site practices, the significance of these impacts is considered to be **low to insignificant**.
- The drilling of pilot wells may introduce preferential flow pathways between aquifers. The adoption of the methodology presented in the NSW Code of Practice for Coal Seam Gas Well Integrity will reduce the potential significance of this impact. Following the implementation of mitigation the impact is of **low significance to insignificant**.
- Modelling of cumulative pilot operational impacts to groundwater within the Bohena Creek Alluvium and the Pilliga Sandstone groundwater sources indicates that impacts are **not significant**, defined as long-term drawdown of less than 0.5 m.
- Risks to water resources may arise when considering introduction of produced water to the environment as a result of pipeline, tank, pond or tanker leakage, spillage or failure. Following the successful implementation of appropriate site management procedures and appropriate infrastructure design, construction, maintenance and monitoring, the likelihood

of impacts occurring and the severity of impacts will be reduced to **low significance to insignificant**.

- A detailed baseline and on-going monitoring program will be implemented to provide baseline water level and quality data, validate results of modelling and provide early warning of any potential impact to water resources within and surrounding the Program area.

Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

1.1 Background

Santos NSW (Eastern) Pty Ltd is proposing to undertake the Energy NSW Coal Seam Gas (CSG) Exploration and Appraisal Program in the Narrabri area within Petroleum Exploration Licence (PEL) 238 and Petroleum Assessment Lease (PAL) 2 (hereafter referred to as the program). As a component of the approval process, Santos is intending to refer the Program to the Commonwealth Department of Sustainability Environment Water Population and Communities (SEWPaC) for assessment and determination under the *Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) (EPBC Act)*.

1.2 Proposed Amendment

The federal government announced in March 2013 that it proposes to make an amendment to the EPBC Act to include 'water resources' as a Matter of National Environmental Significance (MNES), in relation to large coal mining and coal seam gas developments.

The amendment will result in the requirement for coal seam gas and large coal mining to be comprehensively assessed at a national level, in order to ensure the protection of water resources.

At present, any coal seam gas and large coal development that has the potential to have a significant impact on a MNES and is referred to the Australian Government Environment Minister, is referred under the EPBC Act to the Independent Expert Scientific Committee (IESC) for advice on the impacts on water resources. The Minister considers this advice when deciding whether or not to grant approval, though the Minister does not currently have the power to consider and impose conditions directly relating to impacts on a water resource (SEWPaC, 2013).

The amendment adds water resources as a trigger to enable the Minister to decide to approve, or not approve, an action which is likely to have a significant impact on water resources. If approved, the Minister will then set appropriate conditions as part of the project approval process such that any significant impacts on a water resource are acceptable (SEWPaC, 2013). A 'significant impact' is described as an impact which is important, notable, or of consequence, having regard to its context or intensity. An assessment is required to determine whether an action is likely to have a significant impact on a water resource.

In this context, a significant impact on a water resource that is 'acceptable' is considered to refer to an impact that is able to be mitigated or managed in accordance with relevant legislation or conditions which may potentially be imposed by the Minister. No formal definition of 'acceptable' could be identified in the EPBC Act or relevant documentation.

1.3 Study Objective

In anticipation of the proposed amendment to the EPBC Act, Santos commissioned an assessment of the potential risks of the proposed pilot activities, and associated works, on the water resources within the potential influencing distance of the proposed action.

1.4 Scope of Work

The Scope of Work of this assessment is summarised as follows:

1. Identify the locations of all pilot wells and related infrastructure associated with the Program, as defined in Section 3;
2. Define the risk assessment framework;
3. Define the activities to be referred;
4. Identify all water resources within the area of the Program;
5. Consider the Program, including all stages of works, activities and infrastructure, and identify the potential for any impacts, including indirect impacts, on water resources;
6. Identify measures required to mitigate or manage potential risks and associated impacts on water resources;
7. Consider the proposed measures to avoid or reduce impacts on water resources and identify if these are adequate to reduce the level of impact below the 'significant impact' threshold; and
8. Consider the likelihood of significance of potential impacts to water resources after the application of mitigation and management measures.

The consideration of specific EPBC listed species that are legally defined as MNES is outside the scope of this report. This is addressed in a separate report supporting this referral. Consideration is made however of the dependency that an ecosystem may have on water resources.

1.5 Assumptions and Limitations

CH2M HILL was contracted by Santos to undertake an assessment of the potential impacts associated with the pilot activities on water resources within the potential influencing distance of the Program. This report is based on the information that has been made available to CH2M HILL from the sources listed in the report. The conclusions drawn in the report are based on the data available at the time of writing and any subsequent additional information may allow refinement of the conclusions. It should be noted that:

- This report has been prepared under the express instructions by, and solely for the use of Santos.
- The findings of this report represent the professional opinion of experienced Hydrogeologists and Environmental Scientists.
- All work carried out in preparing this report has utilised and is based upon CH2M HILL's current professional knowledge and understanding of current relevant Australian and New South Wales Government regulation and legislation. In particular, the works have been undertaken based on CH2M HILL and Santos' understanding of the proposed addition of water resources as MNES in the EPBC Act and the potential requirements that this may impose.
- Changes in legislation and guidance may occur at any time in the future and cause any conclusions to become inappropriate or inaccurate. CH2M HILL does not accept responsibility for advising Santos or other interested parties of the facts or implications of any such changes.

- This report has been prepared using factual information contained in data, maps and documents prepared by others. No responsibility can be accepted by CH2M HILL for the accuracy of such information.

2 Assessment of Significant Impact

2.1 Referral of Proposed Action

Under the EPBC Act, a person must not take an action that has, will have, or is likely to have a significant impact on any MNES without approval from the Australian Government Environment Minister or the Minister's delegate. To obtain approval, a 'proposed action' must be referred. The purpose of the referral is to obtain a decision on whether the proposed action will need formal assessment and approval under the EPBC Act.

Currently a referral must be made for actions that are likely to have a significant impact on the following MNES:

- Listed threatened species and communities;
- Listed migratory species;
- Ramsar wetlands of international importance;
- Commonwealth marine environment;
- World heritage properties;
- National heritage places;
- The Great Barrier Reef marine park; and
- Nuclear actions.

The addition of water resources as an MNES into the EPBC Act has yet to be formally introduced into federal law. However, Santos considers it prudent to assess the potential impact of the Program on water resources, on the assumption that the amendment will be formally introduced into law in the future.

For the purposes of this assessment a water resource is defined as:

"being surface water or ground water, 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" (Commonwealth Water Act 2007)

The referral of the proposed action requires the following information:

- A description of the environment and likely impacts;
- Measures to avoid or reduce impacts; and
- Conclusion on the potential for significant impacts to MNES.

The referral form should contain sufficient information to provide an adequate basis for a decision on the likely impacts of the proposed action.

For the purposes of this assessment a significant impact is defined as:

A 'significant impact' is one which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends on the sensitivity, value and quality of the environment which is impacted. It also depends upon the intensity, duration, magnitude and geographic extent of the impacts (EPBC Act 1999).

Source: Matters of National Environmental Significant Impact Guidelines 1.1 (Commonwealth of Australia, 2009)

2.2 Significant Impact Guidelines

As the MNES definition of significant impact for water resources has yet to be defined, the existing MNES definitions have been adopted for the purpose of this assessment.

The MNES Significant Impact Guidelines (version 1.1) (Significant Impact Guidelines) identifies the requirements for a robust assessment of whether an action will have, or is likely to have, a significant impact on a MNES. The SIG indicates the following questions should be answered to consider whether an action requires referral:

1. Are there any MNES located in the area of the proposed action (noting that the area of the proposed action is broader than the immediate location where the action is undertaken); consider also whether there are any MNES adjacent to or downstream from the immediate location that may potentially be impacted?
2. Considering the proposed action at its broadest scope (that is, considering all stages and components of the action, and all related activities and infrastructure), is there potential for impacts, including indirect impacts, on MNES?
3. Are there any proposed measures to avoid or reduce impacts on MNES (and if so, is the effectiveness of these measures certain enough to reduce the level of impact below the significant impact threshold?
4. Are any residual impacts, following the implementation of mitigation measures, of the proposed action on MNES likely to be significant impacts (important, notable, or of consequence, having regard to their context or intensity)?

Significant impact criteria are provided for each of the MNES within the Significant Impact Guidelines (Commonwealth of Australia, 2009). As the amendment has yet to be released for water resources, a list of criteria is not currently available. The SEWPaC has, however, released an indicative list of significant impact criteria which can be applied to water resources and these will be referred to within this assessment. An action is likely to have a significant impact on water resources if there is a chance or possibility that the action will result in:

- A change in the quantity, quality or availability of surface or ground water;
- Alteration to ground water pressure and/or water table levels;
- Alteration to the ecological nature of a wetland;
- Diversion or impoundment to rivers or creeks;
- Alteration to drainage patterns;

- Reduction in biological diversity or change in species composition;
- Alteration to coastal processes, including sediment movement or accretion, or water circulation patterns;
- Persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the environment such that biodiversity, ecological integrity, human health or other community and economic use may be substantially adversely affected; and/or
- Increased demand for, or reduction in the availability of, water for the environment.

When is a significant impact likely?

To be 'likely', it is not necessary for a significant impact to have a greater than 50% chance of happening; it is sufficient if a significant impact on the environment is a real or not remote chance or possibility.

Source: Matters of National Environmental Significant Impact Guidelines 1.1 (Commonwealth of Australia, 2009)

2.3 Impact Assessment Methodology

The adopted methodology for assessing the significance of an impact is as follows:

- Definition of the proposed activities;
- Identification of receptors and determination of their sensitivity to the proposed activities;
- Assessment of the magnitude of potential impacts of the proposed activities prior to adoption of mitigation activities;
- Determination of the significance of the potential impacts of the proposed activities;
- Identification of potential mitigation measures which can reduce the magnitude and significance of the potential impacts of the proposed activities;
- Assessment of the magnitude of the impacts of the proposed activities following adoption of mitigation activities; and
- Determination of the significance of the potential impacts of the proposed activities.

2.3.1 Water Receptor Sensitivity

The levels of sensitivity to be applied to the water resources identified as receptors within the MNES framework are presented in Table 2-1. The sensitivity criteria have been identified based on the requirement to establish the sensitivity, value and quality of the environment against which the significance of a potential impact can be assessed. The sensitivity criteria have been adopted to be specific to water resources using professional judgment, and the current understanding of the federal and state legislative framework within which sensitive water resources sit.

Table 2-1: Sensitivity of Water Resource Receptor

Sensitivity	Description	Example
High	Attribute has a high quality and rarity on regional or national scale	Water suitable for potable use Supports pristine ecosystems including water dependent MNES Supports EPBC listed species Properties of groundwater support areas of spiritual or cultural significance that are inscribed on the World Heritage List Attributes of water system are unique to the region Water level highly responsive to change in water level Groundwater system isolated from recharge processes and pressure reduction would be permanent
Medium	Attribute has a high quality and rarity on a local scale	Water quality suitable for agricultural or stock use Water supports slightly disturbed ecosystems Supports areas of spiritual or cultural heritage listed on the National Heritage Register Attributes of the water system are locally unique but have few regional equivalents Groundwater has very low recharge rates and very long recovery periods
Low	Attribute has a medium quality and rarity on local scale	Water quality suitable for aquaculture or industrial use Water supports moderately to very disturbed ecosystems Support isolated areas of significant or cultural significance Attributes of the water system are common on a local, regional and national basis and therefore have local equivalents Groundwater has moderate to low recharge rates and medium term recovery periods
Very Low	Attribute has a low quality and rarity on local scale	Water quality unsuitable for any practical use No spiritual or cultural significance Attributes of groundwater system commonly found and widely distributed System completely resilient to change Groundwater has high recharge rates and short recovery periods

2.3.2 Estimating the Magnitude of Impact

Once the potential impacts of an action have been identified, the magnitude of the impact must be determined. The magnitude of an impact is dependent on:

- The scale of the action and its impacts;
- The intensity of the action and its impacts (i.e. the strength and severity of the impacts); and
- The timing, duration and frequency of the action and its impacts.

This is considered in Table 2-2 below. The Significant Impact Guidelines (Commonwealth of Australia, 2009) indicate that positive impacts are not considered as part of the referral process, and thus these are not considered further in this report.

Table 2-2: Magnitude of Potential Impact

Magnitude	Description	Example
Severe	Results in loss of attribute	Irreversible or persistent high-severity impact likely No recovery within foreseeable future Impacts are at a regional, national or international scale Impacts to groundwater may include: - The impact occurs across aquifers regionally - Groundwater discharge features and users are affected at a regional scale or in multiple locations Impact requires significant departure from Federal or State policy or guidance
Moderate	Results in impact on integrity of attribute or loss of part of attribute	Moderate severity impacts likely to persist over time or high-severity impacts that have a short duration only, with rapid recovery upon activity completion Impact extends across regional areas Impacts to groundwater may include: - The impact occurs across aquifers - Groundwater discharge features and users are affected Impact requires departure from Federal or State policy or guidance
Minor	Results in some measurable changes in attributes quality or vulnerability	Low severity impacts are likely to persist over time, or moderate-severity impacts are likely to have a short duration only, with rapid recovery when the activity is completed Impact extends beyond the area of activity or footprint. Impacts to groundwater may include: - The impact is restricted to within that aquifer only - Other aquifers or groundwater discharge features and users are not affected Impact causes minor departure from Federal or State policy or guidance
Negligible	Results in an impact on attribute but of insignificant	Low severity and short-term impacts restricted to the immediate area of activity or footprint No medium or long-term impacts on receptors Insignificant departure from Federal or State policy or guidance

2.3.3 Significance of Potential Impacts

The referral to which this report is appended is required to identify whether any potential impacts are significant, and the level of significance of the impacts referred. The definition of significant impact is based upon the Significant Impact Guidelines (Commonwealth of Australia, 2009) and supplemented by the indicative list presented by SEWPaC (2013), as detailed in Section 2.2.

The significance of a potential impact is a function of the sensitivity of the environmental value in combination with the magnitude of the impact. Table 2-3 presents the criteria used to rank the overall significance of impact. The criteria are designed to identify whether a significant impact may occur through a qualitative assessment. This provides a screen to identify whether potentially significant impacts may occur; in consideration of the list defining potentially significant impacts to water resources (Section 2.2).

Table 2-3: Significance of Impact

Magnitude of Impact	Sensitivity of the Receptor			
	High	**Medium**	**Low**	**Very Low**
High Adverse	Very High	High	Medium	Low
Moderate Adverse	High	Medium	Medium	Low
Minor Adverse	Medium	Medium	Low	Insignificant
Negligible	Low	Low	Insignificant	Insignificant

This referral is concerned with impacts that are predicted to have high or medium significance, after the implementation and application of proposed mitigation and management actions. On this basis, it is proposed that a significant impact identified as having Very High, High or Medium significance as per the matrix in Table 2-3 is considered to be significant with regard to this MNES referral.

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.

This report provides the justification and rationale for the identification of potentially significant impacts, and thus, the outcomes of this report identifies the predicted significance of impacts to water resources.

3 Proposed Action

3.1 Overview

The activities included as part of the proposed action are:

- Operation of the existing Bibblewindi Multi-Lateral Pilot (Bibblewindi 12, 13, 14, 15, 16, 17, 18H, 19H, 21H, 27, 28H and 29), construction, drilling and operation of two additional pilot wells (Bibblewindi 31 and 32), and the operation of existing water flow lines from Bibblewindi Multi-Lateral Pilot to the Bibblewindi Water Transfer Facility;
- Operation of the existing Bibblewindi West Pilot (Bibblewindi 22, 23, 24, 25 and 26) and operation of existing water flow lines from the Bibblewindi West Pilot to the Bibblewindi Water Transfer Facility;
- Operation of the existing Dewhurst 13-18H Pilot (Dewhurst 13, 14, 15, 16H, 17H and 18H) and the construction, drilling and operation of additional lateral wells from well casing within Dewhurst 16H, 17H and 18H;
- Construction, drilling and operation of the Dewhurst 22-25 Pilot (Dewhurst 6, 22, 23, 24 and 25);
- Construction, drilling and operation of the Dewhurst 26-31 Pilot (Dewhurst 26, 27, 28, 29, 30 and 31);
- Construction of the Dewhurst Northern Water and Gas Flow Lines and operation the Dewhurst Northern Water Flow Line;
- Construction of the Dewhurst Southern Water and Gas Flow Lines and operation of the Dewhurst Southern Water Flow Line;
- Operation of a produced water tank at the Bibblewindi Water Transfer Facility (Bibblewindi Water Transfer Tank) to facilitate the transfer of produced water from the pilot wells to the Leewood Produced Water Facility;
- Operation of the Leewood Water Pipeline to transfer water produced by the operation of the above pilot wells from the Bibblewindi Water Transfer Facility to the Leewood Produced Water Facility;
- Operation of the Leewood Produced Water Facility to store water produced by the operation of the above pilot wells;
- Transport of produced water from Leewood Produced Water Facility to an appropriately licensed facility; and
- Construction and operation of ancillary and supporting infrastructure to facilitate the above activities and ongoing maintenance.

It is noted that hydraulic fracturing is not planned to be used and thus is not part of the proposed action.

Table 3-1 and Figure 3-1 depict the locations of the pilot wells and flowlines included within the proposed action. The proposed action will include the following stages of works:

- Construction of flowlines and pilot wells;
- Operation of pilot wells; and

- Decommissioning of the pilot wells at the end of the pilot phase.

Table 3-1: Pilot Wells to be included in the Proposed Action

Pilot ID	Pilot well	Proposed or Existing Well	To be operated during activity	Easting	Northing
Dewhurst 13-18H Pilot	DWH13	Existing	Yes	764567	6616967
	DWH14	Existing	Yes	765592	6616503
	DWH15	Existing	Yes	764654	6617147
	DWH16	Existing*	Yes	765680	6616689
	DWH17	Existing*	Yes	764741	6617327
	DWH18	Existing*	Yes	765766	6616870
Dewhurst 22-25 Pilot	DWH6	Existing	Yes	764249	6610018
	DWH22	Proposed	Yes	763704	6610149
	DWH23	Proposed	Yes	764471	6609505
	DWH24	Proposed	Yes	764025	6610531
	DWH25	Proposed	Yes	764792	6609888
Dewhurst 26-31	DWH26	Proposed	Yes	754309	6599871
	DWH27	Proposed	Yes	754943	6600649
	DWH28	Proposed	Yes	754525	6599701
	DWH29	Proposed	Yes	755159	6600479
	DWH30	Proposed	Yes	755385	6600332
	DWH31	Proposed	Yes	754760	6599547
Bibblewindi Multi-Lateral Pilot	BBW12	Existing	Yes	753818	6604437
	BBW13	Existing	Yes	754200	6603693
	BBW14	Existing	Yes	754456	6603955
	BBW15	Existing	Yes	754027	6604759
	BBW16	Existing	Yes	754728	6604238
	BBW17	Existing	Yes	755033	6604538
	BBW18	Existing	Yes	753388	6604718
	BBW19	Existing	Yes	753647	6604994
	BBW21	Existing	Yes	754168	6605608
	BBW27	Existing	Yes	755478	6604689
	BBW28	Existing	Yes	752989	6604214
	BBW29	Existing	Yes	754273	6603234
	BBW31	Proposed	Yes	753647	6604994
	BBW32	Proposed	Yes	754456	6603954
Bibblewindi West Pilot	BBW22	Existing	Yes	749807	6609043
	BBW23	Existing	Yes	750106	6608555
	BBW24	Existing	Yes	750230	6608719
	BBW25	Existing	Yes	750358	6608877
	BBW26	Existing	Yes	749412	6609350
Notes * Existing wells will be re-entered and deepened to achieve target depth					

3.2 Construction Works

3.2.1 Flow Line Construction

Works associated with the installation of the flowlines include:

- Clearing of vegetation within a proposed ten metre wide corridor;
- Ripping of flowing easement along the full length of the flow lines;
- Fusion bonding of flowlines;
- Installation of flowlines using a ploughing and trenching technique;
- Reinstatement of surface and some minor compaction; and
- Rehabilitation of ground and vegetation disturbances.

The proposed flowlines have been located adjacent to unsealed tracks in order to minimise impacts. The proposed activity is expected to take approximately six to eight weeks to construct and will be operational for the duration of the associated pilot program.

3.2.2 Pilot Well Construction

The activities associated with the construction of the pilot wells is summarised in Table 3-2. Drilling works will include:

- Clearing of vegetation and grading of the ground surface to establish well pads and new access tracks (where required);
- Establishing lease areas up to approximately 1 ha in size each;
- Setting up temporary equipment on each lease area;
- Drilling an open hole through alluvial and/or weathered rock material into competent rock (Purlawaugh Formation) using water-based drilling mud;
- Installing steel surface casing and cementing into place back to the surface using high pressure cementing pumps;
- Drilling to the planned depth and installing production casing to the planned total depth;
- Completing the well using a smaller work over rig to install the downhole pump assembly, telemetry units, motor control centres and hydraulic drive head (well head);
- Installation of well head gas/water separators, gas generators, flow and pressure monitoring and telemetry equipment;
- Construction of water and gas gathering lines from the gas/water separators to water management infrastructure and flare locations; and
- Clearing and grading of areas to support placement of portable flares for flaring of gas during appraisal activities.

Table 3-2: Site Establishment and Drilling for Construction of Proposed Pilot Wells

Pilot ID	Proposed works
Dewhurst 13-18H Pilot	Existing roads and private farm tracks to be utilised and maintained Re-entering through the existing casing and then drilling two new horizontal wells (Dewhurst 16, 17 and 18) in the Bohena coal seam to connect to existing vertical wells (Dewhurst 13, 14 and 15 respectively) and water and gas infrastructure
Dewhurst 22-25 Pilot	Construction of four access tracks from Monument Road and Yellow Springs Trail to lease areas (including one creek crossing) Establishing four lease areas up to approximately 1 ha in size each Installing surface infrastructure on the Dewhurst 6 (existing) and Dewhurst 22-25 lease areas, including separators, metering skids, power generation equipment, telemetry units, motor control centres and drivers Constructing a gas gathering system parallel to the access tracks, Monument Road and Yellow Springs Trail to a flare at Dewhurst 22 Constructing a water gathering system parallel to the gas gathering system with associated piping and pumps at Dewhurst 22; the gathering system extends from the riser located at the edge of the pilot well lease area to the balance tank located at Dewhurst 22 Drilling two vertical wells (Dewhurst 22 and 24) to a depth of approximately 1005 m Drilling a tri-stacked horizontal well (Dewhurst 23) to intercept Dewhurst 22 Drilling a single horizontal well (Dewhurst 25 to intercept Dewhurst 24
Dewhurst 26-31 Pilot	Clearing four 10 metre wide service corridors between Beehive Road and the Dewhurst 26 to 31 lease areas Constructing access roads within the service corridors Establishing the Dewhurst 26 to 31 lease areas each up to approximately 1 ha in size Setting up temporary equipment on each lease area Drilling three vertical wells (Dewhurst 26, 28 and 30) to a depth of approximately 1050 mTVD Drilling three directional wells (Dewhurst 27, 29 and 31) to intercept Dewhurst 26, 28 and 30
Bibblewindi Multi Lateral Pilot	Setting up temporary equipment on each existing lease area Drilling one vertical well (BBW 31) and one horizontal well (BBW 32) on the existing lease pads Installing infrastructure to connect the wells and the existing gas and water gathering system from the Bibblewindi Multi-Lateral Pilot
Bibblewindi West Pilot	Existing roads and private farm tracks to be utilised and maintained No construction activity proposed to existing pilot site

3.3 Operation

Operation of each appraisal well will occur for a three year period. Operation activities will include:

- Extraction of water from the appraisal wells of the estimated volumes in Table 3-3;
- At each well, water produced from the wells will be pumped through the water gathering system to the transfer tank for that pilot, before being pumped to a water transfer tank at the Bibblewindi Water Transfer Facility via existing or proposed flowlines. The Bibblewindi Water Transfer Facility will be used to provide a short-term buffer (24 hours) prior to the produced water being pumped to the approved Leewood Produced Water Facility. The water storage tank at Bibblewindi Water Transfer Facility will be bunded, and equipped with level instrumentation, alarms and trips, to ensure the tank does not over fill; and flow meters on the tank inlet to monitor flow rates; and
- Produced water from the pond will be transported by road tankers to an appropriately licensed facility for treatment, reuse and/or disposal. An average of 35 truckloads per day are estimated to be required to transport produced water from Leewood Produced Water Facility to an appropriately licensed facility in the Sydney metropolitan area.

Table 3-3: Proposed Extraction Rates for Pilots

Pilot ID	Total Abstraction (m^3)	Max abstraction (m^3/day)	Average Abstraction (m^3/day)
Dewhurst 13-18H Pilot	331,121	397	302
Dewhurst 22-25 Pilot	285,140	273	260
Dewhurst 26-31 Pilot	413,801	448	378
Bibblewindi Multi Lateral Pilot	285,110	581	260
Bibblewindi West Pilot	92,940	209	85

The *Review of Environmental Factors for the Leewood – Produced Water and Brine Management Ponds* (Leewood REF) (RPS, 2012) provides the composition of water that has been used as the basis for the design of the Leewood produced water pond. Table 3-4 presents the maximum concentration of parameters likely to be contained within the produced water pond and transported to a licenced facility for treatment and disposal, as summarised from the Leewood REF.

Table 3-4 Produced Water Pond Water Quality Parameters

Parameter	Units	Maximum Concentrations
Parameter	Units	Maximum concentration
Total Dissolved Solids (TDS)	mg/L	31,000
Temperature	°C	30
pH		8.75
Total Suspended Solids (TSS)	mg/L	70
Turbidity	NTU	100
Total Algae Count	Cells/mL	700,000
Carbonate (CO3)	mg/L as CaCO3	780
Bicarbonate (HCO3)	mg/L as CaCO3	13,970

Parameter	Units	Maximum Concentrations
Chloride (Cl)	mg/L	3,950
Sodium (Na)	mg/L	9,300
Sulphate (SO4)	mg/L	64
Calcium (Ca)	mg/L	10
Magnesium (Mg)	mg/L	7
Potassium (K)	mg/L	70
Strontium (Sr)	mg/L	2.8
Barium (Ba)	mg/L	17
Fluoride (F)	mg/L	10
Silica (SiO2)	mg/L	27
Boron (B)	mg/L	1.7
Iron (Fe, dissolved)	mg/L	0.58
Cyanide (Total)	mg/L	0.009
Manganese (Total)	mg/L	0.06
Aluminium (Total)	mg/L	1.0
Phosphorus (Total)	mg/L	0.92
Ammonia	mg/L as N	18
Nitrate	mg/L as N	0.10
Nitrogen (Total)	mg/L	26
Copper (Total)	mg/L	0.26
Zinc (Total)	mg/L	0.31
Arsenic (Total)	mg/L	0.054
Chromium (Total)	mg/L	0.0679
Hexavalent Chromium	mg/L	<0.05
Cadmium (Total)	mg/L	0.06
Mercury (Total)	mg/L	0.022
Molybdenum (Total)	mg/L	0.0056
Nickel (Total)	mg/L	0.028
Antimony (Total)	mg/L	0.0006
Selenium (Total)	mg/L	0.068
Uranium (Total)	mg/L	0.0003
Lead (Total)	mg/L	0.015

The water stored within the produced water pond can be classified as saline or sea water based on the expected maximum concentration of 31,000 mg/L TDS. The potential high concentration of TDS and other water quality parameters has been considered when undertaking the assessment detailed in Section 2.

3.4 Decommissioning

Decommissioning activities will include:

- Decommissioning of pilot wells as per the NSW Code of Practice for Coal Seam Gas Well Integrity (DTIRIS, 2012a). This will include:
    - Sealing the wells from bottom to top by plugging with cement;
    - Pressure testing the cement plug across the surface casing shoe to ensure the wells are sealed;

  - Removing the well head at a depth of greater than 1.5 below surface and burying; and
  - Removal of the well pad and site rehabilitation;
- Venting of gas gathering lines and capping of both gas and water gathering lines; and
- Abandonment of redundant flowlines.

It should be noted that if commercial quantities of gas are identified and regulatory approvals are provided for further development and or extension of the existing licence this infrastructure may be retained for long term operational activities.

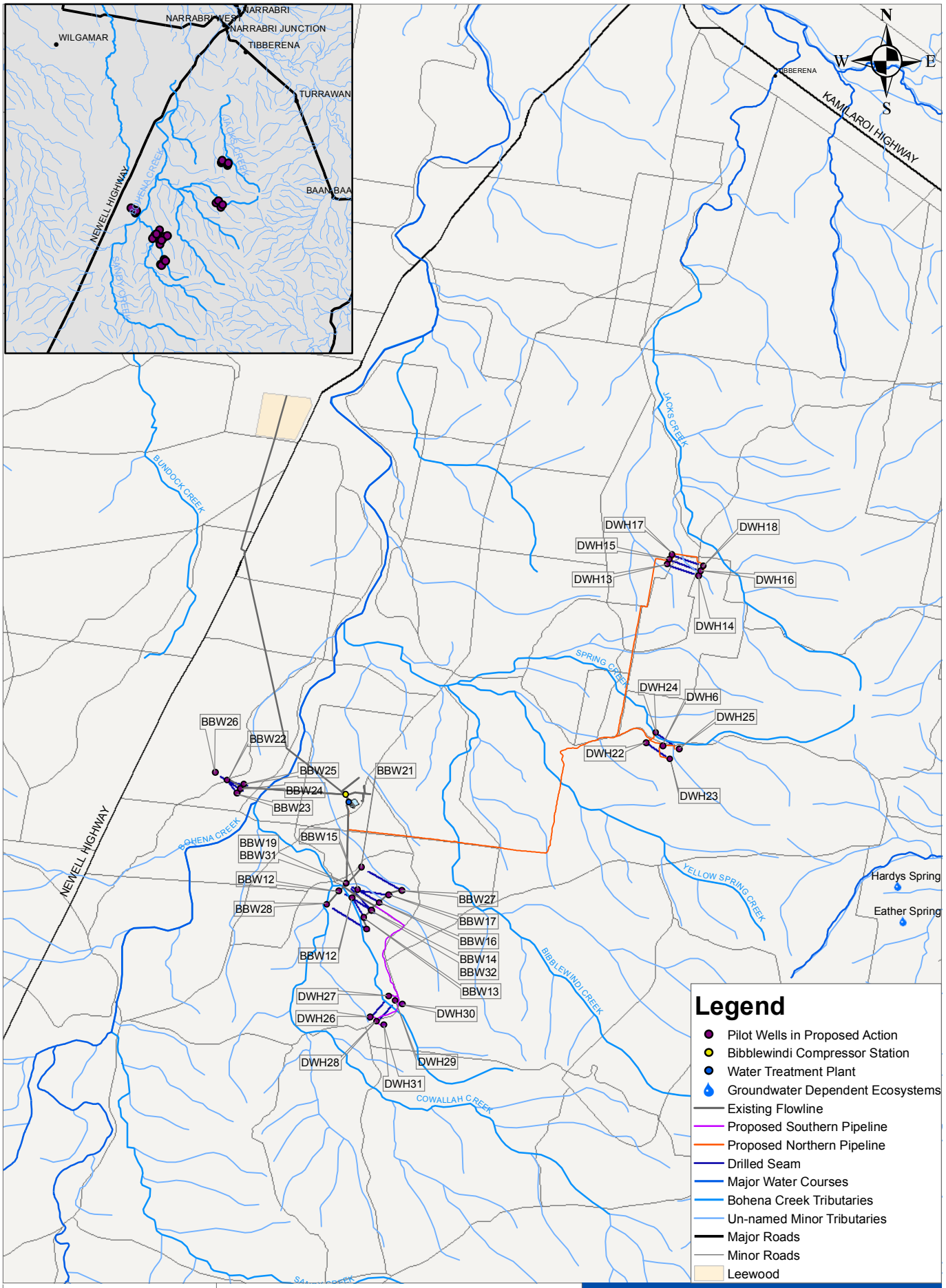

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Figure 3-1
Project Area

4 Existing Environment – Water Resources

This section presents the current understanding of the existing environment with respect to water resources. For the purposes of this assessment, a water resource is defined as surface water or ground water, or a watercourse, lake, wetland (whether or not it currently has water in it) or aquifer; 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 (Commonwealth Water Act 2007).

The Significant Impact Guidelines (Commonwealth of Australia, 2009) indicate that the determination of whether an action is likely, or not, to have a significant impact on a water resource is dependent on the **sensitivity, value**, and **quality** of the environment which is impacted.

Figure 4-1 depicts the water resources of the wider area, and Figure 4-2 focuses on the water resources surrounding the proposed pilot wells and flowlines.

4.1 Surface Water

The proposed action is located within the Namoi River Catchment which forms part of the Murray-Darling Basin (MDB) and covers an area of approximately 42,000 square kilometres (km) stretching from Woolbrook in the east to Walgett in the west. It is bounded to the east by the Great Dividing Range, to the north by the Gwydir catchment, to the south by the Castlereagh, Macquarie and Hunter Catchments and to the west by the Barwon-Darling catchment.

The proposed action is mainly located in the Lower Namoi sub-catchment which commences at Narrabri. The Dewhurst 13-18H wells are located within the Middle Namoi sub-catchment. Figure 4-1 presents the location of wells in relation to the Namoi River sub-catchments.

4.1.1 Creek Systems

Drainage through the project boundary occurs to the north via three small creeks:

- Bohena Creek (Lower Namoi sub-catchment, running southeast to northwest);
- Jacks Creek (Middle Namoi sub-catchment, draining the east north-eastern part of PEL 238); and
- Mollee Creek (Middle Namoi sub-catchment, located north-west of the Leewood Produced Water Facility).

All three creeks are tributaries of the Namoi River which flows in a general east to west direction through Narrabri approximately 20 km to the north of the referral area.

Bohena Creek

Bohena Creek is considered a fifth order stream and is largely ephemeral, flowing predominantly during rainfall events. Bohena Creek remains dry for extended periods between runoff events, sometimes in excess of 12 months (RPS, 2013). It contributes little inflow to the Namoi under normal conditions; however during protracted wet conditions, significant flood inflows to the Namoi can be generated (RPS, 2013). The flow gauge on Bohena Creek at the Newell Highway records an average flow of 127 ML/day, with a median daily flow (the flow that is exceeded 50% of the time) of 0 ML/day.

Bohena Creek is fed by:

- Spring Creek: an undisturbed second order water course, no water was observed to be flowing or pooled within the creek channel (RPS, 2013);
- Yellow Spring Creek;
- Bibblewindi Creek;
- Mt Pleasant Creek (an ephemeral creek): an ephemeral creek which runs north south to Cowallah Creek; and
- Cowallah Creek: an ephemeral creek which runs north south to Bohena Creek.

The tributaries to Bohena Creek are highly ephemeral and only flow during times of heavy rain. Ground truthing undertaken by RPS has verified the lack of riparian vegetation, likely due to the small size and low flow nature along identified drainage features supporting this conclusion (RPS, 2013). Baseflow in these creeks is considered insignificant.

There are also a number of other smaller unnamed drainage features which run into the named creek systems above; these are smaller ephemeral features. The ephemeral nature of the watercourses may support common fish species during migration and breeding and potentially provide feeding areas for some aquatic fauna (RPS, 2013); although it is considered unlikely that they will sustain viable aquatic ecosystems.

Jacks Creek

Jacks Creek is an ephemeral creek which runs north to the join the Namoi River. There are also a number of smaller unnamed drainage features which run into Jacks Creek. These are poorly defined and will also have ephemeral properties. The ephemeral nature of Jacks Creek means it is unlikely that it will sustain viable aquatic ecosystems.

Mollee Creek

Mollee Creek is an ephemeral creek that joins the Namoi River approximately 30 kilometres downstream of Leewood. A headwater tributary of Mollee Creek flows south-east to north through the property. The tributary is not well defined at the location of the Leewood Produced Water Facility (RPS, 2012).

Namoi River

The Namoi River is a perennial surface water system. Measurement at a flow gauge on the Namoi River at Narrabri indicates that the average flow is 1550 ML/day, with the average minimum flow being 618 ML/day in April and the average maximum flow being 3191 ML/day in February. The median daily flow (the flow that is predicted to be exceeded 50% of the time) is 616 ML/day. This section of the Namoi River is a 'losing stream'. The Namoi River system provides a wide range of aquatic habitats and is ecologically important.

The Namoi River is a major source of water for irrigation and stock and domestic, with private water supply at a lesser frequency.

4.1.2 Lakes and Ponds

There are no large standing water bodies within the Program area. There are a number of smaller man-made surface water dams which have not been mapped.

4.1.3 Surface Water Dependent Ecosystems

The Namoi State of the Catchment Report (2010) does not identify any surface water dependent ecosystems (SWDE) within the Program area (Figure 4-1). The nearest SWDEs are:

- The Lagoons (wetland billabong) approximately 23 km to the east of Dewhurst 13 to 18H;
- Narrabri Lagoon (wetland billabong) approximately 25 km to the north of Dewhurst 13 to 18H; and
- Yarrie Lake approximately 16 km to the north-east of the Leewood Produced Water Facility and 29 km to the north-east of Dewhurst 26-31, the nearest pilot.

On this basis it is considered that significant impact will not occur to SDEs and thus these are not considered further in this assessment.

4.1.4 Summary of Surface Water Receptors

A summary of the identified surface water receptors is presented in Table 4-1. The sensitivity of each of the surface water receptors has been assessed based on currently available knowledge.

Table 4-1: Summary Surface Water Receptors Quality

Feature	Sensitivity*	Description
Namoi River	High	The water in the heavily regulated Namoi River is of high quality and is utilised for stock, domestic and irrigation purposes. The water system is unique to the region. The losing nature of the system in the vicinity of the Program area suggests that it contributes to the groundwater within the Namoi Alluvium.
Bohena Creek	Medium	The ephemeral nature of Bohena, Jacks and Mollee Creek support moderately to very disturbed ecosystems. The attributes of the creek systems are considered to be important on a local scale but abundant regionally. The ephemeral nature of the creeks means that they are not used for water supply.
Jacks Creek	Medium	
Mollee Creek	Low	The ephemeral nature of Mollee Creeks is likely to support moderately to very disturbed ecosystems. The creek is likely to have very low value ecologically or for water supply purposes.
Mt Pleasant Creek	Low	The ephemeral nature of the existing creek network is likely to support moderately to very disturbed ecosystems. The characteristics of the creek systems are common within the region. The ephemeral nature of the creeks means that they are not used as water sources for water supply.
Cowallah Creek	Low	These tributaries are headwaters of the Bohena Creek. They are minor ephemeral creek systems, which include remnant pools. They have very low value ecologically or for water supply purposes.
Spring Creek	Low	
Yellow Spring Creek	Low	
Bibblewindi Creek	Low	
Un-named minor tributaries	Very low	
*Determined using criteria set out in Table 2-1 'sensitivity of water resource receptor'.		

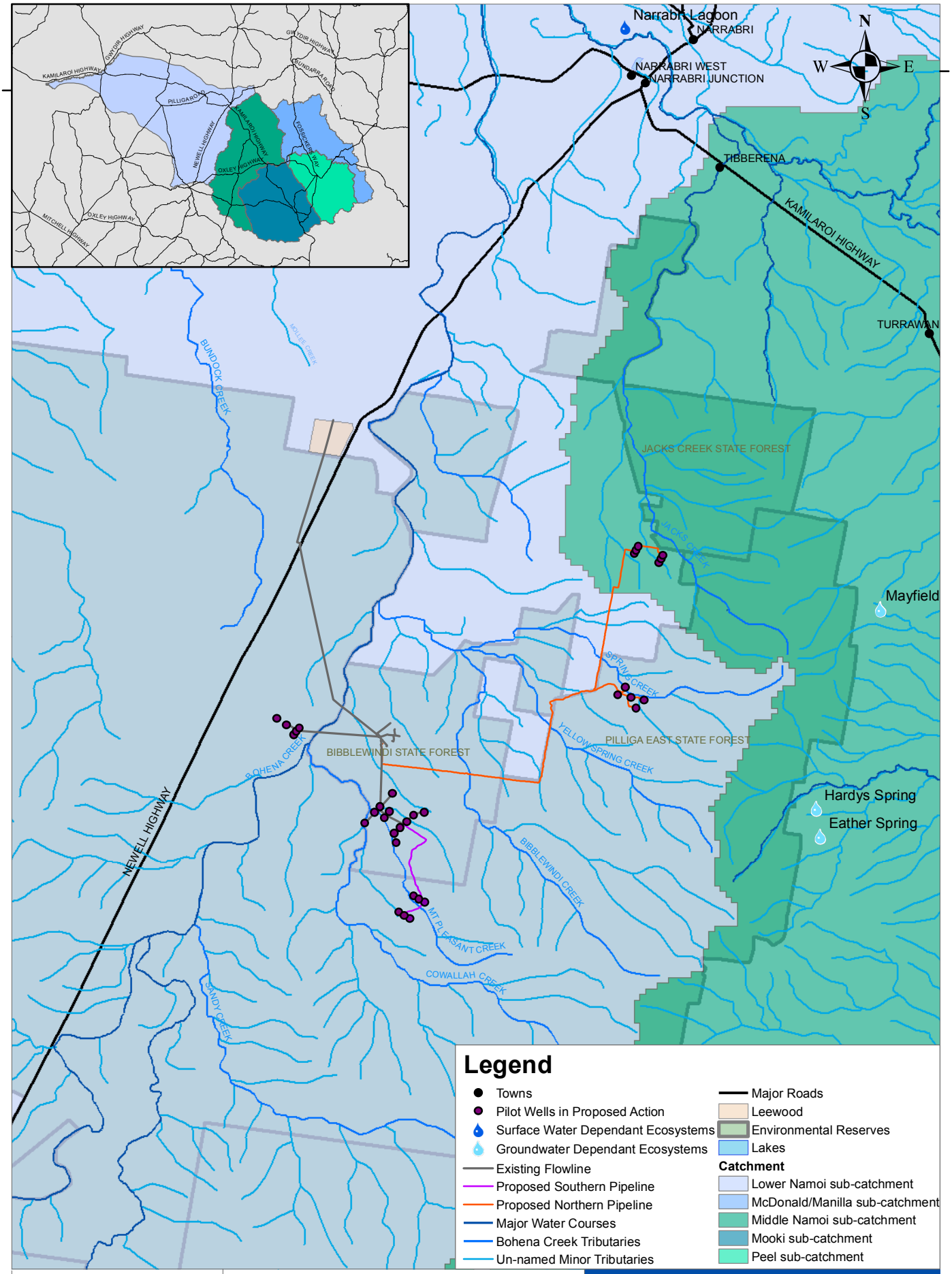

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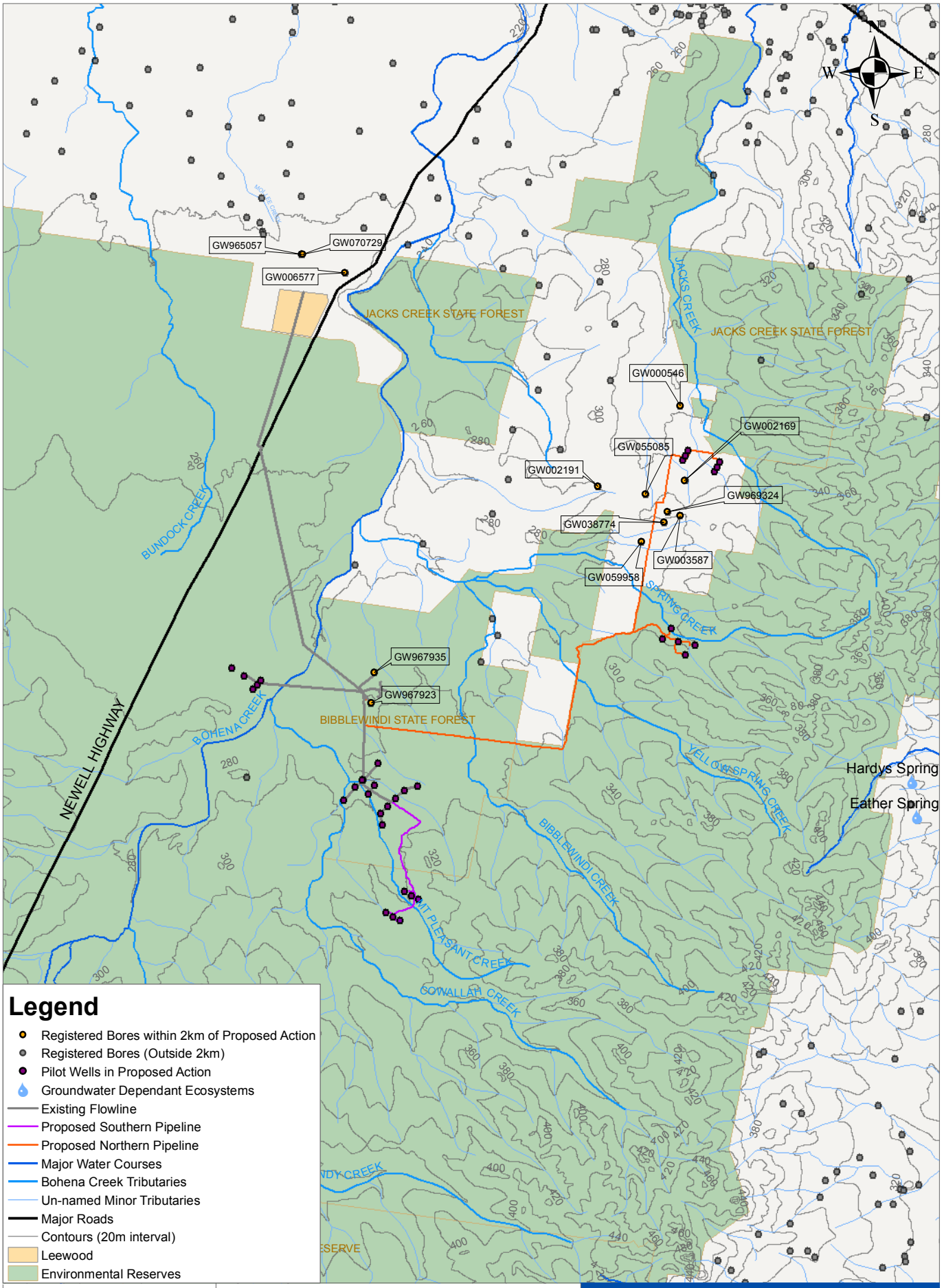
Figure 4-1
Environmental Values - Wider Area



Legend

- Registered Bores within 2km of Proposed Action
- Registered Bores (Outside 2km)
- Pilot Wells in Proposed Action
- Groundwater Dependant Ecosystems
- Existing Flowline
- Proposed Southern Pipeline
- Proposed Northern Pipeline
- Major Water Courses
- Bohena Creek Tributaries
- Un-named Minor Tributaries
- Major Roads
- Contours (20m interval)
- Leewood
- Environmental Reserves

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Figure 4-2
Environmental Values - Proposed Action

4.2 Groundwater

4.2.1 Groundwater Sources

The proposed action is located within both the Permo-Triassic Gunnedah Basin (containing the target seams for CSG development) and the south eastern fringes of the Coonamble Embayment, a southerly extension of the overlying Surat Basin.

The site is underlain directly by unconsolidated alluvium overlying outcrops of the Jurassic Surat Basin strata consisting of the Keelindi Beds and the Pilliga Sandstone (Figure 4-3). The Surat sediments are underlain by the Gunnedah Basin strata including the Triassic Deriah, Napperby and Digby Formations.

The hydrostratigraphy underlying the Program area is presented in Table 4-2 and is depicted schematically in Figure 4-4. Relevant groundwater sources, rock units which can both store and transmit groundwater, which occur beneath the Program area have been identified.

The groundwater sources of highest value (significant transmissive units) within the Program area, and hence most likely to be classed as MNES are:

- Superficial sediments of unconsolidated alluvium; and
- The Pilliga Sandstone.

In addition a number of minor groundwater sources (less significant transmissive units) have been identified within the region, these are:

- The Late Triassic-Early Jurassic Garrawilla Volcanics; and
- The Late Permian Clare Sandstone (of the Black Jack Group).

The coal seams (including the target coal seam) are also considered within this assessment due to their relatively high conductivity in comparison with adjacent strata. Whilst they are not significant groundwater sources in terms of water supply, they can be considered significant transmissive units in the context of produced water extraction. All these units are described in more detail below.

Superficial Sediments

The superficial sediments within the area principally consist of minor deposits of undifferentiated and unconsolidated alluvial/colluvial sediments. These have a limited occurrence and form localised surface cover over the sub-cropping Permo-Jurassic stratigraphy, with a thickness that locally can extend to several tens of metres. Those forming the channel infill along the Bohena Creek and tributaries are collectively known as the Bohena Creek Alluvium, can be defined as a less significantly transmissive unit.

Recharge to the Bohena Creek Alluvium occurs either directly through infiltrating precipitation or via surface-water groundwater interaction with the local tributaries, or through lateral recharge from the Keelindi Beds or Pilliga Sandstone. As the Bohena Creek and its tributaries are ephemeral, recharge through the beds of these creeks only occurs after rainfall events and is short term.

Pilliga Sandstone

The Pilliga Sandstone is a significant transmissive unit in the Program area and forms part of the GAB southern recharge area. At outcrop, within the east and south east of PEL 238 as shown on Figure 4-3, groundwater is inferred to flow in a north-westerly direction towards

the GAB. The Pilliga Sandstone generally comprises gently dipping medium to coarse grained sandstones. The Pilliga Sandstone is utilised for local groundwater supply in the Program area and the water quality is generally good.

The Pilliga Sandstone is overlain by the Keelindi Beds in the majority of the Program area. These consist of sandstone and conglomerate, interbedded with minor shale, siltstone and coal and are understood to be approximately 30 to 50 m thick (AGE, 2006). The Keelindi Beds are considered likely to act as an aquitard, limiting groundwater flow on account of lithological characteristics and bedding, thus confining the underlying Pilliga Sandstone.

Recharge mainly occurs via the infiltration of precipitation into the soil and then into the underlying Pilliga Sandstone where the Pilliga Sandstone outcrops.

The Pilliga Sandstone has experienced a long-term reduction in artesian pressure where the sandstone is confined, although in more recent years data indicates that the reduction in pressure is stabilising. The long-term reduction in pressure is associated with groundwater abstraction in the area, the volume of groundwater now being abstracted has decreased due to the introduction of tighter regulations.

Garrawilla Volcanics

The Garrawilla Volcanics occur at depth in the Program area and form the base of the Surat Basin strata. They generally comprise volcanic flows and pyroclastic deposits and are discontinuous across the region. They are commonly absent in boreholes penetrating the underlying Triassic strata in the Program area and are not regularly utilised for water supply.

The Garrawilla Volcanics are separated from the overlying Pilliga Sandstone by the low conductivity aquitard, the Purlawaugh Formation.

Clare Sandstone

The Clare Sandstone forms part of the Black Jack Group and sits above the Benelebri Formation which in turn overlies, and confines, the Hoskissons coal seam. It is a medium to coarse grained sandstone. The Black Jack Group at the centre of the Bohena Trough is up to 184 m thick. The Clare sandstone reaches up to 95 m thick in the south east of the Mullaley sub-basin south of the Program area. The Clare Sandstone is the only formation of the Black Jack Group with a hydraulic potential as a groundwater resource but the quality of the water is likely to be poor as the sandstone often includes minor coals. Due to its depth and the presence of the alluvium and Pilliga Sandstone at surface, the Clare Sandstone is not significantly utilised. It is considered unlikely that the Clare Sandstone would be considered a MNES under the conditions of the forthcoming amendment bill.

Coal Seams

The coal seams including the target coal seam of the Maules Creek Formation are generally moderately transmissive, exhibiting higher hydraulic conductivity than the adjacent units. However, these units are not utilised for water supply due to the depth and presence of the alluvium and Pilliga Sandstone closer to the ground surface. The coal seams are typically characterised by poor water quality which is saline.

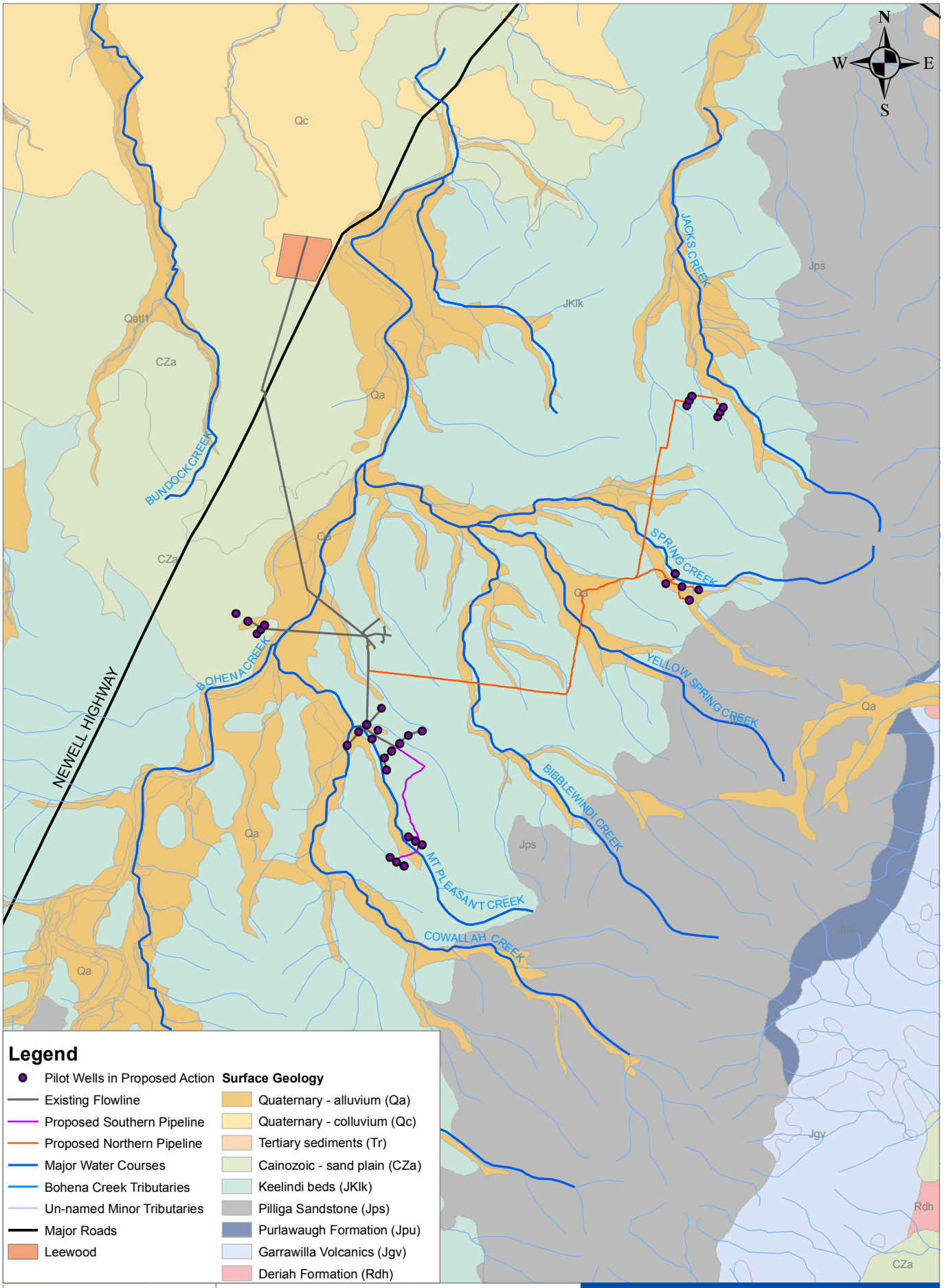

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Figure 4-3
Surface Geology

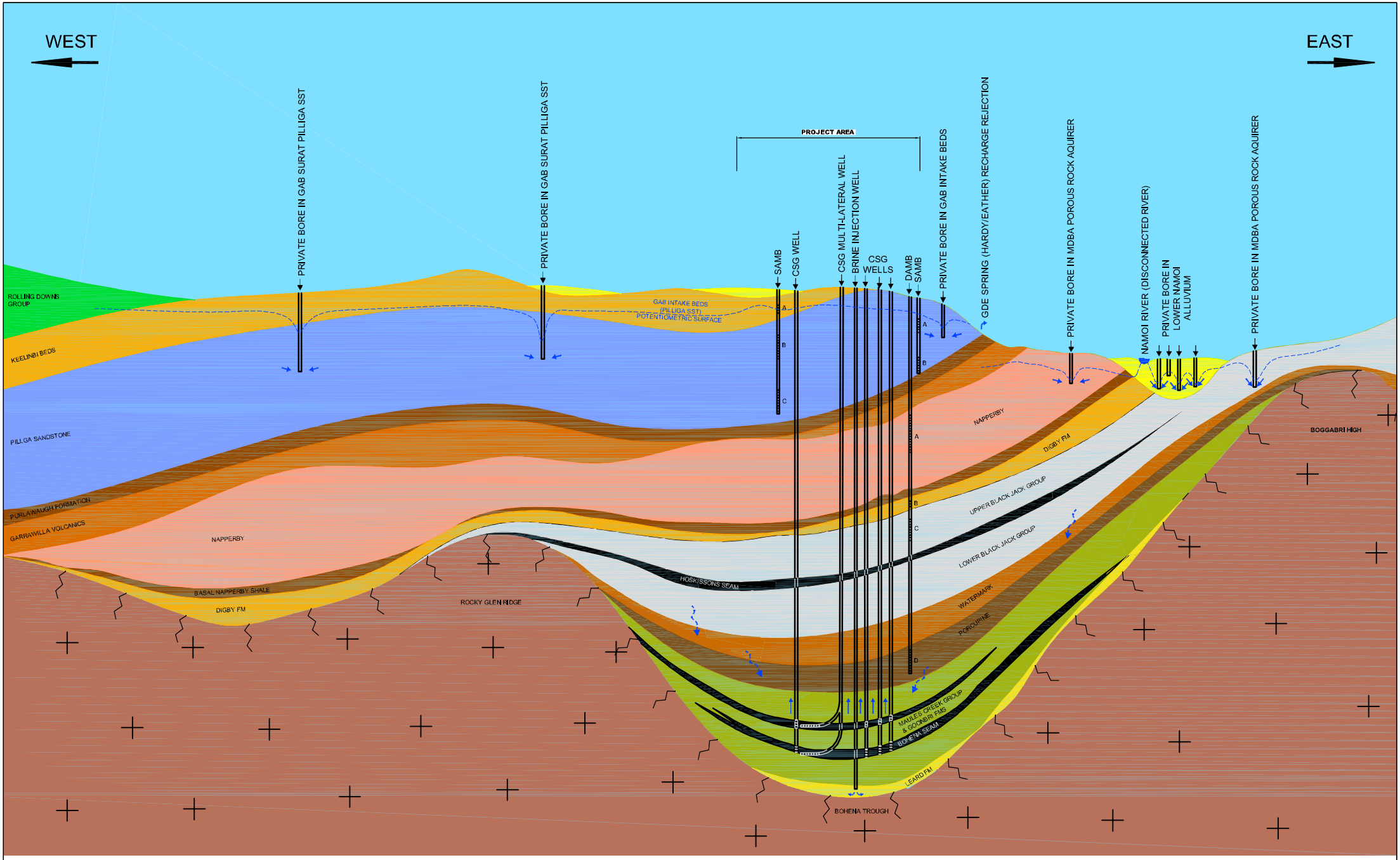

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FIGURE 4 - 4 **PRELIMINARY**

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Level 19, 215 Adelaide Street
Brisbane 4000, QLD, Australia
Ph: +61 7 3169 2900
Fax: +61 7 3169 2999
brisbane@halcrow.com

SANTOS EABU MNES STUDY

SCHEMATIC CONCEPTUALISATION OF HYDROSTRATIGRAPHY OF THE BOHENA TROUGH

job no. 474170
rev no. A

scale NTS date OCTOBER 2012

474170-W-SKT-002

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Table 4-2: Hydrostratigraphy of the Program Area

Province	Period/Epoch	Division	Group	Sub-group	Formation	Lithologies & hydrogeological classification	Relevance to Program
Namoi	Pleistocene				Narrabri Fm & Bohena Creek alluvium	Clay and silt with sand lenses	Potentially sensitive groundwater resources important for local groundwater extraction and ecology
	Pliocene				Gunnedah Fm	Gravel and sand with clay lenses	
	Miocene				Cubbaroo Fm		
GAB Surat Basin	Cretaceous	Middle	Blythesdale		Keelindi Beds	Clayey to Quartzose sandstone, subordinate siltstone and conglomerate	Typically low-yielding & hydraulic impedance to groundwater
		Early			Pilliga Sandstone	Fluvial, medium to very coarse grained, quartzose sandstone and conglomerate. Minor interbeds of mudstone, siltstone and fine grained sandstone and coal.	Potentially sensitive groundwater resources important for local groundwater extraction and ecology
	Jurassic	Late					
		Middle			Purlawaugh Fm	Siltstone and mudstone thinly interbedded with fine grained sandstone and thin coal seams	Probable hydraulic barrier to groundwater movement
		Early					
Gunnedah Basin	Triassic	Late	Garrawilla Volcanics			Dolerite, basalt, trachyte, tuff, breccia	Variably-yielding groundwater resources not commonly utilised locally
		Middle			Deriah Fm	Sandstone	Variably-yielding groundwater resources not commonly utilised locally
					Napperby Fm	Interbedded fine sandstone, claystone & siltstone	
						Basal Napperby Shale	Probable hydraulic barrier
		Early			Digby Fm	Quartzose sandstone (Ulinda Sst)	Typically low-yielding & hydraulic impedance to groundwater
						Lithic sandstone	
						Lithic conglomerate (Bomera Conglomerate)	
	Permian	Late	Black Jack	Nea	Trinkey Fm	Coal measures - siltstone, fine sandstone, tuffs, stony coal	Typically low-yielding & hydraulic impedance to groundwater
					Wallala Fm	Conglomerate, sandstone, siltstone, minor coal bands	
				Coogal	Breeza Coal	Coal and claystone	
					Clare Sandstone	Medium to coarse-grained quartzose sandstone; quartzose conglomerate	Variably-yielding groundwater resources not commonly utilised locally
					Hows Hill Coal	Coal	
					Benelebri Fm	Claystone, siltstone & sandstone; fining up cycles; more sandy towards top	Probable hydraulic barrier
					Hoskissons Coal	Significant Transmissive Unit	Potential depressurisation target
				Brothers	Brigalow Fm	Fining-up sequence of medium to coarse-grained quartzose sandstone and siltstone	Typically low-yielding & hydraulic impedance to groundwater
					Arkarula Fm	Sandstone and siltstone	
					Melvilles Coal	Coal	
					Pamboola Fm	Sandstone, siltstone, minor claystone & coal	
		Middle	Millie		Watermark Fm	Marine siltstone, shales and sandstone	Potential hydraulic barrier
					Porcupine Fm	Fining upward sequence of conglomerate and sandstone to mudstone	Typically low-yielding & hydraulic impedance to groundwater
		Early	Bellata		Upper Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal	
					Rutley Seam	Target seams: Energy NSW CSG Exploration and Appraisal Program	Depressurisation targets
					Namoi Seam		
					Parkes Seam		
					Bohena Seam		
					Lower Maules Creek Fm	Sandstone and conglomerate, siltstone, mudstone and coal	Typically low-yielding & hydraulic impedance to groundwater
					Goonbri Fm	Siltstone, sandstone and coal	
					Leard Fm	Flinty claystone	
			Werrie Basalt and Boggabri Volcanics			Rhyolitic to dacitic lavas and ashflow	
						Tuffs with interbedded shale; rare trachyte and andesitel; weathered basic lavas	

Colour code key		
	STU	Significant Transmissive Unit
	LSTU	Less Significant Transmissive Unit
	PNTU	Probable Negligibly Transmissive Unit
	NTU	Negligibly Transmissive Unit

4.2.2 Groundwater Dependent Ecosystems - Springs and Wetlands

There are no GDEs springs or wetlands within the area of the proposed action. Figure 4-1 shows the locations of the nearest GDEs which are:

- Eather Spring, approximately 10 km from Dewhurst 22 to 25;
- Hardys Spring, approximately 9 km from Dewhurst 22 to 25; and
- Mayfield Spring, approximately 9.5 km from Dewhurst 13 to 18H.

These springs are considered to occur at the interface of the Jurassic Pilliga Sandstone and the Purlawaugh Formation and are therefore most likely to be classed as 'water table springs' and thus not connected to the deeper groundwater systems. These springs occur from the GAB intake beds when the rate of recharge to the shallow groundwater sources exceeds the capacity for deep drainage into the GAB intake beds. The result is preferential discharge of excess shallow groundwater as springs, which are controlled by surface topography and changes in hydraulic conductivity at formation contacts.

Stygofauna communities may exist within subsurface waters and thus can also be classed as a GDE (NSW Office of Water, 2012). Slight changes in groundwater attributes (quality or quantity) may result in changes to the population assemblage. Recent investigation by Eco Logical Australia Ltd has not identified significant stygofauna populations within groundwater sampled from monitoring wells. However, it is considered feasible that stygofauna populations may exist and as such, additional sampling will be undertaken from water produced during the operation of the pilots to further investigate stygofauna populations as part of the exploration and appraisal activity. No further sampling will be undertaken prior to commencement of the proposed activity.

4.2.3 Groundwater Dependent Ecosystems - Terrestrial Vegetation

The Pilliga Forest is classified by the Groundwater Dependent Ecosystem Atlas (Bureau of Meteorology, 2012) as having moderate potential for groundwater interaction, which corresponds to the possible presence of groundwater and the possible utilisation by ecosystems.

Eco Logical Australia Ltd has undertaken an assessment of the potential impact of ecological MNES in support of the referral to which this report is appended, and thus, further assessment is considered outside the scope of this report.

4.2.4 Groundwater Users

Groundwater use within the Program area is limited. This is attributed both to land use constraints arising from the Program area coinciding with the footprint of the Pilliga Forest and lower bore yields associated with the consolidated rock units. The location of private registered bores have been obtained from the NOW bore database (PINEENA) and are presented on Figure 4-2.

It is understood from the PINEENA database and limited bore inventory data obtained within PEL238 that there are no extractions from formations deeper than the Pilliga Sandstone. The majority of bores are utilised for stock and domestic purposes. A town water supply is provided from abstraction bores in Narrabri, to the north of the Program area.

The target strata for CSG extraction are the principal coal seams of the Maules Creek Formation, which is not currently utilised for water supply due to depth, water quality and availability of better quality groundwater near the surface.

There are a total of 10 registered bores within 2 km of the proposed action (Figure 4-2 and Table 4-3).

Table 4-3 Registered Bores within 2 km of the Proposed Action

Registration number	Latitude	Longitude	Final Depth (m bgl)	Inferred Source Aquifer
GW967935	-30.62	149.65	93	Pilliga Sandstone
GW967923	-30.63	149.65	90	Pilliga Sandstone
GW059958	-30.58	149.74	66	Pilliga Sandstone
GW038774	-30.57	149.75	76.2	Pilliga Sandstone
GW003587	-30.57	149.76	72.5	Pilliga Sandstone
GW969324	-30.57	149.75	71	Pilliga Sandstone
GW055085	-30.56	149.75	65	Pilliga Sandstone
GW002169	-30.56	149.76	54.8	Pilliga Sandstone
GW000546	-30.53	149.76	75.7	Pilliga Sandstone
GW002191	-30.56	149.73	56.3	Pilliga Sandstone
GW006577	-30.49	149.64	67.6	Pilliga Sandstone
GW965057	-30.50	149.63	91.5	Pilliga Sandstone
GW070729	-30.48	149.63	58.5	Pilliga Sandstone

4.2.5 Summary of Groundwater Receptors

A summary of the identified groundwater receptors in the Program area can be seen in Table 4-4. The sensitivity of each of the groundwater receptors has been assessed based on available knowledge against the criteria set out in Table 2-1.

Table 4-4: Summary of Groundwater Receptors

Feature	Sensitivity*	Description
Bohena Creek Alluvium	Medium	Groundwater from this source may be abstracted for local use Supports Pilliga Forest Terrestrial GDE Groundwater will have moderate recharge rates however recovery periods are likely to be relatively short as the aquifer is unconfined
Pilliga Sandstone	Medium	This groundwater source is used predominantly for stock and domestic abstractions within the Program area The groundwater system is locally unique due to having few equivalents and forms part of the GAB The groundwater source is partially confined and therefore has low recharge rates and relatively long recovery periods
Garrawilla Volcanics	Low	Water quality generally unknown but considered likely to be un-suitable for use No known abstractions due to its depth The attributes of the groundwater system are likely to be relatively commonly found however recharge rates are very low and recovery is also likely to be limited
Clare Sandstone	Very Low	Water quality generally poor due to the presence of minor coals and unsuitable for any use No known abstractions due to its depth and quality The attributes of the groundwater system are likely to be relatively commonly found however recharge rates are very low and recovery is likely to be limited
Coal seams including the target formation	Very Low	Water quality highly saline and unusable for any purpose Attributes of this system are commonly found and widely distributed The nature and depth of this formation results in its lack of use as a water resource
Groundwater Dependent Ecosystem springs and wetlands	High	High priority GDEs exist at Eather, Hardys and Mayfield springs The presence or absence of EPBC listed species (or other federal or state protection) is unknown Adopting the precautionary principle, it is assumed that these GDEs are of high sensitivity
Stygofauna populations	High	Stygofauna communities may exist in the unconsolidated alluvium within the area of the proposed action Due to the lack of knowledge on the presence of these receptors and their potential sensitivity to small changes in groundwater levels and quality, their sensitivity has been designated as high
*Determined using criteria set out in Table 2-1 'sensitivity of water resource receptor'.		

5 Potential Impacts and Management/Mitigation Measures

5.1 Potential Impacts

A number of potential impacts to water resource MNES have been identified. Table 5-3 (at the end of this section) presents a risk assessment detailing the nature of the activity, the resultant risk, cause of the risk and the potential impact. The risk assessment has been undertaken considering the outcomes of the numerical groundwater flow modelling discussed in Section 5.2. The final column in Table 5-3 presents the proposed management and/or mitigation approaches that are identified in the relevant REF documents for each pilot.

5.2 Cumulative Groundwater Impact Assessment

A cumulative groundwater impact assessment has been undertaken by Santos in order to understand the potential impacts of the Program on the groundwater resources of the Program area. This has involved the development of a numerical groundwater flow model to provide a quantitative estimate of inter-aquifer fluxes and predict the water level drawdown arising from the cumulative produced water extraction. The numerical groundwater flow model development methodology and outcomes are discussed in the following sections.

5.2.1 Model Development

Model Code and Layering

A 3-dimensional numerical groundwater flow model has been constructed within the area of the proposed activity. The model has been calibrated using MODFLOW-2005 and the graphical user interface Groundwater Vistas™ in order to provide a basis for predictive simulations for the produced water extraction relating to the Program. The hydrogeological conceptualisation discussed in Section 4.2 was used to inform development of the numerical groundwater flow model. Table 5-1 below illustrates the relationship between stratigraphy and model layering.

Table 5-1 Stratigraphy and Model Layering Correlation

Epoch	Hydrostratigraphic Unit	Model Layer
Quaternary	Alluvium	1
Jurassic	Pilliga Sandstone	2 and 3
	Purlawaugh Fm	4
	Garrawilla Volcanics	
Triassic	Deriah Fm	5 and 6
	Napperby Fm	
	Digby Fm	
Permian	Black Jack Group	7, 8 and 9
	Millie Group (Porcupine Fm & Watermark Fm)	10
	Upper Maules Creek Fm	11
	Target coal seams (Rutley Namoi & Bohena seams)	12
	Lower Maules Creek Fm	13
Pre-Permian	Basement	14

Configuration of Pilot Program

The numerical model was developed and refined to consider the cumulative impact of CSG activities within PEL 238 and PAL 2. This includes the five pilot sites under consideration within the proposed action. The results of the cumulative groundwater impact assessment are therefore considered to be conservative.

In the vicinity of each pilot, the model cells were refined horizontally from 500 m by 500 m grid cell spacing to 50 m by 50 m. The in-seam extent of the lateral wells was identified and MODFLOW well boundaries applied to the respective cells in Layer 12 of the model.

Depressurisation of the target seam was accomplished using MODFLOW drains. The depressurisation schedules for all pilots follow a similar pattern, consisting of successive reduction of assigned DRN boundary head, from the value of groundwater head pertaining at that location to a value calculated as 35 m above the elevation of the top of the model layer that represents the target seam at that location.

Historical Abstraction

Historical water extraction was recorded at three pilot sites between March 2009 and February 2012. As a consequence of the magnitude of these historical abstractions and the likely impacts on heads in the respective target seams, these historical water extraction data were incorporated into the simulations.

Predicted Water Rates

Predicted water extraction rates simulated in the numerical groundwater flow model were as per that specified in Table 3-3. Water extraction rates for the five additional pilots modelled for conservatism were synthesised from the predicted water extraction rates.

Initial Conditions and Transient Simulation Protocols

Initial values of groundwater head, or 'Initial Heads' (IH), are commonly derived from monitoring data, where available. In this case, prior monitoring data to adequately describe IH are not available. Hence IH have been derived from a precursor "*steady-state model*", calibrated to limited data available for the shallow alluvial groundwater sources (Namoi alluvium) and sparse head data for deeper layers obtained during exploratory drilling. These IH have been used as seed heads for the "*historical model*" for the simulation of the historical pilot water extraction. The historical model incorporates some water level/pressure recovery which will have occurred between the end of the historical water extraction and the commencement, or recommencement, of the ten exploration sites. The historical model yields "historical heads" (HH) representing the groundwater condition at the time of the start of the "*predictive model*". The predictive model starts with HH to simulate the impacts of prognosed water extractions and incorporates the planned pilot site water extraction. The predictive model yields "pilot heads" (PH) representing the groundwater conditions at the end of the extraction phase of the last of the ten pilot sites. A fourth model, the "*recovery model*" was developed to simulate the recovery of groundwater heads over a period of 500 years. Three transient models were required in this instance to maintain model stability and optimise computational resources.

5.2.2 Model Outcomes

The outcomes of the numerical groundwater flow modelling with respect to the predicted maximum drawdown in selected hydrostratigraphic units are summarised in Table 5-2

Table 5-2: Predicted Maximum Drawdown

Hydrostratigraphic Unit (HSU)	HSU No.	Model Layer	Maximum Hydraulic Head Reduction in Layer (m)	Time at which Maximum Drawdown Occurs
Bohena Creek alluvium	8	1	<0.5	≥500 years
Pilliga Sandstone	10	3	<0.5	≥500 years
Garrawilla Volcanics	9	4	1.4	≥500 years
Triassic Strata (Deriah, Napperby and Digby Formations)	3	6	3.8	400 years
Permian (Clare Sandstone)	4	7	>50	>46 years
Porcupine and Watermark Formations	5	10	>50	62 years
Maules Creek Formation seams	11	12	995	46 years

Modelling of the CSG produced water extraction from the target coal seams, required to achieve satisfactory seam depressurisation, inevitably results in substantial hydraulic head reduction in the corresponding and directly overlying model layers (model layers 7, 8 and 9). However, the quality of the produced water is very poor, the same source strata are not utilised for private groundwater extraction and the modelling indicates they do not have a significant hydro-ecological role in the Program Area.

Based on the model outputs, the less significantly transmissive Permian strata, including the Clare Sandstone, and late Triassic to early Jurassic strata, including the Garrawilla Volcanics, may experience greater than 0.5 m drawdown in places (Table 5-2). However, the quality and accessibility of the groundwater within these formations is poor, especially within the Program area, and there are no known abstractions within the Program area due to their depth and the availability of better quality sources of water.

The findings of the cumulative groundwater impact assessment indicate that depressurisation of the target coal seam, as a result of pilot activities, results in a negligible decline in water levels (less than 0.5 m) within the Namoi Alluvium and the Pilliga Sandstone groundwater sources. The impact in shallower geologic formations is generally not manifested for a considerable amount of time (≥500 years), by which time the calculated fluxes generating these impacts and the extents of drawdown are diminished to magnitudes likely to be undetectable within the natural range of annual fluctuations.

Table 5-3: Water Resources Impacts and Mitigation Measures

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
Site establishment, operation and management	Vegetation clearance, earthworks and stockpiling	Increased surface runoff	Channelling of stormwater flow, compaction of soils and reduced infiltration	Change to surface water flow regime	• Wells pads and gathering lines to be constructed in either previously disturbed areas or immediately adjacent to existing cleared areas or tracks to minimise vegetation clearance and groundwater disturbance • Routine monitoring of surface water systems
		Increased sediment loads	Vegetation clearance	Sedimentation of surface water systems	• Implementation of erosion and sediment control measures e.g. silt fences, diversion drains, contour banks • Wells pads and gathering lines to be constructed in either previously disturbed areas or immediately adjacent to existing cleared areas or tracks to minimise vegetation clearance and groundwater disturbance • Routine monitoring of surface water systems
		Littering of surface waters	Waste produced during site establishment	Impact to aquatic ecosystems	• Appropriate waste receptacles will be provided in designated areas of each work site • All wastes will be removed from the proposed activity at the completion of the works for recycling or disposal at an appropriately licensed facility • All staff and contractors will be made aware of waste management procedures during the site induction and through toolbox talks

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					• Portable toilets will be provided on site and will be regularly serviced by a licensed contractor
Site establishment, operation and management (continued)	Vegetation clearance, earthworks and stockpiling (continued)	Sedimentation of exposed aquifers	Earthworks including digging trenches and laying flowlines	Contamination of groundwater sources resulting in negative impact on groundwater dependent ecosystems	• Routine monitoring of groundwater systems
		Redirection of natural drainage patterns	Drainage bunding within the site to manage surface run-off from lease areas	Reduced flow to surface water and groundwater systems	• Natural drainage patterns will be retained where possible • Routine surface water and groundwater monitoring
	Road works	Changes to surface water regime and increased erosion	Construction or amendment to creek crossing to enable vehicle movement	Disruption of fish habitats and ecosystems due to impoundment, impediment or change in flow regime	• Existing creek crossings will be utilised as much as possible for access and the placement of gas and water gathering lines • Construction will occur across watercourses during dry periods where flows are not occurring, with the activities conducted in line with the relevant guidelines • Any creek crossings will be designed to minimise up and downstream erosion of the bed and banks, and changes to flow velocity
				Impediment or increase in flow	• Existing creek crossings will be utilised as much as possible for access and the placement of gas and water gathering lines • Construction will occur across watercourses

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
Site establishment, operation and management (continued)	Road works (continued)	Changes to surface water regime and increased erosion (continued)	Construction or amendment to creek crossing to enable vehicular movement (continued)	Increase in erosion of bed and banks Changes to flow velocity in the creek	during dry periods where flows are not occurring, with the activities conducted in line with the relevant guidelines • Any creek crossings will be designed to minimise up and downstream erosion of the bed and banks, and changes to flow velocity • Surface water monitoring program including AUSRIVAS survey
	Transportation and storage of materials	Spillage of fuel, chemicals and/or drilling additives	Inadequate storage of fuel, chemicals and/or drilling additives	Contamination of surface water and/or groundwater systems and dependent ecosystems	• Storage of all fuels and oils on site will be minimised • Fuels and oils will be kept in a secure, bunded storage area in accordance with relevant legislation • The site will be inspected by an appropriately experienced environmental management specialist, to ensure that environmental protection measures are effective and that satisfactory mitigation is provided to minimise and avoid risks from pollution • A spill kit will be available at all active work sites with training identifying implementation method • Any spills or leaks will be contained and cleaned up immediately using the spill kit. Contaminated material will be removed from the site for disposal at a licensed waste facility • Plant and equipment will be inspected daily to

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					ensure these are properly maintained • Post-incident and routine surface water and groundwater monitoring will be conducted
Site establishment, operation and management (continued)	Transportation and storage of materials (continued)	Spillage of fuel, chemicals and/or drilling additives (continued)	Road accident	Contamination of surface water and/or groundwater systems and dependent ecosystems	• All vehicles transporting chemicals and/or additives will be equipped with a spill kit • Any spills or leaks will be contained and cleaned up immediately using the spill kit • Contaminated material will be removed from the site for disposal at a licensed waste facility • Routine surface water and groundwater monitoring will be conducted
			Inadequate construction and operation of drilling sump		• Sumps will be constructed with a plastic liner used to prevent leakage • Sumps will be bunded and provided with run-on control to prevent the ingress of surface water into the sump during rainfall events • Liner removed after drilling • Water to be re-used or taken to a licensed disposal facility • Drill cuttings will be transferred to metal bins or lined pit and stored on site until drilling is complete and then disposed of appropriately • Excess fluids and cement slurries from cementing will be segregated in steel waste tanks and removed and disposed of by a licensed waste

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					disposal company • General site waste and mud contaminated slurry will be segregated and stored in bins on site for subsequent disposal of a suitably licensed waste management facility • Routine surface water and groundwater monitoring
Site establishment, operation and management (continued)	Drilling, design, completion, integrity	Passage of water between transmissive units	Poor well design and construction technique	Contamination of groundwater sources and pressure loss resulting in negative impact on groundwater and surface water dependent ecosystems	• Wells to be steel lined and pressure grouted in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity • Drilling & well construction in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity and the minimum construction requirements for water bores in Australia • Routine surface water and groundwater monitoring • Compliance with Aquifer Interference Policy
		Loss of drilling fluid/mud into a formation	Inappropriate mud or drilling technique	Contamination of groundwater and/or surface water and resulting negative impact to groundwater and/or surface water dependent ecosystems	• Wells to be steel lined and pressure grouted in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity • Drilling & well construction in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity and the minimum construction requirements for water bores in Australia • Routine surface water and groundwater monitoring

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					• Compliance with Aquifer Interference Policy
Site establishment, operation and management (continued)	Drilling, design, completion, integrity (continued)	Inadequate control of artesian pressure	High groundwater pressure/poor mud control/incorrect drilling assumptions	Erosion, surface water contamination and resulting negative impact to groundwater and/or surface water dependent ecosystems	• Evidence to date indicates non-artesian conditions within the vicinity of the pilot activities; this will be confirmed through further geological and hydrogeological investigation • Drilling & well construction in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity and the minimum construction requirements for water bores in Australia • Drillers licensed for work under artesian conditions • Routine groundwater monitoring • Surface water monitoring program including AUSRIVAS survey • Compliance with Aquifer Interference Policy
	Well abandonment	Failure of sections of the well casing, pressure seals and grouting	Incorrect well decommissioning and abandonment procedure	Contamination of groundwater sources and pressure loss resulting in negative impact to groundwater and surface water dependent ecosystems	• The wells will be cemented, plugged and abandoned in accordance with the NSW Code of Practise for Coal Seam Gas Well Integrity • The wells will be sealed from bottom to top by plugging with cement in approximately 200 m increments • Pressure testing the cement plug across the surface casing shoe to ensure the wells are sealed • Removing the well head to a depth of greater than 1.5 m below surface and burial

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					• Routine surface water and groundwater monitoring
CSG extraction	Coal seam depressurisation	Drawdown in groundwater formations	Produced water extraction causing drawdown in groundwater source and reduction in the quantity of water held within the aquifer	River baseflow/ springs affected impacting groundwater/surface water dependent ecosystems	• The cumulative groundwater impact assessment undertaken for PEL 238, detailed in Section 5, indicates that depressurisation of the target coal seam, as a result of pilot activities, will result in negligible decline in water levels within the Bohena Creek Alluvium and the Pilliga Sandstone groundwater sources • Pressure gauges installed adjacent to pilot wells with monitoring points to assess impacts on overlying formations • Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Compliance with Aquifer Interference Policy
		Reduction or loss of artesian pressure	High groundwater pressure/poor mud control/incorrect drilling assumptions	River baseflow/ springs affected impacting groundwater/surface water dependent ecosystems	• Evidence to date indicates non-artesian conditions within the vicinity of the pilot activities • Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Pressure gauges to be installed adjacent to pilot wells with monitoring points to assess impacts on overlying formations

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					• Compliance with Aquifer Interference Policy
CSG extraction (continued)	Coal seam depressurisation (continued)	Decline in groundwater quality	Vertical leakage of potentially lower quality groundwater between formations	Groundwater quality decline and associated impact to groundwater dependent ecosystems	• Groundwater flow induced by CSG activities will be from generally 'good quality' aquifers to 'lower quality' coal seam aquifers and hence the risk to groundwater dependent ecosystems is low • Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Compliance with Aquifer Interference Policy
Gathering systems and water management	Produced water transport	Uncontrolled discharge of highly saline produced water to the environment	Leak of water pipe or controls	Soil, surface water and shallow groundwater contamination impacting on environmental values	• Water will only be conveyed through appropriately designed and constructed piping systems • Water pressure within the pipes to be monitored remotely and if pressure drops occur (indicative of leakage) wells will be shut down and lines fixed before being put back into service. The extent of the impact would therefore be small, localised and short-term • The pressure will be controlled/limited by a pressure safety valve (PSV) located at each well site separator to ensure piping overpressure does not occur • Any spills or leaks will be contained and cleaned up immediately using the spill kit • Contaminated material will be removed from the

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					site for disposal at a licensed waste facility • The proposed baseline water quality monitoring of the surface water system will monitor, detect and measure any departure in water quality from the baseline. Furthermore, trigger values will be derived based on the monitoring data to refine • The groundwater monitoring program implementation will enable baseline monitoring which will set the baseline for ongoing monitoring to enable the detection of any pipeline failure
Gathering systems and water management (continued)	Produced water transport (continued)	Uncontrolled discharge of highly saline produced water to the environment	Road accident	Soil, surface water and shallow groundwater contamination impacting on environmental values	• All vehicles transporting produced water will be equipped with a spill kit • Any spills or leaks will be contained and cleaned up immediately using the spill kit • Contaminated material will be removed from the site for disposal at a licensed waste facility • The proposed baseline water quality monitoring of the surface water and groundwater system will monitor, detect and measure any departure in water quality from the baseline
			Seepage/spillage from tank at Bibblewindi Water Transfer Facility	Soil, surface water and shallow groundwater contamination impacting on environmental values	• The tank will be contained within a synthetically lined earthen bund designed to hold a volume of 110% of the total tank storage volume • The tank will include level sensors and transmitters to alert operators in the event of a

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					tank high level • Any spills or leaks will be contained and cleaned up immediately • Contaminated material will be removed from the site for disposal at a licensed waste facility • The proposed baseline water quality monitoring of the surface water and groundwater system will monitor, detect and measure any departure in water quality from the baseline
Gathering systems and water management (continued)	Produced water transport (continued)	Uncontrolled discharge of highly saline produced water to the environment	Seepage/spillage from pond at Leewood Produced Water Facility	Soil, surface water and shallow groundwater contamination impacting on environmental values	• Pond design in accordance with 'Manual for Assessing Hazard Categories and Hydraulic Performance of Dams' (DERM, 2012) and NSW Dam Safety Committee requirements • Pond liner system will comprise a primary polyethylene geomembrane liner, underlain by a leak detection system, underlain by a secondary liner • Seepage collection systems will be implemented and monitored on a routine basis • Routine monitoring of pond integrity, pond liner condition, pipe work and valves, environmental impacts, wildlife management systems and surface survey will be undertaken • Any spills or leaks will be contained and cleaned up immediately • Contaminated material will be removed from the

Operational Area	Activity	Risk	Cause	Impact	Management/Mitigation Approach
					site for disposal at a licensed waste facility • The proposed baseline water quality monitoring of the surface water and groundwater system will monitor, detect and measure any departure in water quality from the baseline

6 Predicted Significance of Impact

The predicted significance of impact on water resources as an MNES is based on:

- The identification of the potential water resources which could be impacted by the proposed action, and the sensitivity of these receptors, as per Section 4 of this report;
- The identification of the potential impacts that could affect the integrity of the receptors, as per Section 5 of this report; and
- The identification of the mitigation and monitoring measures to be applied to the proposed action to minimise the likelihood of a potentially significant impact occurring, as per Section 5 of this report.

An assessment has been made on the significance of the potential impacts on the water resource MNES as a result of the proposed action. The full impact assessment, which identifies the significance of potential impacts both prior to and following mitigation and monitoring measures is presented in Appendix A. The impact assessment is summarised below for each component of works.

6.1 Site Establishment, Operation and Management

A total of nine potential impacts were identified during site establishment, operation and management. These impacts related specifically to vegetation clearance and earthworks; road works; transportation and storage of materials; construction and operation of drilling sump and drilling design, completion and integrity.

Following the successful implementation of appropriate site management practices and requisite mitigation as identified in Section 5, it is anticipated that there will be **no high or medium significant impacts to water resource MNES**. The predicted significance of adverse potential impacts is low to insignificant in all cases.

6.2 CSG Extraction

A total of two potential impacts were identified as being associated with the extraction of produced water to enable gas extraction. These impacts relate to the drawdown of groundwater sources and subsequent reduction in the quantity of water held within aquifers and the potential groundwater quality decline as a result of groundwater drawdown.

The cumulative groundwater impact assessment, detailed in Section 5, indicates that the predicted drawdown in the Bohena Creek alluvium and Pilliga Sandstone is negligible (less than 0.5 m) and will not be manifested for a considerable amount of time (>500 years).

Additionally, following the successful implementation of appropriate mitigation and monitoring measures, as identified in Section 5, it is predicted that there will be **no high or medium significant impacts to water resources MNES**. The significance of adverse potential impacts is low to insignificant in all of cases. The operation of the pilot wells is predicted to have no significant impact on either groundwater source, including its functions, users and dependencies (e.g. GDEs), or surface water receptors.

6.3 Gathering Systems and Water Management

A total of three potential impacts were identified as associated with the proposed gathering systems to be implemented on site. These impacts relate specifically to the uncontrolled discharge of produced water to the environment due to a pipe leak or rupture, truck spill during transportation and/or spillage or seepage from a storage tank or pond. Of importance, is the highly saline nature of the produced water to be gathered, stored and transported.

Following the successful implementation of appropriate site management practices and appropriate infrastructure design, construction, maintenance and monitoring, as identified in Section 5, it is anticipated that there will be **no high or medium significant impacts to water resource MNES**. The significance of adverse potential impacts is low to insignificant in all cases.

7 Summary of Potential Impacts

A number of potential impacts are identified during the construction and operation phases of the activity. The following conclusions are drawn:

- **No significant impacts** with very high or high likelihood of occurrence have been identified.
- The majority of potential impacts identified can be classed as typical construction type impacts following improper site practices, and can be mitigated by adopting best practice site environmental processes and monitoring as is currently planned. Following successful application of mitigation including maintaining best site practices, the significance of these impacts is considered to be **low** to **insignificant**.
- The drilling of pilot wells may introduce preferential flow pathways between aquifers. The adoption of the methodology presented in the Coal Seam Gas Well Integrity Code of Practice will reduce the potential significance of this impact. Following the implementation of mitigation the impact is of **low significance** to **insignificant**.
- Modelling of the CSG produced water extraction from the target coal seams, required to achieve satisfactory seam depressurisation, inevitably results in substantial hydraulic head reduction in the corresponding and directly overlying model layers (model layers 7, 8 and 9). However, the quality of the produced water is very poor, the same source strata are not utilised for private groundwater extraction and the modelling indicates they do not have a significant hydroecological role in the Program Area.
- Modelling of cumulative pilot operational impacts to groundwater within the Bohena Creek Alluvium and the Pilliga Sandstone groundwater sources indicates that impacts are not significant, defined as long-term drawdown of less than 0.5 m. The less significantly transmissive Permian strata, including the Clare Sandstone, and late Triassic to early Jurassic strata, including the Garrawilla Volcanics, experience greater than 0.5 m drawdown in places. However, the quality and accessibility of the groundwater within these formations is poor, especially within the Program area, and there are no known abstractions within the Program area due to their depth and the availability of better quality sources of water.
- The produced water extracted from the CSG wells, transferred and stored at the Bibblewindi Water Transfer Facility and Leewood Produced Water Facility and transported to a licenced waste facility is expected to be highly saline. This poses a high risk to water resources when considering introduction of produced water to the environment as a result of pipeline, tank, pond or tanker leakage, spillage or failure. Following the successful implementation of appropriate site management procedures and appropriate infrastructure design, construction, maintenance and monitoring, the likelihood of impacts occurring and the severity of impacts will be reduced to **low significance** to **insignificant.**
- A detailed baseline and on-going monitoring program will be implemented to provide baseline water level and quality data, validate results of modelling and provide early warning of any potential impact to water resources within and surrounding the Program area.

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Abbreviations	
AIP	Aquifer Interference Policy
AMB	Aquifer Monitoring Bore
CSG	Coal Seam Gas
DAMB	Deep Aquifer Monitoring Bore
DST	Drill Stem Test
EPBC	Environmental Protection, Biodiversity and Conservation
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem
GMA	Groundwater Management Area
GMZ	Groundwater Management Zone
HMTF	Hunter Mooki Thrust Fault
HSU	Hydrostratigraphic Unit
MAR	Managed Aquifer Recharge
MDBA	Murray Darling Basin Authority
MNES	Matters of National Environmental Significance
NGP	Narrabri Gas Project
NOW	New South Wales Office of Water
NSW	New South Wales
PAL	Petroleum Assessment Lease
PEL	Petroleum Exploration Licence
PIP	Pre-drilling project initiation package
SAMB	Shallow Aquifer Monitoring Bore
SDE	Surface Water Dependent Ecosystem
SEWPaC	Commonwealth Department of Sustainability, Environment, Water, Population and Communities
SIG	Significant Impact Guidelines
TD	Total Depth
TVD	True Vertical Depth

Glossary

Aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs
Confined aquifer	An aquifer that lies below a low permeability material; the piezometric surface in confined aquifers is above the base of the confining material; e.g. artesian aquifers
Controlled Action	A proposed action that is likely to have a significant impact on: a matter of national environmental significance; the environment of Commonwealth land (even if taken outside Commonwealth land); or the environment anywhere in the world (if the action is undertaken by the Commonwealth)
Ecosystem	The community of a plant, animal and other organisms existing within a defined area, and their interactions within the community and their non-living environment
Ephemeral	An ephemeral waterbody is a transient/short-lived water feature. Ephemeral streams usually only exist following a precipitation event
Groundwater Dependent Ecosystem (GDE)	Ecosystems which have their species composition and their natural ecological processes determined by groundwater
Intermittent	Water bodies which last for longer periods, but not all year round
Losing stream	A stream where water is lost to the surrounding and underlying groundwater system
MNES	There are eight matters of national environmental significance under the EPBC Act; sometimes referred to as MNES matters (see Section 2.0 for full list of MNES)
Minister	The Australian Government Minister for Sustainability, Environment, Water, Population and Communities
Particular Manner	Action to carry out in accordance with the manner specified
Permeability	The property or capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure
Proposed action	A project, a development, an undertaking, an activity or series of activities
Significant Impact	A significant impact is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. All of these factors should be considered when determining whether an action is likely to have a significant impact on the environment.
Stygofauna	This is an encompassing term for all animals that occur in subsurface waters
Water resources	Surface water or ground water, 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

Appendix A:
Impact Assessment

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
Site establishment, operation and management	Vegetation clearance, earthworks and stockpiling	Increased surface runoff and sediment loads	Namoi River	High	Minor Adverse	Availability of dilution within Namoi River likely to render this impact negligible in scale and severity	Medium	• Well pads and gathering lines to be constructed in either previously disturbed areas or immediately adjacent to existing cleared areas or tracks to minimise vegetation clearance and groundwater disturbance • Routine monitoring of surface water systems • Implementation of erosion and sediment control measures e.g. silt fences, diversion drains, contour banks	Low
			Bohena Creek	Medium		Impact has potential to be of moderate severity over a short period of time			
			Jacks Creek	Medium					
			Mollee Creek	Low			Low		
			Bohena Creek Tributaries	Low					
			Un-named tributaries	Very Low			Insignificant		Insignificant
		Impact to aquatic ecosystems from littering of surface waters	Namoi River	High	Minor Adverse	Impact likely to be of low severity over a short period of time	Medium	• Appropriate waste receptacles will be provided in designated areas of each work site • All wastes will be removed from the proposed activity at the completion of the works for recycling or disposal at an appropriately licensed facility • All staff and contractors will be made aware of waste management procedures during the site induction and through toolbox talks • Portable toilets will be provided on site and will be regularly serviced by a licensed contractor	Low
			Bohena Creek	Medium					
			Jacks Creek	Medium					Insignificant
			Mollee Creek	Low			Low		
			Bohena Creek Tributaries	Low					
			Un-named tributaries	Very Low			Insignificant		
		Re-direction of drainage/flow, resulting in different flow paths, volumes of water in surface water drainage systems	Bohena Creek	Medium	Minor Adverse	Results in a change that may be measurable in terms of flow conveyance; impact likely to be limited in duration	Low	• Routine surface water and groundwater monitoring	Low
			Jacks Creek	Medium					Insignificant
			Mollee Creek	Low					
			Bohena Creek Tributaries	Low			Insignificant		Insignificant
			Un-named tributaries	Very Low					
		Sedimentation of exposed aquifers due to earthworks, resulting in impact to groundwater system	Bohena Creek Tributaries	Low	Negligible	Impact may result in a localised effect that may be low severity but persistent	Insignificant	• Routine monitoring of groundwater systems	Insignificant
			Un-named Tributaries	Very Low					

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
	Road works, including construction of creek crossings	Disruption to fish habitats and ecosystems due to impoundment, impeachment or increase in flow; increase in erosion of bed and banks	Bohena Creek Tributaries	Low	Minor Adverse	Results in a change that, adopting the precautionary principle may be measurable in terms of flow conveyance. Impact likely to be limited in duration	Low	• Existing creek crossings will be utilised as much as possible for access and the placement of gas and water gathering lines • Construction will occur across watercourses during dry periods where flows are not occurring, with the activities conducted in line with the relevant guidelines • Any creek crossings will be designed to minimise up and downstream erosion of the bed and banks, and changes to flow velocity • Surface water monitoring program including AUSRIVAS survey	Insignificant
			Un-named tributaries	Very Low			Insignificant		
Site establishment, operation and management	Transportation and storage of materials	Contamination of surface water and/or groundwater systems and dependent ecosystems due to spillage of fuel, chemicals and/or drilling additives	Namoi River	High	Negligible	Availability of dilution within Namoi Alluvium likely to render this impact negligible in scale and severity	Low	• Storage of fuels and oils stored on site will be minimised • Fuels and oils will be kept in a secure, bunded storage area in accordance with relevant • The site will be inspected by an appropriately experienced environmental professional, to ensure that environmental protection measures are effective and that satisfactory mitigation is provided to minimise and avoid risks from pollution • A spill kit will be available at all active work sites with training identifying implementation method • Any spills or leaks will be contained and cleaned up immediately using the spill kit; contaminated material will be removed from the site for disposal at a licensed waste facility • Plant and equipment will be inspected daily to ensure these are properly maintained • All vehicles transporting chemicals and/or additives will be equipped with a spill kit • Post-incident and routine surface water and groundwater monitoring	Low
			Bohena Creek	Medium	Moderate Adverse	Impact likely to be of high severity but over a short period of time	Medium		
			Jacks Creek	Medium					
			Mollee Creek	Low					
			Bohena Creek Tributaries	Low			Low		

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
			Un-named tributaries	Very Low					Insignificant
			Bohena Creek Alluvium	Medium			Medium		Low
			Pilliga Sandstone	Medium	Negligible	Transport time and dilution within alluvial aquifer indicates impact will be of lessor scale but over a longer time period	Low		Insignificant
	Construction and operation of drilling sump	Contamination of surface water and/or groundwater systems and dependent ecosystems due to leakage or spillage from sump	Namoi River	High	Negligible	Dilution between point source of pollutant and the River Namoi is likely to be considerable and thus the impact is likely to be of very low severity		• Sumps will be constructed with a plastic liner used to prevent leakage • Sumps will be bunded and provided with run-on control to prevent the ingress of surface water into the sump during rainfall events • Liner removed after drilling • Water to be re-used or taken to a licensed disposal facility • Drill cuttings will be transferred to metal bins or lined pit and stored on site until drilling is complete and then disposed of appropriately • Excess fluids and cement slurries from cementing will be segregated in steel waste tanks and removed and disposed of by a licensed waste disposal company • Routine surface water and groundwater monitoring	
			Bohena Creek	Medium	Moderate Adverse	Impact likely to be of high severity but over a short period of time	Medium		Low
			Jacks Creek	Medium					
			Bohena Creek Tributaries	Low			Low		Insignificant
			Mollee Creek	Low					
			Un-named tributaries	Very Low			Low		
			Bohena Creek Alluvium	Medium			Medium		Low
			Pilliga Sandstone	Medium	Negligible	Transport time and dilution within alluvial aquifer indicates impact will be of lessor scale but over a longer time period	Low		Insignificant
	Drilling, design, completion, integrity	Contamination of groundwater formations and pressure loss resulting in negative impact on groundwater systems and dependent ecosystems due to poor well design and	Bohena Creek Alluvium	Medium	Moderate Adverse	Impact occurs across aquifers and moderate severity impacts may extend over medium to long term	Medium	• Drilling & well construction in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity and the minimum construction requirements for water bores in Australia • Compliance with Aquifer Interference Policy	Low

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
		construction techniques and/or inappropriate mud or drilling technique	Pilliga Sandstone	Medium				• Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Pressure gauges installed adjacent to pilot wells with monitoring points to assess impacts on overlying formations	
			Permo-Triassic Strata	Low					
	Abandonment of well	Well integrity degrades over time producing pathways between aquifers resulting in impacts on water quality and/or quality	Bohena Creek Alluvium	Medium	High adverse	Impact occurs across aquifers and moderate severity impacts may extend over medium to long term; impact may extend regionally	High	• The wells will be cemented, plugged and abandoned in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity • The wells will be sealed from bottom to top by plugging with cement in approximately 200 m increments • Pressure testing the cement plug across the surface casing shoe to ensure the wells are sealed • Removing the well head to a depth of greater than 1.5 m below surface and burial • Routine surface water and groundwater monitoring	Low
			Pilliga Sandstone	Medium					
			Permo-Triassic Strata	Low			Medium		
CSG extraction	Coal seam depressurisation resulting in drawdown of groundwater sources and reduction in the quantity of water held within the aquifer	River baseflow/springs affected impacting groundwater/surface water dependent ecosystems	Bohena Creek Alluvium	Medium	Negligible	Modelling of the cumulative impact of pilot activities within PEL238 indicates a drawdown, as a result of pilot activities of less than 0.5 m within the Bohena Creek Alluvium and the Pilliga Sandstone	Low	• Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Pressure gauges installed adjacent to pilot wells with monitoring points to assess impacts on overlying formations • Compliance with Aquifer Interference Policy	Low
			Pilliga Sandstone	Medium	Negligible				
			Permo-Triassic Strata	Very Low	High adverse	Modelling of the cumulative impact of pilot activities within PEL238 indicates an impact will be observed that persists over time; the impact extends across a relatively small scale however recovery will be relatively slow upon completion of activity			
		Groundwater quality decline and associated impact to groundwater	Bohena Creek Alluvium	Medium	Negligible	Groundwater flow induced by CSG activities will be from generally 'good quality' aquifers to 'lower quality' coal seam aquifers and hence the risk to groundwater dependent ecosystems is low	Low	• Aquifer monitoring bore network designed to provide baseline groundwater levels, validate results of modelling and provide early warning of development of drawdown for significant impact • Pressure gauges installed adjacent to pilot wells with monitoring points to assess	Low

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
		dependent ecosystems	Pilliga Sandstone	Medium	Negligible			impacts on overlying formations • Compliance with Aquifer Interference Policy	
			Permo-Triassic Strata	Very Low	Negligible				
Gathering systems	Produced water transport	Uncontrolled discharge of highly saline produced water to the environment from leak of water pipe or truck accident resulting in soil, surface water and shallow groundwater contamination	Namoi River	High	Moderate Adverse	Magnitude of impact is considered to be moderate adverse due to the uncertainty over the scale of a failure within the pipe line system; significant failure may lead to pollution at such a scale that the Namoi River may not be able to dilute the affects; impact is high severity and short duration	Medium	• Water pressure within the pipes to be monitored remotely and if leakage occurs then wells will be shut down and fixed before being put back into service. The extent of the impact would therefore be small, localised and short-term. • The pressure will be controlled/limited by a pressure safety valve (PSV) located at each well site separator • Baseline water quality monitoring of the surface water system will detect any change in water quality • All vehicles transporting chemicals and/or additives will be equipped with a spill kit • Groundwater monitoring program implementation	Low
			Bohena Creek	Medium					
			Jacks Creek	Medium					
			Mollee Creek	Low					
			Bohena Creek Tributaries	Low					
			Un-named tributaries	Very Low			Low		Insignificant
			Bohena Creek Alluvium	Medium			Medium		Low
			Pilliga Sandstone	High	Negligible		Low		Insignificant
Gathering systems	Produced water storage	Seepage/spillage of highly saline produced water from tank resulting in contamination of soil, surface water and/or shallow groundwater	Namoi River	High	Negligible	Distance from Namoi River and availability of dilution within river likely to render this impact negligible in scale and severity	Low	• The tank will be contained within a synthetic lined earthen bund that is capable of holding 110% of the total tank storage volume • The tank will include level sensors and transmitters to alert operators in the event of a tank high level • The proposed baseline water quality monitoring of the surface water and groundwater system will monitor, detect and measure any departure in water quality from the baseline	Low
			Bohena Creek	Medium	Moderate Adverse	Impact likely to be of high severity but over a short period of time	Medium		
			Jacks Creek	Medium			Medium		
			Mollee Creek	Low			Medium		
			Bohena Creek Tributaries	Low			Medium		
			Un-named tributaries	Very Low			Low		Insignificant
			Bohena Creek Alluvium	Medium			Medium		Low

Operational Area	Action	Potential Impact	Receptor Sensitivity		Pre-Mitigation Impact Significance			Post-Mitigation Impact Significance	
			Receptor	Sensitivity	Magnitude of Impact	Rationale	Pre-Mitigation Significance of adverse Potential Impacts	Management/Mitigation Measure	Post-Mitigation Significance of adverse Potential Impacts
			Pilliga Sandstone	Medium	Negligible	Transport time and dilution within alluvial aquifer indicates impact will be of lesser scale but over a longer time period	Low		Insignificant
	Produced water storage	Seepage/spillage from pond of highly saline produced water resulting in contamination of soil, surface water and/or shallow groundwater	Namoi River	High	Negligible	Distance from Namoi River and availability of dilution within river likely to render this impact negligible in scale and severity	Low	• Pond design in accordance with 'Manual for Assessing Hazard Categories and Hydraulic Performance of Dams' (DERM, 2012) and NSW Dam Safety Committee requirements • Pond liner system will comprise a primary polyethylene geomembrane liner, underlain by a leak detection system, underlain by a secondary liner • Seepage collection systems will be implemented and monitored on a routine basis • Routine monitoring of pond integrity, pond liner condition, pipe work and valves, environmental impacts, wildlife management systems and surface survey will be undertaken • The proposed baseline water quality monitoring of the surface water and groundwater system will monitor, detect and measure any departure in water quality from the baseline	Low
			Bohena Creek	Medium	Moderate Adverse	Impact likely to be of high severity but over a short period of time	Medium		
			Jacks Creek	Medium					
			Mollee Creek	Low					
			Bohena Creek Tributaries	Low			Medium		Low
			Un-named tributaries	Very Low			Low		Insignificant
			Bohena Creek Alluvium	Medium			Medium		Low
			Pilliga Sandstone	Medium	Negligible	Transport time and dilution within alluvial aquifer indicates impact will be of lesser scale but over a longer time period	Low		Insignificant