49. The licence holder must ensure that all river crossings are rehabilitated such that the natural flow of water is unimpeded and stream bank stability is maintained to prevent erosion.

50. The licence holder must comply with any relevant guidelines issued by the Director-General in the rehabilitation of disturbance resulting from prospecting operations under this exploration licence.

51. All rehabilitation of disturbance resulting from prospecting operations under this exploration licence must be completed before the expiry of this exploration licence or as soon as practicable following cancellation of this exploration licence.

52. Boreholes or petroleum wells that have been abandoned as a result of previous mining or prospecting operations, and which have been opened up or used by the licence holder are subject to the conditions of this exploration licence as if the boreholes or petroleum wells were constructed by the holder of this exploration licence.

Environmental Management Report

53. The licence holder must submit an Environmental Management Report to the Department:

a) The report must be prepared according any relevant Director-General's requirements for environmental and rehabilitation reporting.

b) The report must be lodged:

(i) prior to expiry where a renewal of this licence is sought; or

(ii) immediately following the expiry or earlier cancellation of the exploration licence.

c) The report must be prepared to the satisfaction of the Director-General and include information on all disturbance resulting from prospecting operations and rehabilitation carried out within the exploration licence area.

Environmental incident and complaint reporting

54. The licence holder must, in addition to the requirements under section 148 of the *Protection of the Environment Operations Act 1997*:

a) Notify the Department of all:

(i) pollution incidents causing or threatening material harm to the environment;

(ii) breaches of the conditions of this exploration licence; and

(iii) breaches of environmental protection legislation (as defined in the *Protection of the Environment Administration Act 1991*),

arising in connection with prospecting operations under this exploration licence.

b) The notification must be given immediately, i.e. promptly and without delay, after the licence holder becomes aware of the incident, breach or complaint.

Note. Refer to www.resources.nsw.gov.au/environment for notification contact details.

c) Submit an Environmental Incident and Complaints Report to the Department within seven (7) days of all:

(i) pollution incidents causing or threatening material harm to the environment;

(ii) breaches of the conditions of this exploration licence;

(iii) breaches of environmental protection legislation (as defined in the *Protection of the Environment Administration Act 1991*); and

(iv) complaints from landholders or the public alleging environmental harm or a breach of conditions of this exploration licence or of environmental protection legislation,

arising in connection with prospecting operations under this exploration licence.

d) The Environmental Incident and Complaints Report must include:

(i) the details of the exploration licence;

(ii) contact details for the licence holder, complainant and landholder;

(iii) a map showing the area of concern;

(iv) a description of the nature of the incident or complaint, likely causes and consequences;

(v) a timetable showing actions taken or planned to address the incident or complaint; and

(vi) a summary of all previous incidents or complaints relating to prospecting operations under this exploration licence.

Note. The licence holder should have regard to any relevant Director-General's guidelines in the preparation of an Environmental Incident and Complaints Report. Refer to www.resources.nsw.gov.au/environment for further details.

Exploration (geological) reports

55. Reports required under section 131 of the *Petroleum (Onshore) Act 1991* and Part 3 of the *Petroleum (Onshore) Regulation 2007* must be prepared in accordance with the *New Guidelines for Digital Data Submission and Reporting of Onshore Petroleum Exploration in New South Wales* (NSW Trade & Investment – Division of Resources & Energy, February 2012), as amended or replaced from time to time.

Security

56. The licence holder must provide and maintain a security deposit of **$1,657,000** to secure funding for the fulfilment of obligations of all or any kind under the Act in respect of the licence, including obligations that may arise in the future. The security deposit must be maintained until the obligations are fulfilled.

57. The security deposit is to be provided by way of a cash deposit (with no entitlement to any interest thereon) or in such other form as may be approved by the Minister.

SCHEDULE 3

WORK PROGRAM

Years 1 and 2

- 4 Coreholes/Wells
- 2 Lateral Production Pilots
- Technical Studies
- 120 kilometres New Seismic

- **Indicative Expenditure of $14,500,000**

Any variation to the above program may only occur with the prior approval of the Minister in accordance with the *Petroleum (Onshore) Regulation 2007.*

Narrabri SHIRE
Heart of the North West

Memorandum

TO:	**Narrabri Shire Councillors**
FROM:	**Paul Bawden – Director of Planning and Development**
DATE:	**5 August 2013**
SUBJECT:	**DA 769/2013 – Lot 241 DP 1120041, 300 Yarrie Lake Road, Narrabri**

1. Introduction/Context

The purpose of this Briefing is to address both matters raised by Councillors and also to advise of some legal matters that have been raised through the peer review process and clarify on the context of the submissions is also proposed.

2. Current and Proposed site activities

The property has an existing approval to be used for an Operations Centre including office, workshop and external storage area, through an approval granted in December 2007 (77/2008). These functions do not facilitate activities in the coal seam gas industry, rather constitute support services. In particular the site provides for the storage of equipment and a range of ancillary support services for exploration activities.

The majority of the site is undeveloped however a second development approval was granted in April 2013 (546/2013). This provided for the expansion of existing operations including the provision of chemical storage and hard stand areas for the future siting of plant. This was confirmed in correspondence from the applicant's consultant in January 2013.

The current application (769/2013) is providing for the siting of the foreshadowed plant that would involve two separate operations being: cement bulk storage and blending plant (this would essentially involve the dry mixing of cement and additives which would then be transported to a drilling site for mixing and injecting into the wells); and fluids treatment facility (this essentially involved the treatment of the liquids resulting from boring activities and is seen as best environmental practice by the EPA).

The size and scale of the amount of liquids and material on the site can best be compared to a local agricultural supplies business that involves pesticides and the like.

3. Environmental Assessment

The applicant has provided a range of material that outlines the activities and their environmental implications. This material has been referred to the Environmental Protection Authority (EPA) who are satisfied with the character and proposed management of these products and have provided the concurrence that could be conditioned as part of a development consent.

4. Land Use Management

At the time DA77/2008 was granted the site was zoned 1(a) General Rural under LEP 1992 within which the current activities are permissible with consent.

On the 21 December 2012 LEP 2012 commenced and the site was rezoned to RU1 Primary Production.

While this was essentially a direct translation the new zoning permits all forms of agricultural activities but only a more limited range of industrial land uses. In effect the current Operations Centre became a prohibited development that relied on existing use rights.

While Council subsequently approved DA 546/2013 in April 2013 and formalised the additional area/uses, they do not have the benefit of existing use rights.

Several related submissions have questioned the Councils ability to approve the proposed development in the new land use zoning. The contention is ill founded based on Council's legal advice have received given the use is ancillary and subservient to the existing approved uses on the site.

However, the legal advice has identified an additional land use planning constraint. The issue follows a recent test case in which existing use rights are considered to be limited to the area of land (rather than the full parcel) subject to the 2008 approval – whereas the applicant is now seeking the infrastructure behind this area. As such, the infrastructure would either need to be re-sited or the land would need to be rezoned.

In response to this issue, the applicant this afternoon advised that they seek to have the application deferred until such time as they can address the issues.

5. Submissions

The current report to Council provides a summary of some 37 matters raised in submissions. Apart from the most recent issue regarding the land use zoning the other matters are considered to have been reasonably addressed. However there does appear to have been some confusion with a request from the EDO to review some of the paperwork regarding the previous approvals. Having regard to the request form Santos to defer the current application the matters with the EDO can be discussed further.

Yours faithfully,

Paul Bawden
DIRECTOR OF PLANNING and DEVELOPMENT

<table>
<tr><td></td><td></td><td>This in turn falls into the overall site WBTP bunded area, as described earlier above.</td></tr>
<tr><td></td><td>Inconsistency of information annual salt loads provided in Section 6.1.1.1, Table 6-2 and that provided in Table 3, Section 5.4 of the Conceptual Irrigation Project design plan provided in Appendix 3.</td><td>Unfortunately Santos provided two tables with different numbers. One was correct, the other inadvertently contained incorrect numbers. Santos confirms that the correct annual salt load information is provided in Table 3, Section 5.4 of the BeneTerra report (reproduced below as per Appendix 3 of the REF).

<table>
<tr><th>Salt or ion added</th><th>Amended permeate (kg/ha-yr)</th></tr>
<tr><td>Sodium</td><td>490</td></tr>
<tr><td>Calcium</td><td>190</td></tr>
<tr><td>Chloride</td><td>440</td></tr>
<tr><td>Sulphate</td><td>0</td></tr>
<tr><td>Bicarbonate</td><td>1200</td></tr>
<tr><td>Total salts</td><td>2320</td></tr>
</table>

Section 6.1.1.1 and Table 6.2 of the REF have been updated for completeness.</td></tr>
<tr><td></td><td>Dust mitigation measure referenced to be contained in Section 6.1.1.2 (refer to reference in Section 6.1.4.4) relate to soil quality and land stability rather than dust control. Specific dust control mitigation is required, particularly during construction and the soil amelioration process.</td><td>A number of sections of the REF outline specific dust control mitigation measures that will be implemented as part of the construction and operation of the facilities. In particular, Section 6.1.4.4 of the REF outlines the air quality criteria for occupied residences on privately owned lands. Active dust mitigation and suppression techniques will be conducted during construction activities and soil amelioration and cultivation activities will be conducted in a manner which minimises soil erosion and dust impacts.</td></tr>
<tr><td></td><td>How management practices (mitigation measures) described in Section 6.2.1 will be monitored to determine effectiveness in mitigating impacts to the adjacent stand</td><td>Santos will be using soil moisture content measurements in real time to adjust and manage its irrigation practices. With careful management, it is highly unlikely that the Brigalow will be affected. In addition, as stated in Section 6.2.1 of the REF, proven management practices will be used to mitigate against any harm to the adjacent stand of Brigalow. As per bullet point 3 in Section 6.2.1, operators will be on site to undertake "regular visual inspections along the boundary of the sprinkler system". Appropriate site preparation to the irrigation area will be undertaken to ensure adequate control.</td></tr>
</table>

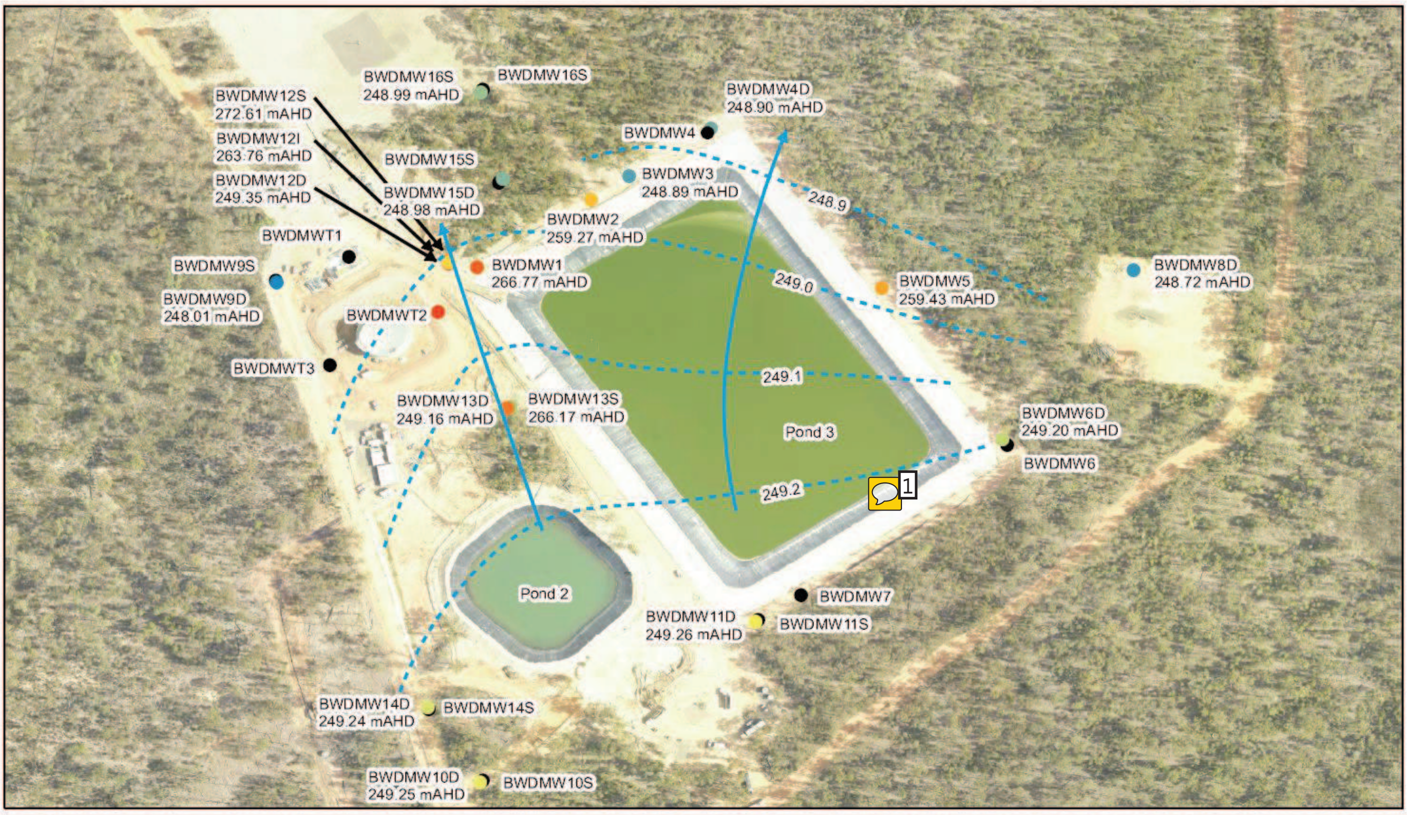


Fig 2-1 Bibblewindi Water Transfer Facility - Groundwater Elevation and Flow Direction (inferred from BWDMW3, 4D, 6D, 8D, 9D, 10D, 11D, 13D, 14D, 15D, and 16D)

Note: BWDMWT1-3 were decommissioned in 2013 and BWDMW01 was decommissioned in 2014

EHS Support *consider it done* Santos We have the energy.

N

0 0.05 0.1 0.2
Kilometers

Groundwater Flow Direction
Groundwater Contour

Summary of Comments on VIP BWTF VIP-altered Contour and GW flow.pdf

Page: 1

Number: 1 Author: Tony Subject: Sticky Note Date: 13/05/2017 8:20:40 AM

Different contour line heights to CH2MHILL

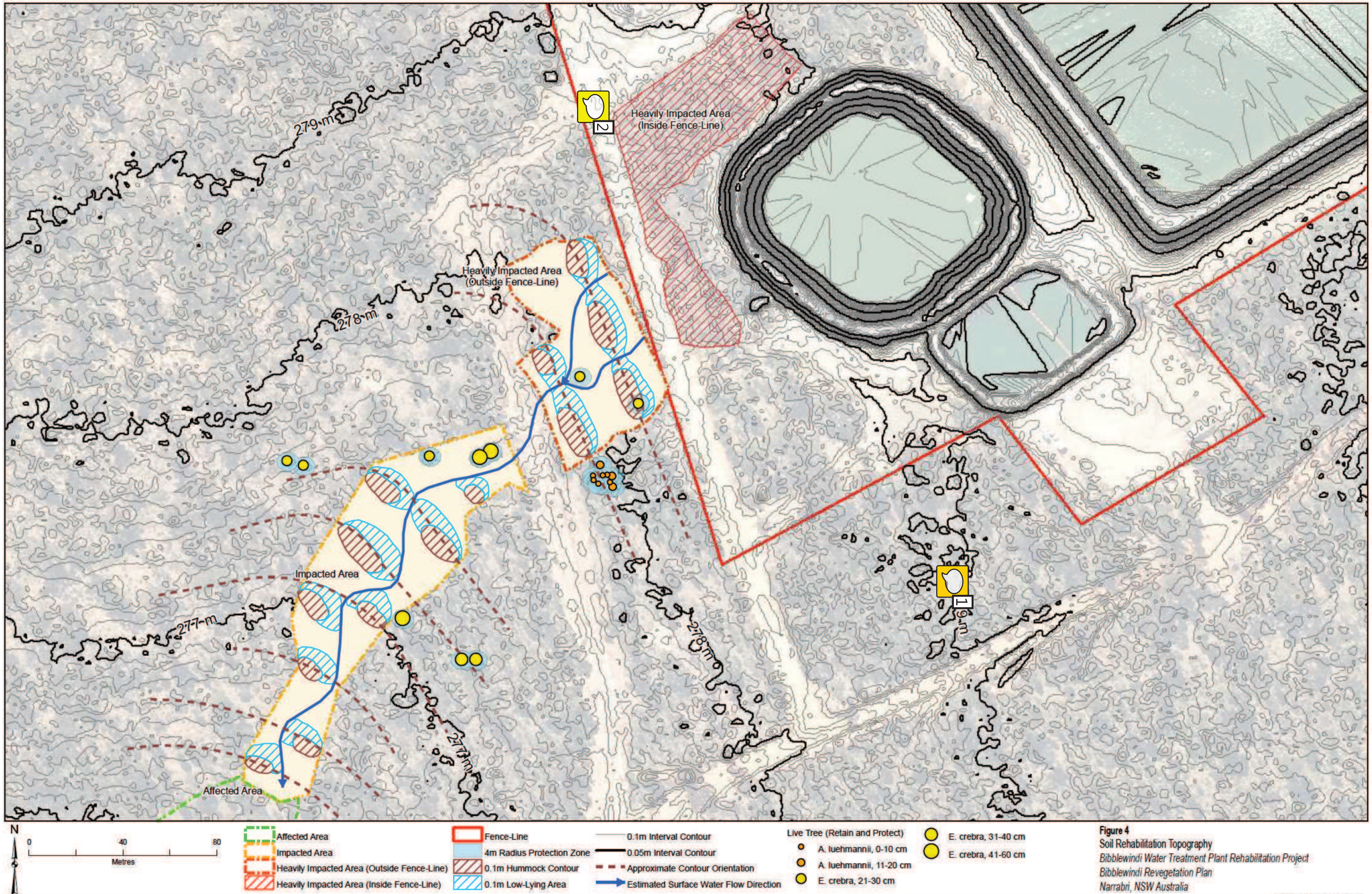


Figure 4
Soil Rehabilitation Topography
Bibblewindi Water Treatment Plant Rehabilitation Project
Bibblewindi Revegetation Plan
Narrabri, NSW Australia

CH2MHILL

KWO \\WATERLOO\GIS\PROJECTS\SANTOS\GIS\MAPFILES\REHABILITATION\SOIL_REHAB_TOPOLOGY.MXD NDYER 2/13/2013 08:56:20

Summary of Comments on 24. BIBBLE~1.PDF

Page: 32

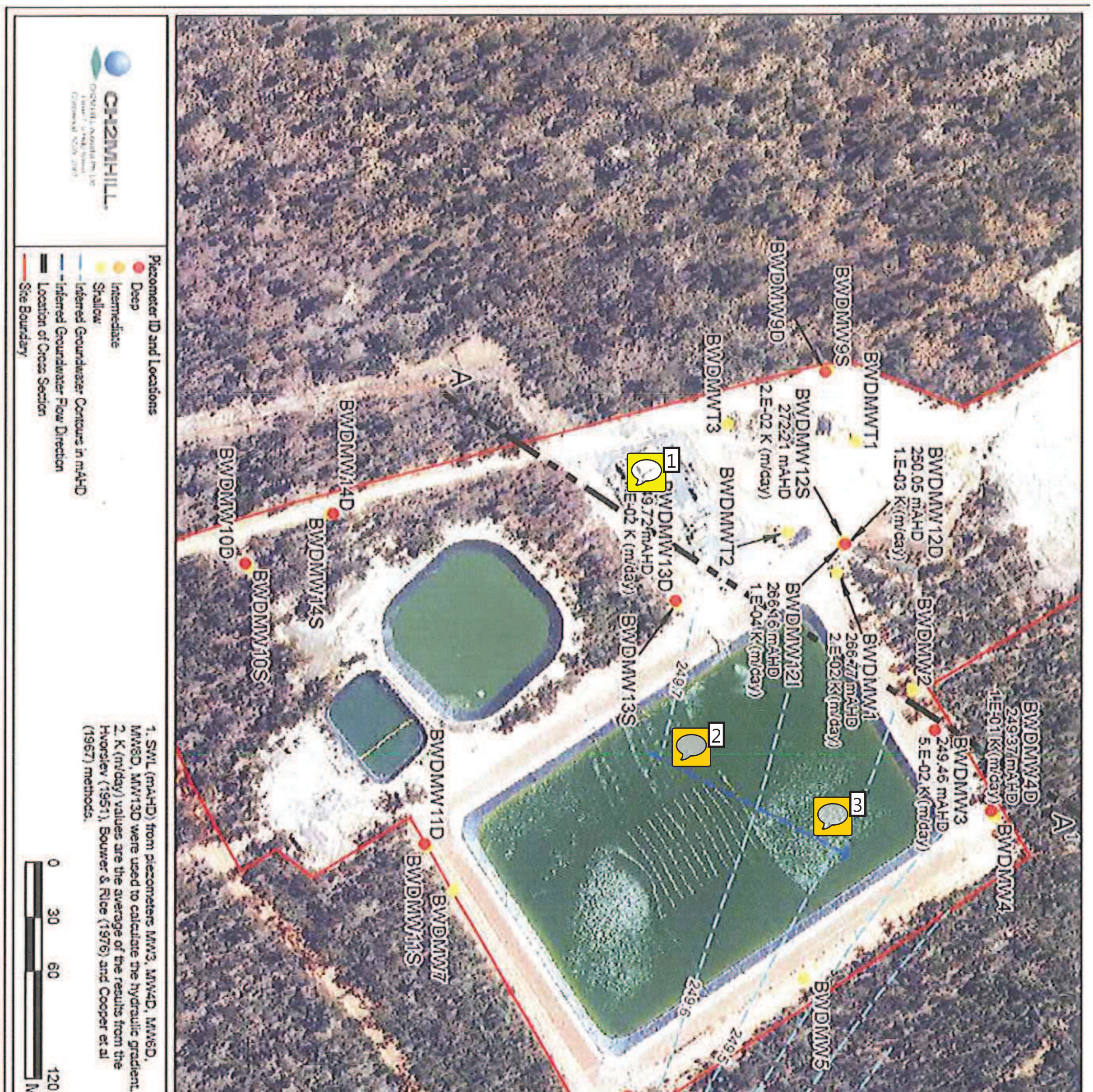
Number: 1 Author: Tony Subject: Sticky Note Date: 13/05/2017 8:26:25 AM

Contour line height of 279 m.
This height is different in some later representations

Number: 2 Author: Tony Subject: Sticky Note Date: 14/10/2014 5:25:57 PM +11'00'

site of 10,000 litre over 4 hours spill/discharge.

ATTACHMENT A – MAP OF BIBBLEWINDI BORE LOCATIONS



Summary of Comments on EPA-Santos Bibblewindi Investigation Report - Final - To be released.PDF

Page: 13

Number: 1 Author: Tony Subject: Sticky Note Date: 14/10/2014 5:22:20 PM +11'00'

spill/discharge of 10,000 litres over 4 hours, happened from here

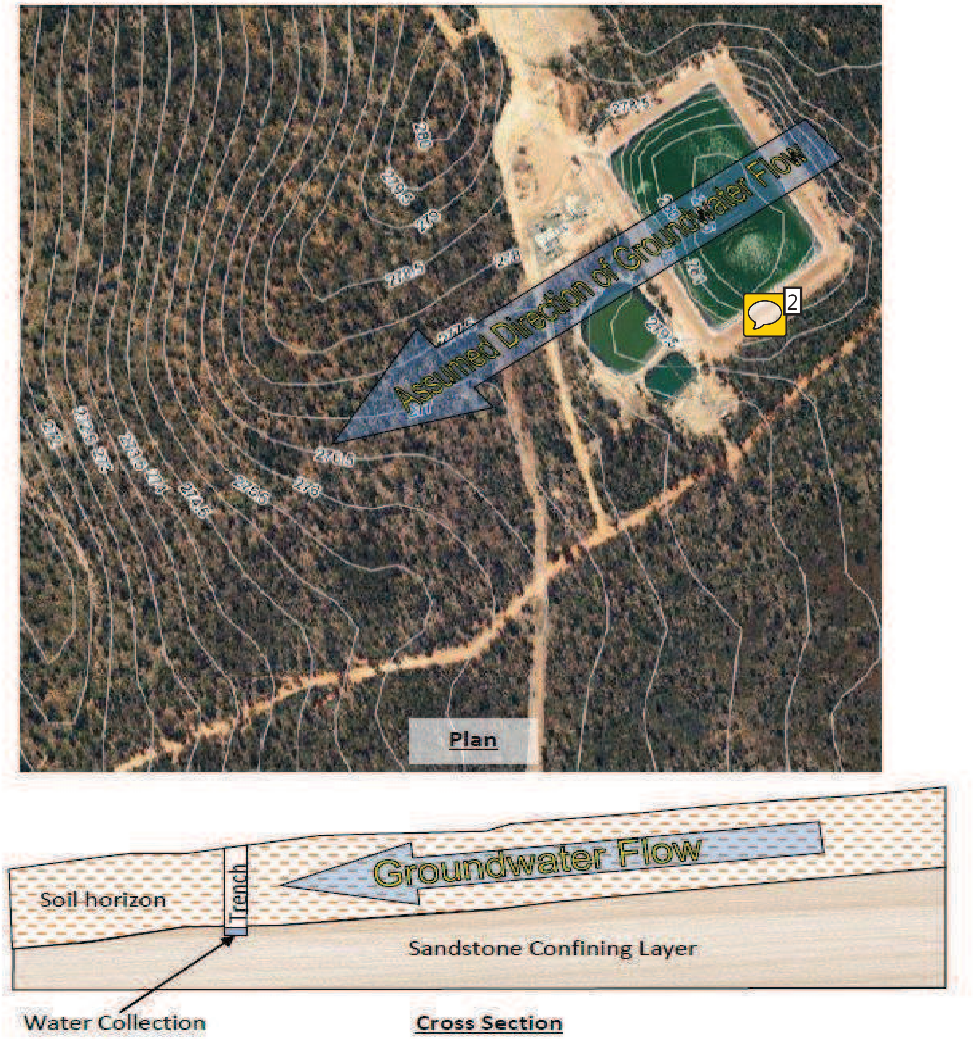
Number: 2 Author: Tony Subject: Sticky Note Date: 27/03/2017 6:52:46 AM +11'00'

contour lines are less in height than the lines in the other CH2MHILL Report.

Number: 3 Author: Tony Subject: Sticky Note Date: 27/03/2017 6:54:17 AM +11'00'

ground water flow has been reversed 180 degrees to that contained in the CH2MHILL report.

Figure 4-3 - Inferred Groundwater Flow Direction



To determine if shallow groundwater is present and impacted, it is proposed that test pits will be excavated to the top of the Pilliga sandstone formation along the proposed location of the trench. Soil samples will be analysed at incremental depths for chemical and geochemistry analytes, with intercepted groundwater assessed as a transport mechanism for salinity and heavy metals into the impacted area. An additional test pit will be excavated up hydraulic gradient of the ponds, as a background location. The test pits will be backfilled immediately after sampling and compacted using the bucket of the excavator.

Once the samples have been analysed, a decision can be made as to whether the soil and groundwater is impacted and a trench needs to be installed. In addition, design specifications for the interception trench will be determined along with how the intercepted groundwater will be managed.

Summary of Comments on Doc 224 - 18 p327-390 CH2MHILL remediationplan.pdf

Page: 32

Number: 1 Author: Tony Subject: Sticky Note Date: 27/03/2017 7:10:43 AM +11'00'

This figure from a CH2MHILL document obtained under GIPA shows the contour line heights and the assumed ground water flow.
This figure alone puts big doubts into the other records validity of the area.

Number: 2 Author: Tony Subject: Sticky Note Date: 13/05/2017 8:34:16 AM

281 m certainly different to other contour heights

Australian Government

Department of Sustainability, Environment, Water, Population and Communities

Santos

We have the energy.

Referral of proposed action

Santos NSW (Eastern) Pty Ltd
Narrabri Gas Project
Gunnedah Basin, NSW

October 2014

Prepared by:

eco logical AUSTRALIA

Referral of the Project

Project title: Narrabri Gas Project

1 Summary of proposed action

1.1 Short description

Santos NSW (Eastern) Pty Ltd (Santos) is proposing to develop natural gas from coal seams in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri. The primary objective of the Narrabri Gas Project (the proposed development, or the Project) is to commercialise natural gas from coal seams for the Eastern Australia gas market and to support the energy security needs of NSW.

The Project seeks to develop gas wells, gas and water gathering systems, and supporting infrastructure southwest of Narrabri for the commercial production of gas. The natural gas produced would be treated to a commercial quality at a centralised gas processing facility on a rural property located southwest of Narrabri (the Leewood property).

The key components of the Project include construction and operation of exploration, appraisal and production activities and infrastructure to be carried out under proposed petroleum production leases including:

- Exploration and appraisal - Seismic acquisition, chip holes, core holes and appraisal wells.
- Gas field - Drilling of production wells, monitoring bores and gas and water gathering systems and in-field compression.
- A central gas processing facility for the dehydration, compression and treatment of the gas to commercial quality.
- Water management, treatment and beneficial reuse facilities that are required after the proposed petroleum production leases are issued.
- Supporting infrastructure such as power generation and distribution and operational management facilities.

The referral does not include the ongoing exploration and appraisal activities undertaken pursuant to Petroleum Exploration Licence 238 and Petroleum Assessment Lease 2 including, for example, the exploration and appraisal program the subject of EPBC Referral 2013/6918.

Santos currently has no plans to use hydraulic fracture stimulation in the Project area and is not seeking approval to use hydraulic fracture stimulation for the Project. Geological data indicates it would not increase gas flows in the coal seams that are being targeted. If additional geologic data supported the use of the technology in the future, a range of additional Government approvals would be required and community consultation would be undertaken.

The estimated $2 billion dollar Project is forecast to create approximately 1,200 jobs during the construction phase and sustain approximately 200 jobs during the operational phase. The Project would contribute to the NSW economy, including the regional economies of NSW, via the direct supply chain, in addition to the creation of indirect job opportunities. This Project has the potential to supply up to 50% of NSW’s gas requirements which is significant given the impending expiration of existing interstate gas contracts.

The project will be delivered in conjunction with the joint venture partners EnergyAustralia and Santos NSW (Eastern) Pty Ltd as the tenement holders.

1.2 Latitude and longitude

The four points included in the table represent the corner points of a rectangle which completely encompasses the Project.

LOCATION POINT	LATITUDE	LONGITUDE
1	30° 18' 25.73" S	149° 28' 4.90" E
2	30° 20' 34.93" S	149° 52' 44.10" E
3	30° 46' 17.65" S	149° 49' 11.43" E
4	30° 45' 15.06" S	149° 22' 42.51" E

1.3 Locality and property description

The Project is located within existing petroleum tenures Petroleum Exploration Licence (PEL) 238, Petroleum Assessment Lease (PAL) 2, and Petroleum Production Lease (PPL) 3, in the Narrabri local government area in NSW, between approximately 20 and 45 kilometres south of Narrabri and within the Bibblewindi, Jacks Creek, and Pilliga East State Forests.

The Project area will avoid the following conservation areas, Brigalow Park Nature Reserve, Pilliga National Park, the Pilliga East State Conservation Area and the Pilliga Nature Reserve.

In order to develop the necessary gas wells and gathering systems for the Project, Petroleum Production Leases must be granted over the areas where production activities may take place. As a result, Santos NSW Pty Ltd and EnergyAustralia Narrabri Gas Pty Ltd, lodged four Petroleum Production Lease Applications (PPLAs), No. 13, 14, 15 and 16, with the NSW Department of Trade and Investment, Regional Infrastructure and Services on 1 May 2014. The PPLAs were lodged over parts wholly within PEL 238 and PAL 2.

1.4 Size of the development footprint or work area (hectares)

The total Project area is approximately 98,000 hectares in size. However, surface infrastructure will directly impact approximately one percent of the total Project area, and this area will be quantified during the detailed impact assessment phase.

It is important to recognise that for projects such as the Narrabri Gas Project, not all wells are drilled and operational at once. Within the Project area, exploration, appraisal, and production would all occur to maintain the target gas production rate throughout the Project life. The rehabilitation and decommissioning of individual well sites would be undertaken progressively in accordance with regulatory requirements and industry standards.

1.5 Street address of the site

Access to the Project area is via the Newell Highway between Coonabarabran and Narrabri.

1.6 Lot description

Lot/Plan Number					
1//1023058	2//757126	37//757104	13//757086	276//815515	554//613281
1//1040807	2//771141	38//43335	14//609017	28//44006	56//757114
1//1049313	2//781866	38//757104	14//757083	28//757104	57//757114
1//1050103	2//790376	39//705390	14//757084	28//757120	58//757114
1//1064422	2//829368	39//757104	14//757120	29//44006	59//757104
1//126331	2//843278	39//843103	141//708354	29//757083	6//757083
1//131115	2//860120	4//1064422	142//708354	29//757104	6//757098
1//217871	20//757083	4//45260	143//708354	29//757120	6//757126
1//232897	20//757084	4//715462	144//708354	3//1064422	60//757104
1//248407	20//757087	4//757084	15//757083	3//1114784	61//804736
1//32500	20//757098	4//757086	15//757084	3//115246	62//791840

1//588635	20//757120	4//757087	15//757086	3//45260	62//804736
1//604751	201//877118	4//757097	15//757098	3//623250	63//804736
1//623250	202//877118	4//757126	15//757120	3//715462	67//44033
1//652381	21//1034651	4//790376	16//757087	3//757083	67//757104
1//653073	21//1055453	4//843278	16//757098	3//757087	68//44033
1//653174	21//757083	40//705390	161//802977	3//757097	68//757104
1//653781	21//757086	40//757104	163//1012802	3//757098	69//757104
1//713934	21//757087	40//843103	164//1012802	3//757126	7//757084
1//730132	21//757120	401//872809	17//757084	3//790376	7//757087
1//757084	22//1055453	402//872809	17//757098	3//843278	7//757126
1//757086	22//746781	403//872809	18//757087	30//757104	7//805987
1//757095	22//757084	404//872809	18//757098	31//1034772	70//757104
1//757098	22//757086	405//872809	18//757120	31//705370	7001//1030015
1//757103	22//757087	42//757120	181//628398	31//719217	7001//1032496
1//757126	22//757093	42//856653	1811//840549	31//757083	7001//1068410
1//757128	22//757120	431//1018381	1812//840549	31//757087	7001//1122341
1//771141	23//757087	432//1018381	182//628398	31//757104	7002//1030015
1//781866	24//757086	441//708169	182//814965	32//1034772	7002//1032496
1//790376	24//757087	442//708169	1821//880046	32//757083	7002//1068410
1//837801	24//757098	45//757093	1822//880046	32//757086	7002//1118445
1//843278	241//620138	45//757120	183//814965	32//757087	7003//1032496
1//860120	242//620138	451//1038294	184//814965	32//757104	7003//1068406
10//705417	25//757086	452//1038294	185//814965	32//828711	7003//1117084
10//757084	25//757098	46//757120	19//757086	33//757087	7003//1118445
10//757098	25//757120	47//757114	19//757098	33//757104	7004//1068409
102//708414	25//863891	48//757114	2//1023058	33//791317	7004//1118445
102//852566	251//777153	5//757084	2//1040807	331//1095730	7005//1059043
103//852566	252//777153	5//757086	2//1049313	332//1095730	7005//1068409
104//852566	253//777153	5//757093	2//1050103	34//757087	7005//1118446
11//746733	26//757086	5//757126	2//1064422	34//757104	71//757104
11//757084	26//757098	5//790376	2//1114784	34//791317	8//757084
11//757098	26//757120	5//843278	2//115246	35//757087	8//757087
11//805987	26//863891	51//43308	2//126331	35//757104	8//757097
12//746733	27//757086	51//757114	2//623250	35//757114	8//757098
12//757083	27//757098	52//43308	2//713934	36//757087	8//757126
12//757084	27//757120	52//757114	2//715462	36//757104	8//805987
12//757086	271//815515	53//43308	2//757084	36//757114	9//705417
12//757087	272//815515	53//757114	2//757087	36//828078	9//757083
12//757098	273//815515	54//821267	2//757093	361//603671	9//757084
13//609017	274//815515	55//821267	2//757095	363//845815	9//757087
13//757084	275//815515	551//609651	2//757098	37//43335	

1.7 Local Government Area and Council contact (if known)

The Project is located in the Narrabri Local Government Area (LGA). The contact for Narrabri Shire Council is:

Ms Dianne Hood
General Manager - Narrabri Shire Council
T: (02) 6799 6866

1.8 Time frame

Subject to obtaining all the required regulatory approvals, construction of the Project is expected to commence in early 2016. Mobilisation and construction of the gas processing facility and water treatment facility would occur for two years between approximately 2016 and 2017, with wells progressively drilled from mid-2016 over the life of the development.

1.9	**Alternatives to the proposed action**		No
		X	Yes, refer to section 2.2
1.10	**Alternative time frames etc.**	X	No
			Yes, you must also complete Section 2.3. For each alternative, location, time frame, or activity identified, you must also complete details in Sections 1.2-1.9, 2.4-2.7 and 3.3 (where relevant).
1.11	**State assessment**		No
		X	Yes, refer to Section 2.5
1.12	**Component of larger action**	X	No
			Yes, you must also complete Section 2.7
1.13	**Related actions/proposals**		No
		X	Yes This referral relates to a previous referral (EPBC 2013/6918 – 1 October 2013) which pertained to Santos undertaking a natural gas exploration and appraisal program within PEL 238 and PAL 2. The outcome of this referral was *not a controlled action if undertaken in a particular manner*. It is proposed that gas from the Project will be transported via a new gas transmission pipeline linking the Project Area to the existing Eastern Australia pipeline network. A separate referral will be made for any pipeline that will be developed through an independent commercial structure and/or contractual arrangements.
1.14	**Australian Government funding**	X	No
			Yes, provide details:
1.15	**Great Barrier Reef Marine Park**	X	No
			Yes, you must also complete Section 3.1 (h), 3.2 (e)

2 Detailed description of the proposed action

2.1 Description of the proposed action

The Project includes the undertaking, construction and operation of exploration, appraisal and production activities and infrastructure for the commercial production of gas to be carried out under the proposed petroleum production leases:

- Exploration and appraisal activities including approximately 500 km of seismic surveys, approximately 30 coreholes, approximately ten chip holes and approximately ten sets of four-well pilots .
- Installation and operation of up to 850 individual production wells from a maximum of 425 well sets. A single well may be vertical, vertical with a slight incline, or lateral; the latter may include several horizontal connections sometimes referred to as a multi-lateral. The target production peak rate is approximately 200 terajoules (TJ/day).
- Gas and water gathering systems and in-field compression.
- A central gas processing facility for the compression, dehydration and treatment of the gas to commercial quality.
- Water management, treatment and beneficial reuse facilities that are required after the proposed petroleum production leases are issued.
- Supporting infrastructure such as power generation and distribution, communications, roads and operational management facilities.

The regional location of PEL 238, PPL 3 and PAL 2 is shown in Figure 1 with the Project Area and PPLA 13, PPLA 14, PPLA 15 and PPLA 16 detailed in Figure **2**.

General descriptions of construction and operational activities associated with the Project are provided in further detail below.

Gas field life cycle

Gas resources are geographically extensive and variable in quality and quantity. This requires widespread project infrastructure which is progressively developed over the life of a project. Gas field development is a co-ordinated program over time that determines the best locations for all project components, including for example, core holes, pilot wells, production wells, gathering lines, transmission pipelines, gas compression and treatment facilities, ground and surface water monitoring, water management facilities and associated infrastructure.

A summary of the life cycle of a gas field is as follows:

- Exploration. This broadly involves undertaking seismic surveys, chip holes, drilling core holes and collecting baseline scientific data.
- Appraisal. The drilling of core holes and pilot wells to gain knowledge of the gas content and composition, to inform gas field design.
- Construction. Building components of the gas field, including drilling wells, field compression, the gas processing facility and the water treatment facility.
- Operation. Extracting water and gas, compressing gas to commercial quality and treatment and beneficial reuse of the water.
- Well decommissioning and rehabilitation. Once wells are no longer economically producing gas, they are plugged and abandoned and the lease pad rehabilitated.
- Gas project decommissioning and rehabilitation. Once the gas field is no longer commercial, equipment is decommissioned, and the site is rehabilitated.

To produce natural gas from coal seams, water must first be extracted from those seams. This release of pressure allows the natural gas to flow to the surface via the well. After the water and gas are extracted at the well, they pass through a separator at the well head. The water then travels through discrete flowlines to storage and/or treatment facilities. The gas travels through separate flowlines to a processing facility where it is compressed before being sent to market (refer Figure 3).

It is important to recognise that for projects such as the Narrabri Gas Project, the entire gas field is not developed at once. Within the Project area, exploration, appraisal, and production would all occur to maintain the target gas production rate throughout the Project life. The rehabilitation and decommissioning of the coal seam gas fields would be undertaken progressively in accordance with regulatory requirements and industry standards.

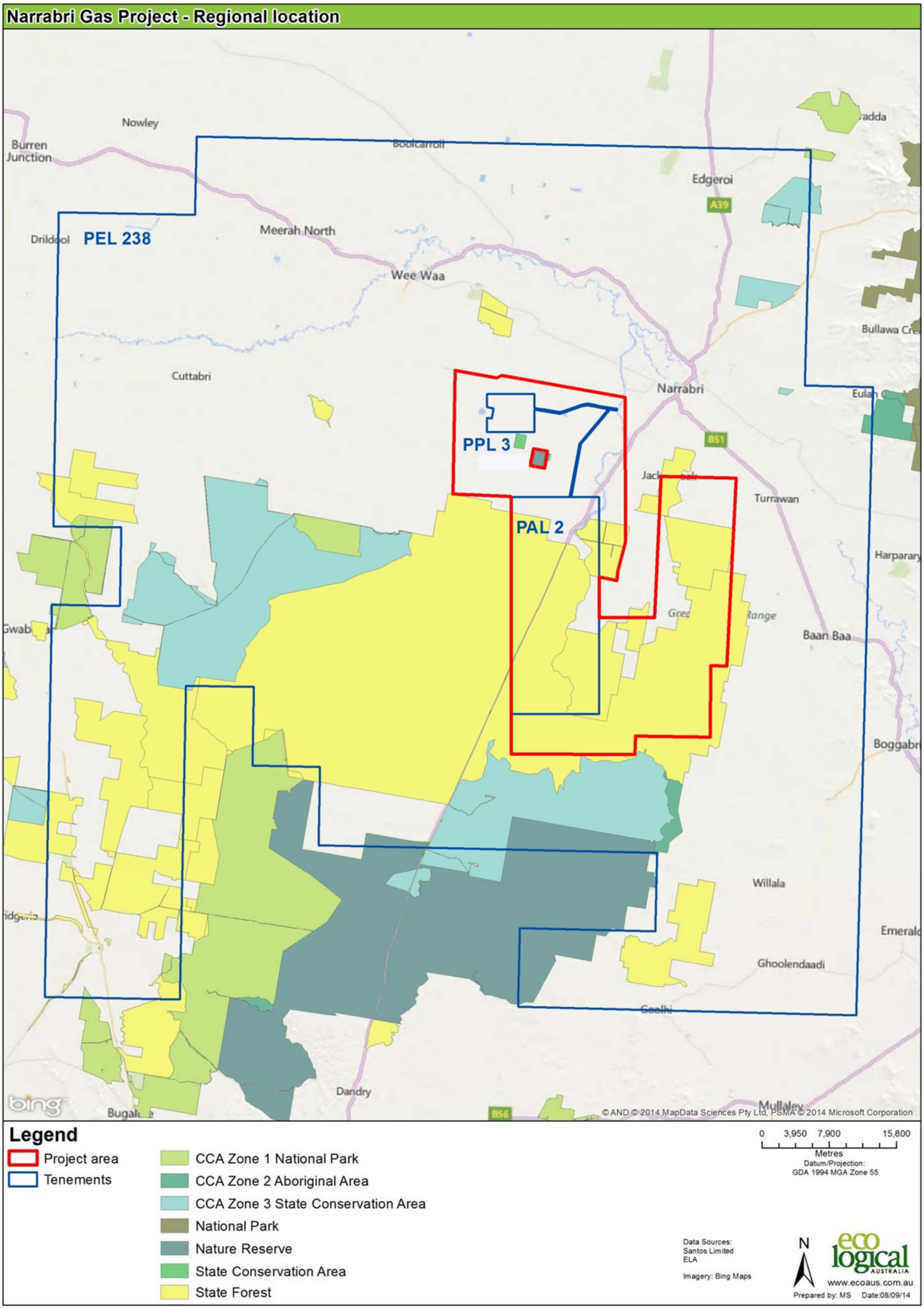


Figure 1: Regional location

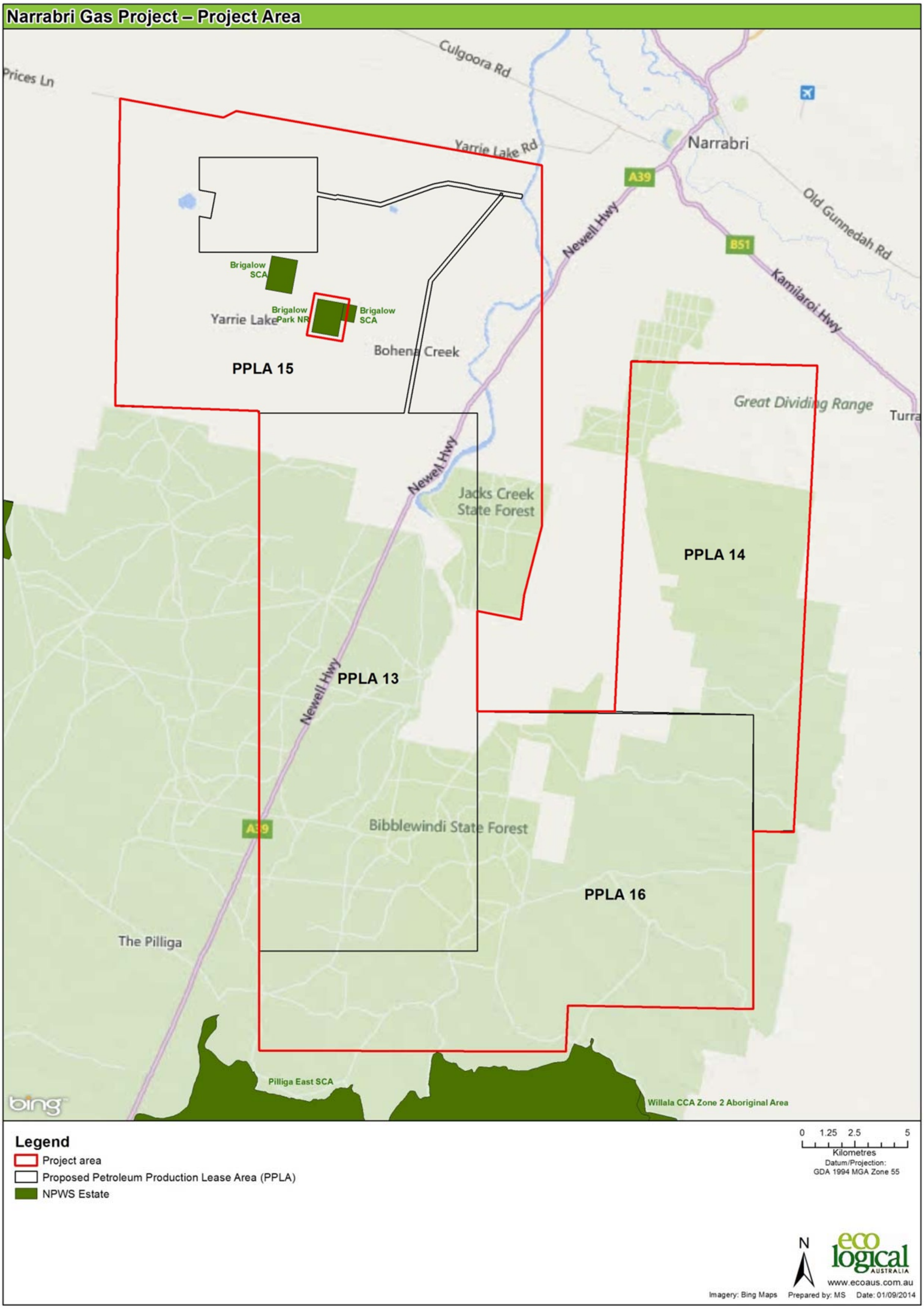


Figure 2: Project area

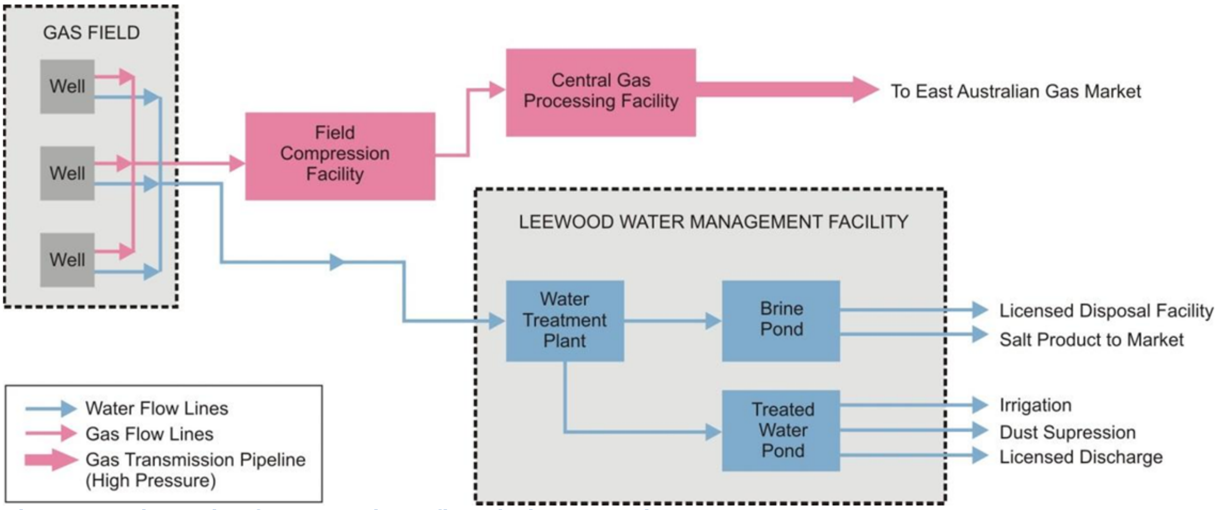


Figure 3: Schematic of water and gas flow during operations

Exploration and appraisal activities

Exploration and appraisal activities as part of the Project would continue through the development of the field over time to help continually enhance the understanding of the resource. Exploration and appraisal activities would include seismic surveys, chip holes, core holes and pilot wells, associated temporary supporting infrastructure (flares or water balance tanks) and the installation of monitoring equipment. Permanent water and gas management facilities would be utilised where possible.

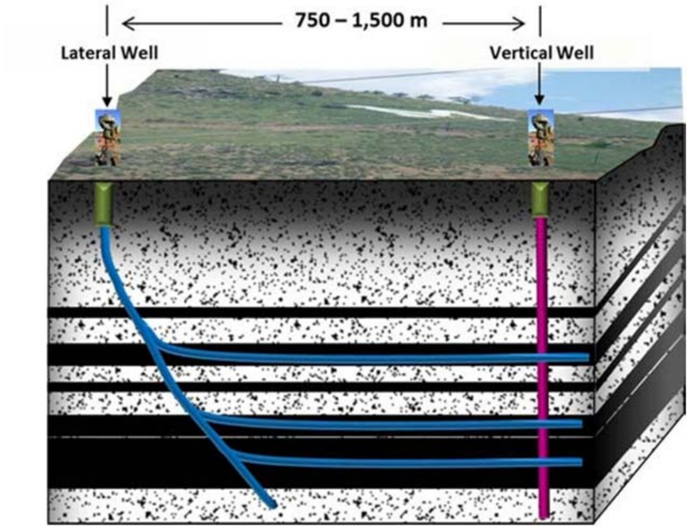
Santos proposes to drill approximately 30 core holes, approximately ten chip holes and approximately ten sets of four-well pilots during the exploration and appraisal process. Approximately 500 kilometres of seismic surveys are also proposed. At completion of exploration and appraisal, all wells will either be:

- Plugged and abandoned and the drill pad rehabilitated.
- Converted to monitoring bores.
- Converted to production wells and counted within the total maximum number of production wells proposed.

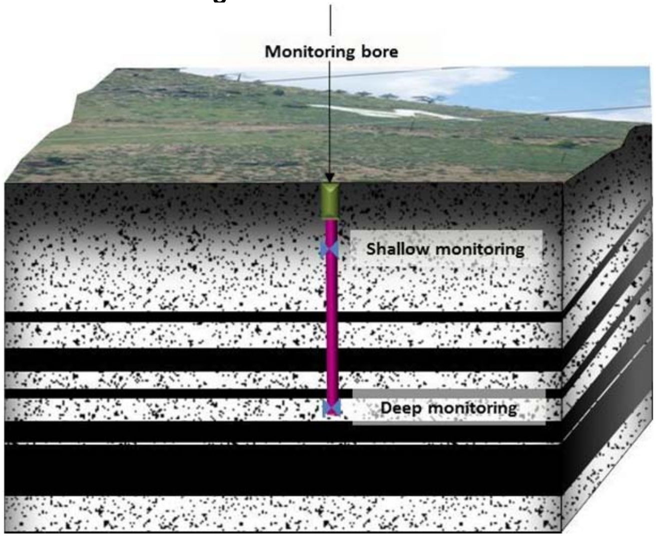
Production wells

It is anticipated that up to 850 individual production wells partnered to a maximum of 425 well sets would be progressively advanced and decommissioned within the Project area over the life of the Project. This would include any core holes or pilots drilled as part of the exploration and appraisal program that are converted to production wells as noted above. All drilling activities would be undertaken in accordance with the NSW Code of Practice for Coal Seam Gas Well Integrity (DTIRIS 2012).

A single well may be vertical, vertical with a slight incline, or lateral; the latter may include several horizontal connections sometimes referred to as multi-laterals. Wells would be drilled using a minimum number of well pad locations with wells and monitoring bores co-located on the same pad, where possible in order to reduce environmental footprint (refer to Figure 4 and Figure 5).



A: A well set consisting of one lateral well and one vertical well



B: Monitoring bore

Figure 4: Types of well and bore configurations. (A): A well set consisting of one lateral well and one vertical well. (B): Monitoring bore.

The well pads would be spaced approximately 750 to 1,500 metres apart, depending on surface geography and subsurface characteristics. Each well pad would be approximately 100 by 100 metres (one hectare) in size during drilling and construction.

In order to provide a stable working area for the drill rigs during well installation, vegetation would be either trimmed or cleared and either industrial matting laid, or topsoil scraped and stockpiled for use during site rehabilitation. Following well installation, rehabilitation of the pad commences, with remaining surface facilities to include the well head, metering skids, power generation and remote sensor telemetry unit. If remote communication to the well site is lost, the operator is sent a “Loss of Communications Alarm”. The operator would then travel to the well site to monitor. In the event of a well process failure, the standalone mechanical and electrical process protection devices would shut down the well.

Access to the well pads would be via existing roads and access tracks, wherever possible. Where it is not possible to utilise existing roads and access tracks, new tracks would be constructed. A right of way approximately 12 metres wide would be required for the construction of the new access tracks. The right of way would be restored and reduced to approximately 7 metres during operation; slightly wider on bends as required.

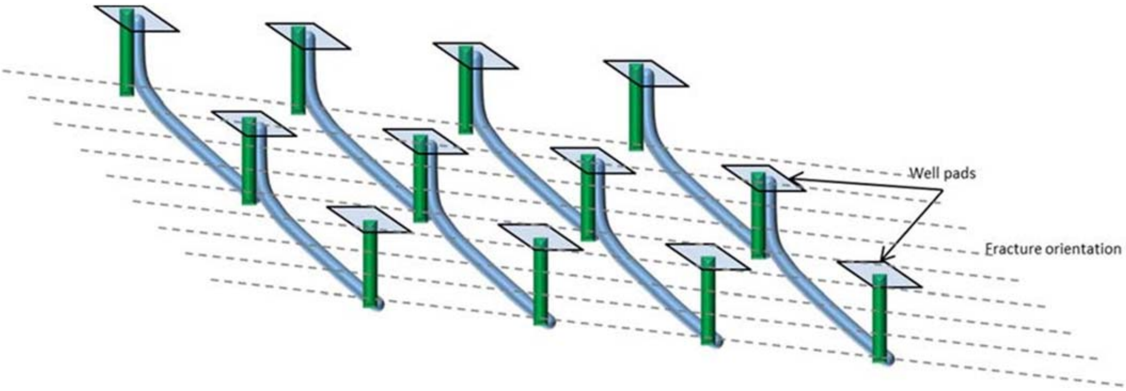


Figure 5: Indicative shared lease pad well configuration (well sets)

The specific location of each well would depend on local operational (e.g. geology/gas accessibility) and environmental factors. It is proposed that the specific location of each well pad within the Project area would be determined in accordance with a field development protocol which would set out the detailed environmental criteria for selecting the specific location of the well pad within the Project area. The environmental criteria would include for example, proximity to watercourses and significant ecology, upper impact limits for ecology and vegetation clearing, cultural heritage considerations, land access, and amenity. It is proposed that field clearance surveys for well micro-siting in accordance with the field development protocol would be undertaken before construction. The development of the Project in accordance with the field development protocol and micro-siting procedure will be detailed and assessed in the detailed impact assessment.

Monitoring Bores

Groundwater monitoring bores to characterise baseline groundwater conditions are in the process of being installed and commissioned as part of the current exploration and appraisal activities under PEL 238 and PAL 2. The installation and commissioning of these groundwater monitoring bores is excluded from this referral. Further water bores will be drilled after the production leases are issued, and these are a part of the proposed action. The entire water bore network will be monitored as part of the Project. The groundwater monitoring network will comprise shallow depth monitoring bores completed in the Great Artesian Basin (GAB) Surat Pilliga Sandstone and overlying sediments whilst deeper monitoring bores will target groundwater conditions in the underlying Permo-Triassic Gunnedah Basin strata. The network will be designed and instrumented to yield continuous data on groundwater pressures and water quality across the monitoring domain which encompasses the Project area.

Gas and water gathering systems

The gas and water gathering systems (comprised of a network of separate, low pressure, underground pipelines) would link each well head to the in-field compression, gas processing facility, and the water management, treatment and beneficial reuse facilities, respectively (refer to Figure 4 and Figure 6).

Where possible, the gas and water gathering systems would be co-located proximal to, and parallel with, existing access roads, tracks or other existing linear features such as fence lines to minimise the need for any additional clearing. The corridors of any new access tracks constructed would also be used to co-locate the gathering systems to further minimise the need for additional clearing. The right of way width would be consistent with that described above.

Installation of the gas and water gathering systems would be undertaken via plough-in, trenching or directional drilling, depending on selected piping material, subsurface soil conditions and land use. The burial depth of the gathering systems would range from 0.75 to 2 metres depending on land use, specific assessment of crossings (such as creeks/roads/existing or new infrastructure) would be assessed and designed accordingly during detail design. The specific location of the gathering system will be in response to the locations of the wells and would be guided by the field development protocol.

Where required, field compression will be installed to boost the gas to the centralised gas processing facilities. The compression stations will require services such as power, process equipment, communications, instrumentation and control. The field compression will be minimised and optimised during detailed design.

Central gas processing facility

A new central gas processing facility would be constructed and operated at the Leewood property, with some in-field compression potentially also required closer to the central location of the wells depending on gas pressure. In-field compression would comprise of package compressors that boost the gas pressure to enable it to be transported to the central gas processing facility.

At the central gas processing facility the gas will be conditioned to a domestic specification by removal of predominately CO_2, then treated to remove suspended moisture before odorisation and export compression (refer Figure 6). The central gas processing facility would be constructed predominantly from prefabricated units transported to site, with a footprint size subject to final design.

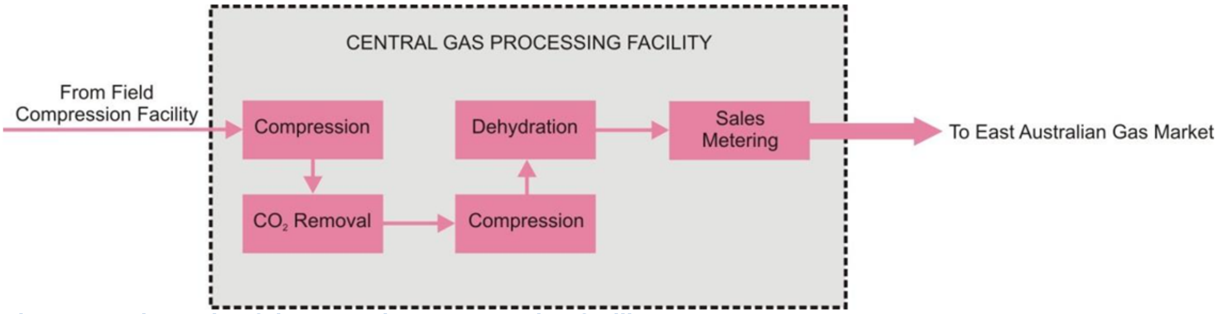


Figure 6: Schematic of the central gas processing facility

Infrastructure installed at the central gas processing facility would include, for example:

- Gas conditioning equipment, as required, to achieve gas quality specification.
- Compressors, compression after coolers and dehydration units.
- Plant overpressure protection systems including pressure safety valves and flares.
- Sales gas metering.
- Power generation equipment.
- Utilities including instrument air, fuel gas systems and power generators.
- Petroleum fuel and lubrication oil tanks.
- Buildings including a control room, switch rooms, equipment shelters, offices, workshop,
- storerooms and first aid room.

Supporting infrastructure

Supporting infrastructure and services would be required as part of the Project.

A concrete batching plant
In order to minimise the transportation of concrete, particularly during the construction of the gas processing facility, a concrete batching plant may be established at the Leewood property.

Worker accommodation
Construction camp(s) would be established as required. The accommodation would consist of demountable buildings and include mess facilities, a canteen, an amenities building, laundry, medical/first aid room and a recreation/games/gym room. Communications facilities and storage

areas, vehicle maintenance and parking areas, fuel handling and storage areas, and facilities for the collection, treatment and disposal of wastes would also be provided.

If well sites are located in remote or difficult to access locations, small relocatable accommodation facilities may be established to service the drill rigs.

Approximately 200 workers associated with the ongoing operations of the Project would primarily reside in Narrabri.

Electricity
Construction activities would use temporary power generators to supply sites and facilities prior to the connection of a permanent supply. Power at the proposed worker accommodation would be generated by diesel generators. During operation, power will be required at each well head, at in-field compression stations and at Leewood for the central gas processing facility and water treatment.

Electricity to power the operational requirements of the Project would likely be provided primarily via a combination of the Wilga Park Power Station, with additional electricity provided from a connection to the existing NSW electricity transmission network, or the utilisation of gas fired turbines located in the Project area. The electricity supply for the Project may be one of the options outlined above, or more likely a combination of some or all of the three.

Any required upgrade to the NSW electricity transmission network and associated infrastructure located outside of the Project area would be subject to a separate approval process.

Water management, treatment and beneficial reuse facilities
Additional facilities are required at the Leewood property in order to treat the produced water (i.e. to remove salt). The construction and operation of a pilot water treatment facility to treat water from Santos' exploration and appraisal activities as part of PEL 238 and PAL 2 will be the subject of a separate approval process. An application is currently under preparation for these works.

The water treatment facility on the Leewood property (which will be the subject of a separate approval) will be upgraded as part of the proposed development to cater for the volumes of water the proposed development would generate.

Subject to detailed engineering design, specific upgrades or additional water management requirements activities required by the proposed development may include:

- An upgrade of the water treatment facility to store and treat the produced water.
- The treatment of increased brine volumes at the Leewood property to produce solid salt products.
- The upgrade of the water treatment plant layout, tanks and pipes to accommodate increased produced water, brine and permeate.
- The management of water treatment by-products. This would include:
  - Permeate management. The beneficial re-use of permeate for dust suppression, during construction activities, for firefighting purposes, for agricultural irrigation activities, and/or discharge to local waterways.
  - Salt management. The commercial re-use of salt after brine treatment, or, the disposal of salt at an appropriately licensed landfill and/or recycling facility.

Sewerage
Onsite sewage management (e.g. septic) is proposed to cater for the worker accommodation and the central gas processing facility. Untreated sewage from the accommodation would be transported from site to local approved treatment facilities. In cases where local facilities cannot accommodate these wastes, sewage would be treated onsite using transportable sewage treatment unit(s).

Telecommunications
Telecommunications services would include voice and data network services and telemetry services. Existing carrier services would be used, where available. Alternative methods would be used where existing services are insufficient and may include:

- A fibre network extended from existing facilities and installed parallel with the water and gas gathering systems.
- Communications equipment accommodated in operational or administration buildings.
- Satellite communications used in remote locations.
- VHF radio network.

Telemetry services would be provided to facilitate the operation and monitoring of field production. Strategically located radio towers would be used for both data telemetry and voice radio services. These services would be connected to the data networks at operation or administration facilities.

Project decommissioning and rehabilitation

A detailed decommissioning and rehabilitation strategy would be developed for the Project. The objectives of the decommissioning and rehabilitation strategy would include:

- Returning disturbed areas to a stable condition similar to that of the surrounding area within an acceptable time frame consistent with stakeholder requirements and expectations.
- Enabling the effective transfer of operating areas to landholders compatible with agreed post-closure land use.
- Minimising disturbance to drainage patterns and avoiding contamination of soil, surface waters and shallow groundwater resources.
- Minimising disturbance to native vegetation and fauna.
- Ensuring each rehabilitated area is capable of supporting sustainable ecosystems.

The overriding rehabilitation strategy is the promotion of natural vegetation regrowth through appropriate topsoil stripping, storage and replacement. Only when the native vegetation fails to regenerate to meet approved rehabilitation target metrics would intervention be considered.

It is anticipated that decommissioning of surface infrastructure, with subsequent rehabilitation, would be undertaken progressively as the wells become depleted during the Project life cycle.

At the cessation of production, the gathering systems would be isolated at the well head and also where they are connected to both the water treatment and gas processing facilities. The gathering systems would then be made safe, isolated, drained, vented and capped in accordance with the Australian Pipeline Industry Association (APIA) Code of Environmental Practice for Onshore Pipelines, 2013. All above ground components of the gathering system would be removed, including all pipeline marker signs.

Rehabilitation of the gathering system corridor would occur after its installation and in accordance with the rehabilitation strategy. After the well sets are decommissioned, the subsurface components of the gathering system would remain in situ as described above, and vegetation maintenance within the gathering system corridor would cease.

Final site rehabilitation for disturbed areas may vary from area to area depending on the nature of the development in that area and input from the local landholder, Traditional Owners and other relevant stakeholders. Any existing infrastructure that is useful to the landholder may remain once agreement is made, and remaining disturbed areas revegetated in accordance with agreed future land use.

Activities not included in the Referral

This referral relates to the activities required for the commercial production of gas proposed to be undertaken under the petroleum production leases, if granted, in respect of PPLA 13, PPLA 14, PPLA15 and PPLA16.

The proponent is currently undertaking, and proposes to continue carrying out, exploration and appraisal activities pursuant to PEL 238 and PAL2, including within the Project Area, until the petroleum production lease applications are determined.

- This referral does not include the ongoing exploration and appraisal activities undertaken pursuant to PEL 238 and PAL 2 for example, the exploration and appraisal program the subject of EPBC Referral 2013/6918 including the operation of pilot wells;
- further exploration and appraisal activity undertaken prior to the petroleum production leases being granted;
- the construction and use of the water management facilities, including but not limited to the Leewood property, for exploration and appraisal purposes;
- the management and use of produced water from the exploration and appraisal activities;
- the installation and use of groundwater monitoring bores;

If the petroleum production lease applications are granted, then the proponent may use the above infrastructure for gas production purposes and the use of such infrastructure for gas production pursuant to the petroleum production leases, if granted, is included in this referral.

This referral does not include the construction and use of the Wilga Park Power Station for gas produced under PEL 238 and PAL 2.

2.2 Alternatives to taking the proposed action

Projections to 2030 indicate that the global, National and State consumption of gas will continue to increase (International Energy Agency 2009). In regards to NSW, growth in annual gas consumption is predicted to be approximately 0.8%, with modelling of existing and committed projects shows that there may be a gas supply shortfall from winter 2018 onwards (AEMO 2013).

NSW currently imports approximately 95% of its gas from other States (Queensland, Victoria and South Australia) (NSW Chief Scientist and Engineer 2013). The interstate gas contracts under which NSW is supplied begin to expire in 2014 and will be almost completely expired by the end of 2017, when the existing gas supply from Moomba will be redirected to Queensland liquefied natural gas (LNG) export facilities (NSW Chief Scientist and Engineer, 2013). Under this scenario, both the gas supply pipelines from Victoria (Eastern Gas Pipeline and NSW-Vic Interconnect) will be at maximum capacity.

On constrained gas supply into NSW markets as a result of increased demand from both NSW consumers and Queensland LNG contracts, the AEMO (2013) Gas Statement of Opportunities noted that “there will be flow-on effects for NSW with potential shortfalls of 50 to 100 TJ/day (terajoules per day) over winter peak demand days from 2018”. AEMO (2013) noted that “committed and advanced projects in NSW are not sufficient to completely alleviate these shortfalls without further support from the Moomba to Sydney Pipeline. Opportunities exist to augment transmission capability between Victoria and New South Wales, increase production in the Cooper Basin, undertake moderate development of the Gunnedah Basin, or develop an alternative transmission route between Queensland and New South Wales.”

The anticipation of restricted gas supply to NSW heightens the need for a local gas resource for NSW to provide increased security for the current demand and to meet the projected future demand. The proposed development would provide infrastructure to help facilitate overcoming these predicted challenges and thereby meet projected demand for the eastern states over the next decades. The

Project would have the capacity to produce approximately 70 PJ per year, which is equivalent to approximately 50% of NSW's gas consumption (using the NSW Chief Scientist and Engineer's (2013) data).

The do nothing option would result in the absence of potentially 50% of NSW gas requirements being available for supply to the NSW gas market. Should the Project not proceed, there is a risk that there would be a shortfall in gas supply resulting from the expiration of interstate gas supply contracts with no other alternative currently secured (Wood et.al. 2013).

The do nothing option would result in the following benefits being forgone:

- Increased gas supply security to meet current and projected future demand.
- Creation of approximately 1,200 jobs during the construction phase and 200 jobs during the operational phase.
- An alternative to coal reserves as a means of energy production and potential for lower carbon emissions from power generation (compared to coal-fired power generation), consistent with the Commonwealth Government's commitments under the Kyoto Protocol.
- Contribution to the State's economy through royalties paid, jobs created and infrastructure investment.
- Improved competition on price, also having flow on benefits for NSW's economic efficiency, productivity and prosperity.
- Contributions to the regional community benefit fund.

Without a feasible alternative to current gas supply, industries reliant on gas may be impacted by rising gas prices as supply contracts expire and are re-negotiated (Wood et.al. 2013).

2.3 Alternative locations, time frames or activities that form part of the referred action

During design development, alternative locations and alternative infrastructure were considered, however, the location of the Project has been selected as:

- It is greater than 2 kilometres from residential zones or identified future residential growth and does not impact on any critical industry clusters (CICs) as defined in the *NSW State Environmental Planning Policy (Mining, Petroleum and Extractive Industries) 2007* (the Mining SEPP).
- It avoids conservation areas such as the Pilliga National Park, the Pilliga State Conservation Area, the Pilliga Nature Reserve and the Brigalow Park Nature Reserve.
- It is consistent with NSW government policy and targets an area that has been identified within the NSW Strategic Regional Land Use Plans and the *Brigalow and Nandewar Community Conservation Area Act 2005* as suitable for development of natural gas from coal seams.
- Exploration and appraisal has taken place to enable an estimation of the recoverable gas resources available in the area to underpin a gas development. The same level of exploration and appraisal has not been undertaken by Santos in other PELs and hence there is not the same level of confidence in the recoverable resources in those areas. As a result, the time required to produce gas from those areas would be substantially longer, thereby delaying further supply to the NSW market.

Further, a range of alternative infrastructure options were considered prior to selecting the current configuration, including for example:

- Alternate well pad sizes.
- Alternate water processing configurations; decentralised rather than centralised.
- An alternate location for the centralised gas processing facility.
- Alternate gas field development logic.

2.4 Context, planning framework and state/local government requirements

The Project will be undertaken in accordance with the requirements of relevant environmental and planning legislation. All associated environmental and planning approvals will be obtained, including but not limited to:

- Commonwealth environmental approval.
- State Government planning approvals.
- Operational approvals (such as an Environment Protection Licence).
- Other approvals required under relevant environmental and planning legislation and regulations.

A list of legislation, policies and guidelines applying to the Project includes:

<u>Commonwealth Legislation</u>

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).
- *National Greenhouse and Energy Reporting Act 2007.*
- *Native Title Act 1993.*
- *Water Act 2007.*

<u>NSW State Legislation</u>

- *Environmental Planning and Assessment Act 1979.*
- *Petroleum (Onshore) Act 1991.*
- *Water Management Act 2000.*
- *Water Act 1912.*
- *Protection of the Environment Operations Act 1997.*
- *Forestry Act 2012.*
- *Native Vegetation Act 2003.*
- *Threatened Species Conservation Act 1995.*
- *Roads Act 1993.*
- *National Parks and Wildlife Act 1974.*
- *Rural Fires Act 1997.*
- *Catchment Management Act 1989.*
- *Noxious Weeds Act 1993.*

<u>NSW State Environmental Planning Policies (SEPPs)</u>

- State Environmental Planning Policy No 44 – Koala Habitat Protection.
- State Environmental Planning Policy (State and Regional Development) 2011.
- State Environmental Planning Policy – Mining, Petroleum Production and Extractive Industries, 2007.

<u>Other relevant policies and plans</u>

- NSW Aquifer Interference Policy 2012.
- NSW Biodiversity Strategy 1999.
- Narrabri Local Environmental Plan 2012.
- Strategic Regional Land Use Plan: New England North West 2012.

2.5 Environmental impact assessments under Commonwealth, state or territory legislation

The Project has the potential to have significant impacts on Matter of National Environmental Significance (MNES), and is therefore being referred to the Commonwealth Department of the Environment under the EPBC Act (i.e. this referral). Santos believes that the Project is a controlled action and will require additional assessment prior to approval.

State assessment
The NSW EP&A Act provides the statutory basis and framework for planning and environmental assessment in NSW. The EP&A Act includes provisions to ensure that the potential environmental impacts of a development are assessed and considered in the decision-making process.

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

The Project is subject to the assessment and approval provisions of Division 4.1 of the EP&A Act. The Minister for Planning and Infrastructure is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Director General or to any other public authority.

Section 79C of the EP&A Act applies to State significant development applications and requires the consent authority to take into consideration a broad range of matters. The matters identified in Section 79C of the EP&A Act would be considered in preparation of a detailed impact assessment for the Project.

Under Division 4.1 of Part 4 of the EP&A Act, the planning and approval process involves the following key steps:

- Submission of a request to the Director-General of the Department of Planning and Infrastructure, including accompanying supporting documentation seeking the Director General’s Requirements for the content of an Environmental Impact Statement (EIS).
- Preparation of an EIS, addressing the matters outlined in the Director General’s Requirements.
- Submission of a development application, accompanied by the EIS.
- Public exhibition of the EIS for a minimum of 30 days.
- Assessment of the application by the Department of Planning and Infrastructure and preparation of the Director-General’s environmental assessment report.
- Determination by the Minister for Planning or delegate, including conditions of approval if development consent for the Project is granted.

A preliminary environmental assessment (PEA) was completed to inform Santos’ request for Director-General’s Requirements for use in the preparation of an EIS for the Project (GHD 2014). Secretary’s Environmental Assessment Requirements were issued for the Narrabri Gas Project on 25 July 2014.

2.6 Public consultation (including with Indigenous stakeholders)

Consultation objectives
Santos has initiated a comprehensive consultation program with the community, government agencies and other potentially affected stakeholders. This program is being undertaken to assist with identifying relevant environmental issues and social impacts, as well as enabling a process to address concerns regarding the Project.

The objectives of the consultation process are to:

- Increase overall awareness and understanding of the coal seam gas industry and in particular the proposed activity.
- Identify and keep informed landholders, neighbours, residents, and relevant local and state government agencies.
- Build and maintain effective relationships with stakeholders and communities based on open communication, trust and understanding of the Project.

- Ensure the interests of stakeholders are considered in the proposed activity design and implementation.
- Provide timely, accurate and credible information to stakeholders and the broader community.
- Identify potential issues and/or risks and strategies for mitigation and resolution.

Approach to consultation

A stakeholder engagement plan has been initiated and stakeholder groups identified. These stakeholder groups have been categorised according to their level of interest in the Project and their potential level of impact on planning, implementation and outcomes of the Project.

Engagement regarding the Project is occurring with all relevant stakeholders to ensure that potential impacts are identified and, where possible, avoided or minimised. To achieve this, communication is being undertaken in an open, transparent manner.

This consultation program will be ongoing throughout the development of the EIS and would continue during construction and operation of the Project. The consultation process is dynamic and the role and importance of stakeholders is likely to vary during the assessment process as new stakeholders emerge as the process progresses. Stakeholders for the Project include:

- Local, State and Commonwealth government authorities.
- Industry stakeholders.
- Property owners and neighbours.
- Aboriginal community and Local Aboriginal Land Councils.
- Registered Native Title Applicants.
- Elected representatives (federal, state and local).
- Interest groups, such as community, environment and business groups.
- The broader community.
- Media (local and national).

There are four levels of targeted engagement and consultation proposed:

- Inform – aimed at community, business and industry in the broader regional and state-wide context.
- Consult – aimed at community groups, industry, business and residents not directly involved but living and operating within the local area; landholders, government departments; non-government organisations, local industry and business.
- Involve – aimed at key stakeholder groups directly involved. This includes neighbouring landholders; government departments listed as referral agencies; non-government organisations; community groups; local contractors and businesses.
- Collaborate – aimed at individuals and entities that are directly impacted by the Project and/or involved in project decisions. This includes landholders; government departments responsible for assessments and approvals; local government; native title claimant groups; and community consultative committees.

Consultation to date

Eastern Star Gas

A number of consultation activities were undertaken in 2010-2011 in response to the Director-General's Requirements for an earlier gas production project proposed for part of the Project area by Eastern Star Gas. Consultation activities undertaken as part of the Eastern Star Gas environmental assessment process included:

- A Planning Focus Meeting held in October 2010.
- Meetings with relevant government authorities.
- Consultation with industry stakeholders.
- Consultation, meetings and field visits with representatives of the Aboriginal community and Local Aboriginal Land Councils.
- Communication with specialist interest groups including community and business groups.
- Site visits and meetings with potentially directly affected property owners.
- Engagement and consultation activities with the broader community, including establishment of a Community Working Group, holding Community Information Sessions, publication of Community Information Sheets and advertising in local media.

The main issues raised by government agencies included: hazard and risk, ecology, rehabilitation, water, waste, heritage, soils, air quality, noise, land use, landscape, traffic, and greenhouse gas emissions.

Santos

Consultation undertaken to date by Santos, in relation to this Project includes:

- Meetings with relevant State and Commonwealth government authorities.
- Information provided to an independently chaired Community Consultative Committee that meets monthly in Narrabri.
- Regular Government Information forums and meetings with local government staff and elected representatives.
- Technical briefings and site tours with the Gomeroi Native Title Applicants, follow up meetings and ongoing liaison.
- Information forums, on-site meetings and site tours with neighbouring landholders, Aboriginal representative groups, farmers and rural industry representatives and local business and contractors.
- Provisions of information through Santos' website and media announcements, shopfronts in Narrabri and Gunnedah, information stands at local agricultural shows and community events.

Proposed consultation

The planned community and stakeholder consultation throughout development of the EIS is described in the summary table below.

STAKEHOLDER	FORMAT/ENGAGEMENT TOOLS
Government	Briefing to Councillors and Officers prior to lodgement of the EIS. Ongoing regular updates to Council. Letters to State and Federal members to provide project updates on the status of the planning approval process. Offer a briefing if required. Notification of EIS exhibition process.
Regulators	Invitation to attend government forums for local and regional staff. Additional one-on-one meetings as required.

STAKEHOLDER	FORMAT/ENGAGEMENT TOOLS
Landholders	Written communication to advise of EIS process. Follow up telephone calls. Opportunity to attend landholder information sessions. Sharing studies and monitoring data. Seek input into EIS development on those areas of interest/concern. Invitation to field tours. Notification in a public newspaper of advice of public exhibition and opportunity to submit comments.
Registered Native Title Applicants	Written communication to advise of EIS process. Follow up telephone calls. Direct and ongoing engagement. Sharing studies and monitoring data. Seek input into EIS development on those areas of interest/concern. Notification in a public newspaper of advice of public exhibition and opportunity to submit comments.
Local Aboriginal communities and Aboriginal Land Council	Direct one-on-one briefings to identify concerns and demonstrate how the EIS is designed to manage/mitigate those issues. Seek input into relevant aspects of EIS development. Sharing studies and monitoring data. Invitation to attend field tours. Advertorials on PEA and EIS summary documents in local media.
Neighbouring landholders	Advertorials on PEA and EIS summary documents in local media. Neighbour landholder meetings as required.
Local community - including schools and all community associations	Community Consultative Committee briefings. Project updates in local papers including fortnightly activities updates. Advertorials on PEA and EIS summary documents in local media. Information forums and community open days. Invitation to attend field tours.
NGOs/ Interest Groups	Direct one-to-one engagements with priority stakeholders to provide opportunity to comment on/input into EIS development. Advertorials on PEA and EIS summary documents in local media. Invitations to attend information forums. Invitation to attend field tours.
Local business/contractor community (existing relationships)	Letters of advice to update on the status of the planning approval process. Advertorials on PEA and EIS summary documents in local media. Invitation to attend information forums. Invitation to attend field tours.
Media	Regular updates in local media to include status of the EIS process.

2.7 A staged development or component of a larger project

This is not a staged development for the purposes of this referral. However, as discussed above, the entire gas field will not be developed all at once. Within the Project area, exploration and appraisal, drilling, production, and decommissioning and rehabilitation activities would occur simultaneously in different parts of the Project area to maintain the target gas production rate throughout the Project life.

It is proposed that gas from the Project will be transported to the NSW gas pipeline network via a new gas transmission pipeline linking the Project Area to the existing Eastern Australia pipeline network. A separate referral will be made for any pipeline that will be developed through an independent commercial structure and/or contractual arrangements.

3 Description of environment & likely impacts

3.1 Matters of national environmental significance

The total Project area is approximately 98,000 hectares in size, however, surface infrastructure would directly impact approximately one percent of the native vegetation in the Project area. The majority of the Project is located within an area known as the ‘Pilliga’, with the remaining approximately 30% located on agricultural land supporting dry-land cropping and pastoral (livestock) activities. The collective term ‘Pilliga’ represents an agglomeration of forested area that totals in excess of 500,000 hectares within north-western NSW around Coonabarabran, Baradine and Narrabri. Within the Pilliga, the Project would be developed primarily within State Forest, and also on some privately managed land, but will avoid the following conservation areas, the Pilliga National Park, the Pilliga State Conservation Area, Pilliga Nature Reserve and Brigalow Park Nature Reserve.

A search of the Department of the Environment (DotE) Protected Matters Search Tool (PMST) for the Project utilising the co-ordinates provided in Section 1.2 of this referral (and a 50 km buffer) was undertaken on 17 March 2014. The results are detailed in the relevant sections below.

3.1 (a) World Heritage Properties

Description

Not applicable – a search of the DotE PMST has not identified World Heritage Properties in the vicinity of the Project area.

Nature and extent of likely impact

N/A

3.1 (b) National Heritage Places

Description

One National Heritage Property is identified approximately 9 kilometres from the Project area, the Narrabri Post Office and former Telegraph Office.

This does not fall within the Project area, and the Project will not impact on the Narrabri Post Office and former Telegraph Office

Nature and extent of likely impact

N/A

3.1 (c) Wetlands of International Importance (declared Ramsar wetlands)

Description

Not applicable – a search of the DotE PMST has not identified Wetlands of International Importance in the vicinity of the Project area.

Nature and extent of likely impact

N/A

3.1 (d) Listed threatened species and ecological communities

Description
The Project has the potential to impact on a number of listed species and ecological communities. The DotE PMST identified eight listed Threatened Ecological Communities (TECs) and 31 listed threatened species as having the potential to occur in the Project area.

A full listing of these species is provided below. Note that additional species to those from the PMST are also included below. These species were identified from the Atlas of NSW Wildlife (OEH 2014a), review of relevant literature, vegetation mapping, flora and fauna survey results, and professional judgement.

Nature and extent of likely impact
A number of flora and fauna surveys have been carried out within the Project area since 2002, totalling more than 13,000 hours of survey effort. The majority of the approximately 98,000 hectare Project area has been covered by one or more of these surveys over this time. These assessments provide a detailed understanding of the biodiversity values of the Project area including the presence and distribution of MNES.

Presence of threatened species and ecological communities
The likelihood of presence or absence of species and ecological communities within the Project area has been assessed. The assessment considered results of field surveys, suitable habitat presence, geographic features of the Project area, searches of the PMST and Atlas of NSW Wildlife and professional judgement by qualified and experienced ecologists. The results are presented in the tables below.

Five terms for the likelihood of occurrence of species and communities are used and are defined as follows:

"Known"	=	the species has been observed within the Project area
"Likely"	=	a medium to high probability that a species uses the Project area
"Potential"	=	suitable habitat for a species occurs within the Project area, but there is insufficient information to categorise the species as likely to occur, or unlikely to occur
"Unlikely"	=	a very low to low probability that a species uses the Project area
"No"	=	habitat within the Project area and in the vicinity is unsuitable for the species

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species.

Nature and extent of likely impact
The Project will impact on threatened species, ecological communities and their potential habitats. The total extent to which impacts will be realised depends on a number of factors, which will be determined during the detailed impact assessment phase. Santos is committed to minimising impacts to MNES as much as practicable during the construction and operation of the Project and where complete avoidance is not possible, management and mitigation measures will be implemented.

The final areas of impact to threatened species, ecological communities and their potential habitats will be informed by a field development protocol. The protocol will be an iterative, constraints based, multicriteria environmental management tool. These will be weighted towards prioritising MNES (including habitat) and other key species for avoidance, and will also consider cultural heritage, land access and amenity. Additionally, field clearance procedures for well micro-siting will be undertaken during construction to ensure that facilities are appropriately located for minimal impact on MNES. The micro-siting procedure and field development protocol will be fully documented in the detailed impact assessment phase.

The total Project area encompasses approximately 98,000 hectares. However, the expected direct impact (i.e. native vegetation clearance) from all surface infrastructure is expected to be approximately one percent of the native vegetation in the Project area. For individual MNES, this figure will be determined during the detailed impact assessment phase. All species and communities have large areas of suitable habitat available within the Project area (detailed below), and only a small portion is likely to be impacted by the Project. Specifically, the loss of habitat will occur in discrete areas across the landscape for the well heads and linear corridors for the gas and water gathering systems which will follow existing tracks where possible. The majority of the clearing associated with well pads and the gas and water gathering systems will be rehabilitated on completion of construction.

Management, mitigation and offsetting
A range of management and mitigation measures will be implemented with the Project. In particular, the following will address impacts to a range of MNES:

- Preparation of a field development protocol which considers threatened species, ecological communities and their potential habitats and prioritising them for avoidance.
- Detailed sensitivity mapping to inform field development planning.
- Micro-siting of well pads.
- Pre-clearing survey to relocate fauna species and habitat features prior to clearing.
- Clearing within approved overall limits for specific ecological features.
- Measures to protect ecological values to be retained, such as exclusion fencing.
- Sediment and erosion controls, signage and site inductions.
- Rehabilitation of disturbed sites, including weed management.
- Minimising surface disturbance with the lateral well design.
- Co-locating gas and water gathering systems with existing roads, access tracks and disturbance corridors, where practicable.
- Construction of the gas and water gathering systems will use a ‘plough-in’ technique where possible as this reduces the width of the corridor required for construction, minimises disruption to topsoil, and minimises the need for traditional trenching and dewatering of open trenches.
- A weed and pest management plan will be developed and implemented.
- A water management plan will be developed and implemented.
- A bushfire hazard and risk assessment will be developed and implemented.

Following the application of reasonable measures to avoid and mitigate impacts to MNES, any residual significant impacts to the species/communities will be offset in a single consolidated biodiversity offset package developed in accordance with the NSW Biodiversity Offsets Policy for Major Projects.

Birds

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACTS?
Anthochaera phrygia	Regent Honeyeater	Endangered, Migratory	Potential	No
Botaurus poiciloptilus	Australasian Bittern	Endangered	Potential	No
Erythrotriorchis radiatus	Red Goshawk	Vulnerable	Unlikely	No
Geophaps scripta scripta	Squatter Pigeon	Vulnerable	Unlikely	No
Lathamus discolour	Swift Parrot	Endangered, Migratory	Potential	No
Leipoa ocellata	Malleefowl	Vulnerable, Migratory	Unlikely	No
Polytelis swainsonii	Superb Parrot	Vulnerable	Potential	No
Rostratula australis	Australian Painted Snipe	Vulnerable	Potential	No

***Anthochaera phrygia* (Regent Honeyeater) – Endangered**

Background – ecology and distribution
The Regent Honeyeater is listed as endangered and migratory under the EPBC Act. This species mainly inhabits temperate woodlands and open forests of the inland slopes of south-east Australia, particularly Box-Ironbark woodland, and riparian forests of River Sheoak. Birds are also found in drier coastal woodlands and forests in some years. The species is known to make large scale nomadic movements across the landscape, which is thought to coincide with flowering times of different eucalypt species on which they feed (DotE 2014a).

There are three known key breeding regions; one in north-east Victoria (Chiltern-Albury) and two in NSW at Capertee Valley and in the Bundarra-Barraba region. In NSW, the distribution is very patchy and mainly confined to the two main breeding areas and surrounding fragmented woodlands, although other known breeding sites, closer to Project area, include the Warrumbungle National Park and Pilliga Nature Reserve (NPWS 1999a).

In 2011, the entire Regent Honeyeater population was estimated to be approximately 350 – 400 individuals; however, given the highly mobile nature of the species accurate estimates are difficult with previous estimates of population size fluctuating between 10 – 2000 (DotE 2014a).

This species is at threat mainly from the loss, fragmentation and degradation of its habitat. The causes for this habitat decline are agricultural clearing, increased dieback and tree decline in agricultural and pastoral areas, grazing by livestock and rabbits, which prevents native vegetation from regenerating, silvicultural practices that promote dense regrowth of immature trees via the removal of large spreading trees from box-ironbark woodlands, and the removal of ironbark trees for fence posts, firewood and timber supplies (DotE, 2014a).

Regent Honeyeater within the Project area
Regent Honeyeaters have been recorded sporadically in the Pilliga. OEH records have been from four years since 1991 (1991, 1992, 1997 and 2003) (OEH 2013b). The presence of Regent Honeyeaters in the Pilliga may be linked to fluctuations in eucalypt flowering within the region including *Eucalyptus albens* (White Box). Minor and sporadic breeding occurs in Warrumbungle National Park, the Pilliga and Mudgee-Wollar region.

There are no existing records for the species within the Project area and the species has not been identified to date during field surveys. The species has been recorded nearby with two records in the Pilliga Nature Reserve, and one in Pilliga East State Forest. Breeding behaviour has been observed in the Pilliga Nature Reserve; however the important Bundarra-Barraba breeding area is located 150 kilometres to the east.

As part of the ongoing detailed impact assessment phase of the Project, Eco Logical Australia (ELA) mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated that there is approximately 67,291 hectares of potential foraging habitat for the Regent Honeyeater in the Project area.

The Project area contains habitat that the species may utilise on occasion, but is unlikely to rely upon for its survival. Whilst the species has the potential to occur, it is does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation
The Regent Honeyeater has the potential to be impacted both directly and indirectly by the project. However, it is unlikely that the Project would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging habitat, the total extent of which will be determined during the detailed impact assessment phase. Vegetation types likely to be impacted by the Project constitute only transient foraging habitat rather than a significant foraging resource for the Regent Honeyeater (i.e. does not contain profusely flowering winter-blooming species). There is no known breeding habitat within the Project area.

Vegetation clearance will also result in habitat fragmentation. However, the Regent Honeyeater is a highly mobile species with a large home range, and the scale of disturbance from the Project is unlikely to cause fragmentation of this species' habitat within the Pilliga region.

Vegetation clearance will result in the removal of key tree species, which may provide foraging resources for the Regent Honeyeater. This, coupled with increased disturbance, may result in the proliferation of aggressive honeyeater species and increase competition for foraging resources. Given the wide extent of available habitat within the Project area, and its' likely use more as a transient rather than core resource, increased competition within the disturbed sections of the Project area is unlikely to have a significant impact on the Regent Honeyeater.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Regent Honeyeater are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
Occurrence records and analysis of available habitat do not indicate there is an important population or habitat critical to the survival of the Regent Honeyeater within the Project area. Whilst the Project may have direct and indirect impacts on the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Botaurus poiciloptilus* (Australasian Bittern) – Endangered**

Background – ecology and distribution
The Australasian Bittern listed as endangered under the EPBC Act. It is a stocky stork-like bird which uses its mottled colouring as camouflage in swampy vegetation. The Australasian Bittern is distributed from south-eastern Queensland through to south-eastern South Australia, Tasmania and Western Australia (DotE, 2014b). In NSW, the species occurs mainly along the coast regions and

throughout the Murray-Darling Basin in flooded wetland vegetation. The species is highly dependent on inundated wetlands and plains where it builds nests in large emergent macrophytes such as *Phragmites australis*, *Baumea* spp., and *Typha* spp. The Australasian Bittern is an active hunter which targets fish, beetles, snakes, frogs as well as leaves and fruit. The species has been known to construct feeding platforms out of reeds in permanent swamps, which are often littered with the remains of prey (OEH, 2014).

The Australasian Bittern is also known to occur in New Zealand and a number of islands in the Pacific including New Caledonia. It is thought that between 25 and 50 per cent of the population (approximately 2500-3000 individuals) of the species resides in Australia (DotE, 2014b).

This species is at threat from loss and degradation of habitat through in-filling or clearance of wetlands and associated vegetation, river regulation, heavy grazing and urbanisation (DotE, 2014b).

Australasian Bittern within the Project area

The Atlas of NSW Wildlife contains records of the Australasian Bittern within 10 km of the Project area. The species has not been recorded in the Project area, however the Project area contains some limited foraging resources for the species around some farm dams with emergent macrophytes present.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 100 hectares of potential foraging habitat for the Australasian Bittern in the Project area.

The Project area contains habitat that the species may utilise on occasion. Whilst the species has the potential to occur, it does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation

The Australasian Bittern has the potential to be impacted both directly and indirectly by the Project. However, it is unlikely that these would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging habitat, the total extent of which will be determined during the detailed impact assessment phase. The Project area does not contain considerable areas of permanent water or large macrophyte beds. As such the Project area is considered to contain only minimal transient foraging habitat and not a significant foraging or breeding resource for the Australasian Bittern.

Alterations to the hydrological regime of the Project area also have the potential to impact wetland habitats of the Australia Bittern. A detailed impact assessment of water resources is currently being prepared as part of the detailed impact assessment phase of the Project, and this will determine impacts to hydrological regimes and flow on effects to wetland-dependent species such as the Australasian Bittern. Nevertheless, the Project area contains only minimal transient foraging habitat for this species.

Habitats for this species are located outside of the main body of the Pilliga and are not likely to be fragmented by the Project.

As the species is a wetland dweller it may be at risk from increased predation from pest species which gain new or increased access to the area as a result of the Project. These risks will be managed through a pest management protocol to be developed and implemented by Santos.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Australasian Bittern are detailed in Section 4. These include the development and implementation of management plans for surface, groundwater and pest management measures.

Summary
Occurrence records and analysis of available habitat do not indicate there is an important population or habitat critical to the survival of the Australian Bittern within the Project area. Whilst the Project may have direct and indirect impacts to the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Lathamus discolour* (Swift Parrot) – Endangered**

Background – ecology and distribution
The Swift Parrot is listed as endangered and migratory under the EPBC Act. It is a wide-ranging, highly mobile species which is endemic to south-eastern Australia (DotE 2014c). Swift Parrots breed in Tasmania during spring and summer (Sept to Jan), then migrate to Victoria, the eastern parts of South Australia and up to south-east Queensland in the autumn and winter months. In NSW this species mostly occurs on the coast and south west slopes. It is known to use habitat within the Namoi Catchment Management Area (OEH 2013b).

On the mainland, birds occur in areas where eucalypts are flowering profusely or where there is abundant lerp (from sap-sucking bugs) infestations (OEH 2013b). Favoured feed trees include winter flowering species such as *Eucalyptus robusta* (Swamp Mahogany), *Corymbia maculata* (Spotted Gum), *C. gummifera* (Red Bloodwood), *E. sideroxylon* (Mugga Ironbark), and *E. albens* (White Box). Commonly used lerp infested trees include *E. microcarpa* (Inland Grey Box), *E. moluccana* (Grey Box) and *E. pilularis* (Blackbutt).

Breeding season survey data suggest that the population is at best stable (DotE 2014c). The most recent estimates of the Swift Parrot suggest that less than 1,000 pairs remain (DPIPWE 2010).

Current threats to the Swift Parrot include clearing and fragmentation of wintering and breeding habitats (i.e. Tasmania) decline of nest site availability, competition from other species and death from collision (Garnett and Crowley 2000).

Swift Parrot within the Project area
There are no existing records for the Swift Parrot within the Project area and the species has not identified during field surveys. The closest records from the Atlas of NSW Wildlife (2014) are approximately 24 kilometres to the east in Boggabri and 55 kilometres to the south east near Gunnedah.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 47,236 hectares of potential foraging habitat for the Swift Parrot in the Project area.

The Project area contains foraging habitat that the species may utilise on occasion. Whilst the species has the potential to occur, it is does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation
The Swift Parrot has the potential to be impacted both directly and indirectly by the Project. However, it is unlikely that these would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging habitat, the total extent of which will be determined during the detailed impact assessment phase. Vegetation types likely to be impacted by the Project constitute only transient foraging habitat rather than a significant foraging resource for the

Swift Parrot (i.e. does not contain profusely flowering winter-blooming species). This species breeds exclusively in Tasmania.

Vegetation clearance will also result in habitat fragmentation. However, the Swift Parrot is a highly mobile species with a large home range, and the scale of disturbance from the Project is unlikely to cause fragmentation of this species' habitat within the Pilliga region.

Vegetation clearance will result in the removal of key tree species, which provide foraging resources for the Swift Parrot. This, coupled with increased disturbance, may result in the proliferation of aggressive honeyeater species and increase competition for foraging resources. Given the wide extent of available habitat within the Project area, and its' likely use as a transient rather than core resource, increased competition within the disturbed sections of the Project area is unlikely to have a significant impact on the Swift Parrot.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Swift Parrot are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
Occurrence records and analysis of available habitat do not indicate there is an important population or habitat critical to the survival of the Swift Parrot within the Project area. Whilst the Project may have direct and indirect impacts to the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Polytelis swainsonii (Superb Parrot) – Vulnerable

Background – ecology and distribution
The Superb Parrot is listed as vulnerable under the EPBC Act. This species is found throughout eastern inland NSW and northern Victoria, with occasional vagrants recorded in southern Queensland (DotE 2013e). In the South Western Slopes of NSW their core breeding area is roughly bounded by Cowra and Yass in the east, and Grenfell, Cootamundra and Coolac in the west. Birds breeding in this region are mainly absent during winter, when they migrate north to the region of the upper Namoi and Gwydir Rivers. The other main breeding sites in NSW and Victoria are in the Riverina along the corridors of the Murray, Edward and Murrumbidgee Rivers where birds are present all year round.

The species inhabits Box-Gum, Box-Cypress-pine and Boree Woodlands and River Red Gum Forest. In the Riverina the birds nest in the hollows of large trees (dead or alive) mainly in tall riparian *Eucalyptus camaldulensis* (River Red Gum) Forest or Woodland. On the South West Slopes nest trees can be in open Box-Gum Woodland or isolated paddock trees. Species known to be used are *E. blakelyi* (Blakely's Red Gum), *E. melliodora* (Yellow Box), *E. bridgesiana* (Apple Box) and *E. polyanthemos* (Red Box). During the breeding season, individuals may forage up to 10 kilometres from nesting sites, primarily in grassy box woodland. The species feed in trees and understorey shrubs and on the ground and their diet consists mainly of grass seeds and herbaceous plants. Also eaten are fruits, berries, nectar, buds, flowers, insects and grain (OEH 2013b).

This species is most at threat from habitat clearing and degradation (DotE 2013e). Additional threats include grazing by stock reducing the amount of food available to Superb Parrots, the exploitation of water in watercourses throughout the range of the species directly affecting the health of both the breeding and foraging habitats, competition for nest sites, poisoning from insecticides, and other threats including trapping, vehicle strike, and beak and feather disease. The main biological characteristic of the Superb Parrot which threatens its survival is its special requirement for specific breeding habitat (River Red Gum forests) and specific foraging habitat (box woodland) to be located no more than 10 km from each other.

Superb Parrot within the Project area
There are no existing records for the species within the Project area and the species has not been identified during field surveys. The closest records from the Atlas of NSW Wildlife are approximately 20 kilometres to the north of the Project area and east of Narrabri.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 35,647 hectares of potential foraging habitat for the Superb Parrot in the Project area.

The Project area contains habitat that the species may utilise on occasion. Whilst the species has the potential to occur, it does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation
The Superb Parrot has the potential to be impacted both directly and indirectly by the Project. However, it is unlikely that these would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging habitat, the total extent of which will be determined during the detailed impact assessment phase. The species has access to a wide range of foraging resources across the Project area of which only a very small proportion will be affected by the Project. There is no known breeding habitat within the Project area.

Vegetation clearance will also result in habitat fragmentation. However, the Superb Parrot is a highly mobile species with a large home range, and the scale of disturbance from the Project is unlikely to cause fragmentation of this species' habitat within the Pilliga region.

Vegetation clearance will result in the removal of key tree species, which provide potential foraging resources for the Superb Parrot. This, coupled with increased disturbance, may result in the proliferation of aggressive honeyeater species and increase competition for foraging resources. Given the wide extent of available habitat and foraging resources within the Project area, increased competition within the disturbed sections of the Project area is unlikely to have a significant impact on the Superb Parrot.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Superb Parrot are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
Occurrence records and analysis of available habitat do not indicate there is an important population or habitat critical to the survival of the Superb Parrot within the Project area. Whilst the Project may have direct and indirect impacts to the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Rostratula australis* (Australian Painted Snipe) – Endangered**

Background – ecology and distribution
The Australian Painted Snipe is listed as endangered under the EPBC Act. It is a stocky wading bird around 220-250 mm in length with a long pinkish bill. This species is generally seen singly or in pairs, or less often in small flocks (DotE 2014n). Flocking occurs during the breeding season, when adults sometimes form loose gatherings around a group of nests. Flocks can also form after the breeding season, and at some locations small groups regularly occur. Groups comprising of a male and up to six offspring have been observed.

The species generally inhabits shallow terrestrial freshwater (occasionally brackish) wetlands, including temporary and permanent lakes, swamps and claypans (DotE 2014n). They also use inundated or waterlogged grassland or saltmarsh, dams, rice crops, sewage farms and bore drains. Typical sites include those with rank emergent tussocks of grass, sedges, rushes or reeds, or samphire; often with scattered clumps of *Muehlenbeckia* sp. (Lignum) or canegrass or sometimes *Melaleuca* spp. (Tea-tree). The Australian Painted Snipe sometimes utilises areas that are lined with trees, or that have some scattered fallen or washed-up timber (Marchant & Higgins 1993).

The Australian Painted Snipe has been recorded in all states of Australia. It is most common in eastern Australia, where it has been recorded at scattered locations throughout much of Queensland, NSW, Victoria and south-eastern South Australia. It has been recorded less frequently at a smaller number of more scattered locations farther west in South Australia, the Northern Territory and Western Australia (DotE 2014n).

The total population size of the Australian Painted Snipe is effectively unknown, but tentative estimates range from a few hundred individuals to 5000 breeding adults (DotE 2014n). The reporting rate of the Australian Painted Snipe in eastern Australia has decreased by more than 90% since the 1950s, despite an increase in the number of observers and surveys, and awareness among observers that records of the snipe should be reported.

The primary factor in the decline of the Australian Painted Snipe has probably been a loss and alteration of wetland habitat. Predation by feral animals (cats and foxes) is also a potential threat.

Australian Painted Snipe within the Project area

There are no existing records for the species within the Project area and the species has not been identified during field surveys. The Atlas of NSW Wildlife contains two records of the Australian Painted Snipe, from 1992 and 2007, within 10 km of the Project area.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 100 hectares of potential breeding and foraging habitat for the Australian Painted Snipe throughout the Project area:

The Project area contains habitat that the species may utilise on occasion. Whilst the species has the potential to occur, it is does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation

The Australian Painted Snipe has the potential to be impacted both directly and indirectly by the Project. However, it is unlikely that these would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging and breeding habitat, the total extent of which will be determined during the detailed impact assessment phase. The Project area does not contain considerable areas of permanent water or wetlands. As such the Project area is considered to contain only minimal transient foraging habitat and is unlikely to provide a significant foraging or breeding resource for the Australian Painted Snipe.

Alterations to the hydrological regime of the Project area also have the potential to impact wetland habitats of the Australian Painted Snipe. A detailed impact assessment of water resources is currently being prepared as part of the detailed impact assessment phase of the Project, and this will determine impacts to hydrological regimes and flow on effects to wetland-dependent species such as the Australian Painted Snipe. Nevertheless, the Project area contains only minimal areas of foraging and breeding habitat for this species.

As the species is a wetland dweller it may be at risk from increased predation from pest species which gain new or increased access to the area as a result of the Project. These risks will be managed through a pest management protocol to be developed and implemented by Santos.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Australian Painted Snipe are detailed in Section 4. These include the development and implementation of management plans for surface- groundwater and pest management measures.

Summary
Occurrence records and analysis of available habitat do not indicate there is an important population or habitat critical to the survival of the Australian Painted Snipe within the Project area. Whilst the Project may have direct and indirect impacts to the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Mammals

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Dasyurus maculatus	Spotted-tailed Quoll	Endangered	Potential	Potential
Nyctophilus corbeni (formerly N. timoriensis)	South-eastern/Greater Long-eared Bat	Vulnerable	Known	Potential
Chalinolobus dwyeri	Large-eared Pied Bat	Vulnerable	Potential	No
Petrogale penicillata	Brush-tailed Rock-wallaby	Vulnerable	Unlikely	No
Phascolarctos cinereus	Koala	Vulnerable	Likely	Potential
Pseudomys pilligaensis	Pilliga Mouse	Vulnerable	Known	Potential
Pteropus poliocephalus	Grey-headed Flying-fox	Vulnerable	Unlikely	No

Dasyurus maculatus maculatus **[south-eastern mainland population] (Spotted-tailed Quoll) – Endangered**

Background – ecology and distribution
The Spotted-tailed or Tiger Quoll (south-eastern mainland population) is listed as endangered under the EPBC Act. It occupies a range of environments within a disjunct distribution along the east coast of Australia, extending from south-eastern Queensland through NSW and Victoria to Tasmania. The species is found in a variety of habitats, including sclerophyll forest and woodlands, coastal heathlands and rainforests. Occasional sightings are made in open country, grazing lands, rocky outcrops and other treeless areas (DotE 2013f).

The Spotted-tailed Quoll is essentially terrestrial, but is also an agile climber (OEH 2014b). Nesting occurs in rock shelters, hollow logs, caves or tree hollows and they use numerous dens within the home range. Estimates of home ranges vary from 800 hectares to 20 square kilometres and individuals may move several kilometres in a night (NPWS 1999b). One individual was tracked travelling eight kilometres in one night (Belcher et al. 2008). This species feeds on a wide variety of birds, reptiles, mammals and invertebrates and uses several 'latrines' within its territory for defecation (OEH 2014b).

The total population size of the Spotted-tailed Quoll is considered low. Expert estimates of the total population size vary, though it is likely that the total number of mature adults is greater than 2,000 and less than 10,000 (DotE 2013f).

Current threats to the Spotted-tailed Quoll include habitat loss and degradation, predation from red foxes, dingos, and domestic dogs, fire, direct killing from landholders, vehicle strike, poisoning from cane toads, and 1080 baiting from pest-control programs.

Spotted-tailed Quoll within the Project area

The Spotted-tailed Quoll occurs more frequently in coastal areas however there are scattered records west of the Project area along the Barwon River. It has been recorded in the Pilliga in the 1990s (Paull and Date 1999).

There are no existing records for the species within the Project area and the species has not been identified during field surveys. The closest records from the Atlas of NSW Wildlife are approximately 25 kilometres to the south east and 45 kilometres to the north east of the Project area.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 69,631 hectares of potential breeding habitat and an additional 10,988 of potential foraging habitat for the Spotted-tailed Quoll throughout the Project area.

The Project area contains potential habitat for the Spotted-tailed Quoll and the proximity of existing records relative to the large extent of this species' home range, suggests the species has the potential to occur within the Project area. Spotted-tailed Quoll within the Pilliga region may be considered an important population.

Potential impacts and mitigation

The Spotted-tailed Quoll has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance will result in the removal of potential foraging and breeding habitat, the total extent of which will be determined during the detailed impact assessment phase.

Vegetation clearance will also result in habitat fragmentation. However, the Spotted-tailed Quoll is a highly mobile species with a large home range, and the scale of disturbance from the Project is unlikely to cause fragmentation of this species' habitat within the Pilliga region. Importantly, this species has been observed in cleared landscapes and is able to cross fragmented areas between vegetation remnants.

The Spotted-tailed Quoll may be directly impacted by increased mortality due to:

- Vehicle strike, as construction and operation increase activity within the Project area.
- Predation from pest species such as dogs, foxes and cats, which may increase in number and gain greater access to the Project area.
- Poisoning by baits (e.g. 1080) used in pest animal management programs.

These impacts will be minimised through appropriate control measures such as considering the potential presence of this species in pest animal management planning. Pest species may also impact the Spotted-tailed Quoll indirectly through competition. This issue will be addressed via the development and implementation of a pest management plan.

Disruption to den sites and breeding habitat may also occur during construction and operations if these features are located near to infrastructure. Micro-siting, preclearance surveys and construction/operation controls will reduce the risk of such impacts.

The Project is unlikely to increase other key threats to the Spotted-tailed Quoll such as direct killing from landholders and poisoning from cane toads.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Spotted-tailed Quoll are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
Occurrence records and analysis of available habitat indicate there is potential foraging and breeding habitat for the Spotted-tailed Quoll within the Project area. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Nyctophilus corbeni* (South-eastern Long-eared Bat) – Vulnerable**

Background – ecology and distribution
The South-eastern Long-eared Bat is listed as vulnerable under the EPBC Act. Overall, this species' distribution coincides approximately with the Murray Darling Basin (DotE 2013g). It is common in the Pilliga region (OEH 2013b). Within these regions, the species inhabits a variety of vegetation types, including mallee, *Allocasuarina luehmannii* (Bull-oak) and box-eucalypt dominated communities. It is more common in box/ironbark/cypress-pine vegetation that occurs in a north-south belt along the western slopes and plains of NSW and southern Queensland (OEH 2013b).

The species roosts in tree hollows, crevices, and under loose bark. It is a slow flying agile bat, using the understorey to hunt non-flying prey, especially caterpillars and beetles, and will even hunt on the ground. Movement patterns are not well known, although roost sites have been recorded as an average of 1.89 ± 1.61 kilometres (range 0.34–7.06 kilometres) from the capture point of bats (Schulz and Lumsden 2010). It appears the species requires large, intact areas of habitat to persist (Turbill et al. 2008).

There is no data on the population size for this species. The South-eastern Long-eared Bat is rare throughout most of its distribution.

Threats to this species include habitat loss and fragmentation, fire, forestry activities removing hollow bearing trees, tree hollow competition, overgrazing, predation by feral species, exposure to agrichemicals, and climate change.

South-eastern Long-eared Bat within the Project area
The South-eastern Long-eared Bat has its core distribution centred on the Pilliga region and NSW OEH considers the Pilliga region to be a distinct stronghold for this species (OEH 2014b).

This species has been previously recorded in the Project area (Milledge 2012) and as part of the ecological studies for the detailed impact assessment phase of the Project.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 69,631 hectares of potential breeding and foraging habitat for the South-eastern Long-eared Bat throughout the Project area.

The South-eastern Long-eared Bat is known to occur throughout the Pilliga region, which is considered a stronghold for this species. Therefore the South-eastern Long-eared Bat within the Project area is an important population.

Potential impacts and mitigation
The South-eastern Long-eared Bat has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance will result in the removal of potential foraging and breeding habitat, the total extent of which will be determined during the detailed impact assessment phase.

As the species is thought to require large areas of intact habitat to persist, fragmentation due to the Project may also negatively impact the species. This species has been recorded traveling up to three kilometres in a foraging excursion (Churchill 2008), and therefore co-locating infrastructure with existing access roads, tracks or other existing linear features, siting infrastructure within currently disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction will assist in reducing impacts from fragmentation.

Disruption to foraging and roosting sites and breeding habitat may also occur during construction and operation if these features are located near infrastructure. Noise at dusk and dawn and night-time lighting are specific issues. Micro-siting, preclearance surveys and construction/operation controls will reduce the risk of such impacts.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the South-eastern Long-eared Bat are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
The Project area contains an important population of the South-eastern Long-eared Bat. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Chalinolobus dwyeri* (Large-eared Pied Bat) – Vulnerable**

Background – ecology and distribution
The Large-eared Pied Bat is listed as vulnerable under the EPBC Act. It is an insectivorous bat distributed from Shoalwater Bay in Queensland through to Ulladulla in NSW. Important populations for this species occur in the Hunter Valley, Sydney Basin and Southern Tablelands of NSW. There are scattered records from the New England Tablelands and North West Slopes.

The species is manoeuvrable and forages below the canopy (OEH 2013b; DotE 2014h). The preferred breeding habitat for the Large-eared Pied Bat is caves (near their entrances), crevices in cliffs, old mine workings and in the disused, bottle-shaped mud nests of the *Hirundo ariel* (Fairy Martin). The species has been known to use hollow-bearing trees as roost sites (DotE 2014h). Females have been recorded raising young in maternity roosts (c. 20-40 females) from November through to January in roof domes in sandstone caves. They remain loyal to the same cave over many years (OEH 2013b). Breeding females have recently been recorded in sandstone caves at Coonabarabran, NSW (DotE 2014h).

This species tends to occur in small populations of around 50 individuals, particularly around sandstone escarpments and cliff lines. There is insufficient data to estimate population of the Large-eared Pied Bat, though it appears to exist in a number of small populations throughout its range (DotE 2014h).

The only confirmed threat to the Large-eared Pied Bat is disturbance and damage to primary nursery sites by flooding and animals (such as humans and goats). Potential threats to this species include clearing or timber harvesting in or around roosts, loss of foraging habitat, predation by foxes, habitat destruction by agricultural and urban development, drought, and forestry operations (DotE 2014h).

Large-eared Pied Bat within the Project area
Previous surveys have detected the Large-eared Pied Bat near the Project area in East Pilliga State Forest (NPWS 2000a; NPA 2002).

There are no existing records for the species within the Project area and the species was not identified during field surveys. The closest records from the Atlas of NSW Wildlife are approximately 10 kilometres to the south in Pilliga Nature Reserve and 25 kilometres to the north east near Mt Kaputar National Park.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 67,291 hectares of potential foraging habitat for the Large-eared Pied Bat throughout the Project area.

The Project area contains habitat that the species may utilise on occasion for foraging, however no core breeding habitat (caves) are present. Whilst the species has the potential to occur, it is does not have an important population or habitat critical to the survival of the species within the Project area.

Potential impacts and mitigation
The Large-eared Pied Bat has the potential to be impacted both directly and indirectly by the Project. However, it is unlikely that these would constitute a significant impact as defined under the EPBC Act.

Vegetation clearance will result in the removal of foraging habitat, the total extent of which will be determined during the detailed impact assessment phase. It is an insectivorous species, with access to foraging resources across the entire Project area. Core breeding habitat (caves) will not be impacted by the Project.

Vegetation clearance will also result in habitat fragmentation. However, the Large-eared Pied Bat is a mobile species that tends to occur around sandstone escarpments and cliff lines. Neither these types of habitats nor breeding sites will be impacted by the Project.

Disruption to foraging habitat may occur during construction and operation if these features are located near to infrastructure. Noise at dusk and dawn and night-time lighting are specific issues. Micro-siting, preclearance surveys and construction/operation controls will reduce the risk of such impacts.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Large-eared Pied Bat are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
Occurrence records and analysis of available habitat does not indicate there is an important population or habitat critical to the survival of the Large-eared Pied Bat within the Project area. Whilst the Project may have direct and indirect impacts to the species, these are unlikely to be significant. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Phascolarctos cinereus **(Koala) (combined populations of QLD, NSW and ACT) – Vulnerable**

Background – ecology and distribution
The Koala (combined populations of QLD, NSW and ACT) is listed as vulnerable under the EPBC Act. This species is associated with a wide range of temperate, tropical and sub-tropical forests as well as semi-arid communities. Koalas feed almost exclusively on leaves of Eucalypt species, although they have been known to forage on other genera as well (DotE 2014i).

The Koala has a fragmented distribution throughout eastern Australia from north-east Queensland to the Eyre Peninsula in South Australia. In NSW, the Koala mainly occurs on the central and north coasts with some populations to the west of the Great Dividing Range including the Liverpool Plains and the Pilliga. The Koala was briefly historically abundant in the 1890s in the Bega District on the south coast of NSW, although not elsewhere, but it now occurs in sparse and possible disjunct populations. Koalas are also known from several sites on the southern tablelands (OEH 2013). Distribution and population size has varied, with population size believed to have sharply dropped between 1930 and 1980 due to hunting, predation by the European Fox, widespread ringbarking of eucalypts and wildfire.

Koalas have large overlapping home ranges with larger home ranges present in areas of poorer quality habitat (recorded up to 135 hectares in central Queensland) (DotE 2014i).

A decline in the total population of the listed Koala population has been demonstrated across its range over the 1990-2010 period. Overall the population size of the Koala was estimated in 2010 to be 188,000 (DotE 2014i).

The main threats to the Koala are ongoing habitat loss and habitat fragmentation, vehicle strike and predation by domestic or feral dogs, drought and incidences of extreme heat and disease (DotE 2014i).

Koala within the Pilliga and the Project area
At over 500,000 hectares, the Pilliga includes a diverse range of vegetation communities and associated fauna habitats across a range of soil fertilities, which are generally lower in the east and higher in the west. The north-east Pilliga (including the Project area) has been surveyed for Koalas at various times, including during periods when the Koala populations in the Pilliga were considered to have been at historical peaks. Very few koalas have ever been found in the north-east Pilliga. The vast majority of Koala records are in the central and western Pilliga, areas supported by more productive soils, fewer fires, and greater access to permanent water along major drainage lines. Conversely, the north-east Pilliga has been more frequently burnt by wildfires, has less productive soils and only one major creek system which supports few areas of permanent water.

The combination of low soil fertility, associated nutrient-poor vegetation, frequent wildfires and fewer major watercourses with permanent water are considered likely to be the key reasons why Koala populations have always been low in the Project area.

There is ongoing uncertainty about the overall Koala population size in the Pilliga. The species was thought common during the 1800s, with declines during the 1900s due to habitat degradation and hunting. More recently the population was estimated at 15,000, however this estimate is also now more than 10 years old and the Pilliga has been subject to severe drought during that period (DotE 2014i). Despite this uncertainty, it is considered that the population present is significant and DotE (2014i) recognises the Pilliga as containing an important population of Koalas.

Targeted Koala surveys across the Pilliga, led by Dr Rod Kavanagh (a recognised Koala expert), were completed over two weeks in May 2014. The objective of these surveys was to identify and locate important refuges for the Koala in the context of a general and widespread decline in the abundance of Koala throughout the region. Targeted Koala searches were conducted in 'favourable' Koala habitat, as determined by suitable vegetation types and a desktop assessment. 'Favourable' Koala habitat was generally reflective of major drainage lines in the Pilliga and typically consisted of areas containing dominance, or near dominance of the red gums *Eucalyptus blakelyi*, *E. camaldulensis* or *E. chloroclada* (Dirty Gum) and/or near persistent waterholes. A total of 10 individual Koalas were recorded throughout the surveys. Nine individuals were observed in red gum species and one individual was observed sheltering in *Callitris glaucophylla* (White Cypress Pine) within a drainage line. Koala's were only observed within habitat along Etoo Creek and Baradine Creek in the central and west Pilliga areas. Despite targeted searches, no Koalas were observed within the Project area within the Pilliga.

As part of the ongoing detailed impact assessment phase of the Project, ELA mapped all vegetation within the Project area, categorised it by fauna habitat type and then allocated breeding, foraging or other habitat types based on the likely presence or use of the habitat by the species. This analysis indicated there is approximately 23,005 hectares of potential breeding and foraging habitat for the Koala throughout the Project area.

There is only one primary feed tree (as defined in the Approved Koala recovery plan (DECC 2008) and State Environmental Planning Policy 44 (SEPP 44)) in the Project area, namely *Eucalyptus camaldulensis* (River Red Gum) and this species has a very narrow distribution centred around Yarrie Lake in the north-west of the Project area (outside of the Pilliga). While secondary feed trees such as *Eucalyptus chloroclada, E. conica* (Fuzzy Box), *E. blakelyi, E. dwyeri* (Dwyer's Red Gum), *E. pilligaensis* (Pilliga Box) and *E. populnea* (Poplar Box) do occur in the Project area (within the Pilliga), they are generally restricted to discrete areas along drainage lines or occur as minor components to vegetation communities.

E. chloroclada, *E. blakelyi* and *E. conica* are largely confined to drainage lines on sandy soils, *E. dwyeri* occurs in heath on shallow sandstone, while *E. pilligaensis* and *E. populnea* occur in the north of the Project area largely outside of the Pilliga on finer textured sandy loam. *Callitris glaucophylla* is common in the north-east Pilliga and is used for daytime shelter and feeding (DotE 2014i). Other secondary food trees may also be present.

Criteria for habitat critical to the survival of the Koala are set out in Section 7 of the Draft EPBC Act referral guidelines (DotE 2013i). According to these criteria, the Project area is defined as containing habitat critical to the survival of the Koala due to:

- Records of one or more koala within 5 km of the edge of the Project area within the last 10 years.
- The Project area has forest, woodland or shrubland with emerging trees with 2 or more known koala food tree species in the canopy.
- The Project area is part of a contiguous landscape >1000 hectares.
- Evidence of infrequent or irregular koala mortality from vehicle strike or dog attack at present in areas that score 1 or 2 for koala occurrence.

While the Project area may contain habitat critical to the survival of the Koala as defined in the Draft EPBC Act referral guidelines (DotE 2013i), the paucity of historical records, lack of direct evidence from intensive surveys of the Project area over the past 5 years (including the May 2014 targeted survey) indicates that relatively few Koalas ever utilise the available habitat in the Project area. As such, while the broader central and western Pilliga are known to contain remnant populations, the north-east Pilliga is now considered unlikely to support an important population of this species.

Similar patterns of habitat usage have been found elsewhere, including regional areas on the NSW coast, where some areas of habitat are not utilised while others are occupied by Koalas at relatively high densities (Biolink 2013). It is unlikely that the north-east Pilliga has ever made a substantial contribution to the overall Pilliga Koala population.

Potential impacts and mitigation

The Koala has the potential to be impacted both directly and indirectly by the Project. Despite the occurrence of 'habitat critical to the survival of the Koala' in the Project area as defined in Draft EPBC Act referral guidelines (DotE 2013i), the low proportion of total vegetation clearing (one percent of the native vegetation in the Project area) is considered unlikely to significantly impact on the Pilliga Koala population due to the lack of Koala occurrence and habitat utilisation in the Project area.

According to the most recent Draft EPBC Act referral guidelines from DotE (2013i), the following are the key considerations for determining the significance of impacts to Koala:

- The action could adversely affect habitat critical to the survival of the Koala; and/or
- The action could interfere substantially with the recovery of the Koala through the introduction or exacerbation of key threats in areas of habitat critical to the survival of the Koala. These key threats include:
  - Mortality from vehicle-strikes and dog attack.
  - Barriers to movement.
  - Introduction or spread of disease or pathogens.
  - Increasing the risk of high-intensity fire.
  - Degradation of habitat from hydrological change.

The Project has the potential to exacerbate key threats, as listed above. Vegetation clearance will result in the removal of potential Koala habitat, the total extent of which will be determined during the detailed impact assessment phase.

There is the potential for increased mortality of Koalas due to vehicle strike, as construction and operation increase activity within the Project area and predation from dogs (and other pest species), which may increase in number and gain greater access to the Project area, however due to the lack of Koala occurrence these impacts are considered to be low. These issues will be addressed through construction/operational controls (e.g. preclearance surveys) and the development and implementation of a pest management plan.

Vegetation clearance will also result in habitat fragmentation. However, the Koala is a mobile species with a large home range, and the scale of disturbance from the Project is unlikely to cause fragmentation of this species' habitat within the Pilliga region. Where possible, infrastructure will be co-located with existing access roads, tracks or other existing linear features, or within currently disturbed areas (where possible), and temporarily impacted areas will be rehabilitated following construction. Furthermore, canopy species occurring on the edges of infrastructure locations will be retained where possible, allowing overhanging canopy to remain.

Increased traffic within the Project area has the potential to spread weeds and pathogens, however weed and disease hygiene measures will be developed and implemented as a component of the construction and operational controls for the Project.

Loss of Koala habitat and death of individuals due to high intensity fire has the potential to be exacerbated due to the Project. A bushfire hazard and risk assessment is currently being prepared by Santos which will identify the measures to reduce the risk of fire.

Alterations to the hydrological regime of the Project area are expected to be minor. A detailed impact assessment of water resources is currently being prepared as part of the detailed impact assessment phase of the Project, and this will determine impacts to hydrological regimes and flow on effects to species such as the Koala.

Factors that are likely to reduce the severity of impacts to the Koala:

- No Koalas have been observed in the Project area in the last five years, despite targeted searches.
- Habitat that will be impacted is not considered to be of particularly notable quality as there are few areas with primary feed trees and secondary feed trees generally only occur in discrete areas.

- The Project is located in the north-east of the Pilliga, where the lowest numbers of koalas have been historically known to occur, compared with much higher koala densities in the central, southern and western extent of the Pilliga region.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Koala are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible), rehabilitation of temporarily impacted areas following construction the development and implementation of pest management measures.

Santos is also proposing broad-scale recovery actions in the central and western Pilliga including nil-tenure feral animal control and further targeted surveys to determine habitat utilisation.

Summary
The Project area contains habitat critical to the survival of the Koala, however no Koalas have been observed in the Project area in the last five years, despite targeted searches. The Project has the potential to have direct and indirect impacts to the species. These are unlikely to be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Pseudomys pilligaensis (Pilliga Mouse) – Vulnerable

It is important to note that the *Pseudomys pilligaensis* (Pilliga Mouse) is now considered a southern population of the widespread *Pseudomys delicatulus* (Delicate Mouse) based on genetic analyses, morphological studies and recent surveys which revealed a continuous distribution of the Delicate Mouse to the Pilliga region (Breed and Ford 2007; Ford 2008, as cited in DotE 2014j). It is important to note that this taxonomic change has not yet been formally recognised under the EPBC Act (DotE 2014j), hence this assessment considers the Pilliga Mouse as currently listed.

Background – ecology and distribution
The Pilliga Mouse is listed as vulnerable under the EPBC Act. It is restricted to the Pilliga region of New South Wales, where low-nutrient deep sand supports a distinctive vegetation type (Pilliga Scrub). The Pilliga Mouse is very sparsely distributed and appears to prefer areas with a light ground cover. Recent studies indicate that the Pilliga Mouse is found in greatest abundance in recently burnt moist gullies, areas dominated by broombush and areas containing an understorey of *Acacia burrowii* (Kurricabah) with a *Corymbia trachyphloia* (Brown Bloodwood) overstorey (Paull 2009). Consistent features of the latter two habitats are a relatively high plant species richness, a moderate to high low shrub cover, and a moist groundcover of plants, litter and fungi. Consistent features of gully habitat are an extensive cover by low grasses and sedges, with little shrub cover and large areas of ash-covered ground. It is nocturnal and appears to live in burrows (OEH 2014b).

The overall population of the species is hard to estimate (DotE 2014j. Some evidence suggests there are marked population fluctuations within this species, with population estimates between 50,000 to 100,000 during boom periods (Paull and Milledge 2011).

Threats to the Pilliga Mouse include exploration, infrastructure construction and infrastructure maintenance, loss or degradation of habitat through inappropriate fire regimes, forestry operations and broombrush harvesting, predation by feral cats and foxes, and competition from the common house mouse.

Pilliga Mouse within the Project area
The Pilliga Mouse is found exclusively within the Pilliga scrub. The species was observed as part of previous studies (Milledge 2012) and in recent surveys as part of the ecological assessment for the detailed assessment phase of the Project and is known to occur more broadly in the Project area and Pilliga East State Forest (NPWS 2000a; NPA 2002).

Over the course of several projects associated with the environmental assessment of the Project, ELA mapped and classified all potential Pilliga Mouse habitat within the Project area as either ‘primary’ or ‘secondary’ habitat. ‘Primary’ habitat is considered more likely to be inhabited by the Pilliga Mouse on a more permanent basis, while the ‘secondary’ habitat is less likely to be readily inhabited or is likely to be more suitable after fire and/or during successful breeding years. This analysis indicated there is approximately 9,131 hectares of potential ‘primary’ habitat and an additional 15,318 hectares of potential ‘secondary’ habitat for the Pilliga Mouse throughout the Project area.

The Project area contains both an important population and habitat critical to the survival of the Pilliga Mouse.

Potential impacts and mitigation
The Pilliga Mouse has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance will result in the removal of habitat critical to the survival of the Pilliga Mouse, the total extent of which will be determined during the detailed impact assessment phase.

Vegetation clearance will also result in habitat fragmentation. The species is known to undergo seasonal congregations and dispersals (NPA 2002) suggesting that the species has the ability to move significant distances and is currently doing so within an environment currently bisected by existing roads, trails and drainage lines.

Pest species may also impact the Pilliga Mouse directly through predation (dog, foxes, cats) or indirectly through competition (common house mouse). These issues will be addressed via the development and implementation of a pest management plan.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the Pilliga Mouse are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and rehabilitation of temporarily impacted areas following construction.

Summary
The Project area contains an important population and habitat critical to the survival of the Pilliga Mouse. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Reptiles

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Underwoodisaurus sphyrurus	Border Thick-tailed Gecko	Vulnerable	Unlikely	No
Delma torquata	Collared Delma	Vulnerable	Unlikely	No
Anomalopus mackayi	Five-clawed Worm-skink	Vulnerable	Unlikely	No
Aprasia parapulchella	Pink-tailed Legless Lizard	Vulnerable	Unlikely	No

Amphibians

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Litoria booroolongensis	Booroolong Frog	Endangered	No	No

Fish

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Maccullochella peelii	Murray Cod	Vulnerable	No	No

Flora

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Bertya opponens	Coolabah Bertya	Vulnerable	Known	Potential
Boronia granitica	Granite Boronia	Endangered	No	No
Cadellia pentastylis	Ooline	Vulnerable	No	No
Dichanthium setosum	Bluegrass	Vulnerable	Unlikely	No
Haloragis exalata	-	Vulnerable	Unlikely	No
Homopholis belsonii	Belson's Panic	Vulnerable	Unlikely	No
Lepidium aschersonii	Spiny Peppercress	Vulnerable	Known	Potential
Lepidium monoplocoides	Winged Peppercress	Endangered	Known	Potential
Philotheca ericifolia	-	Vulnerable	Unlikely	No
Prasophyllum sp. *Wybong* (C.Phelps ORG 5269)	a leek-orchid	Critically Endangered	Unlikely	No
Rulingia procumbens	-	Vulnerable	Known	Potential
Swainsona murrayana	Slender Darling Pea	Vulnerable	Unlikely	No
Thesium australe	Austral Toadflax	Vulnerable	Unlikely	No
Tylophora linearis	-	Endangered	Known	Potential

Bertya opponens (Coolabah Bertya) – Vulnerable

Background – ecology and distribution
Bertya opponens is listed as vulnerable under the EPBC Act. It is a slender shrub or small tree, which grows to 4 metres high (Harden 1990). Flowering occurs during July and August. The primary mechanism for pollen dispersal is presumed to be wind given that the flowers lack chemical and colour attractants and the styles and anthers are exposed (NPWS 2002). *Bertya opponens* is considered to be an obligate seeder, in which standing plants are killed by fire but the species often germinates from a soil seedbank shortly afterwards (OEH 2014b).

The species occurs in a number of differing habitats, ranging from stony mallee ridges and cypress pine forests of the inland, to cliff edges in the high rainfall eastern fall areas of the Great Dividing Range. The plant is currently known from only four scattered sites in NSW, with the largest population being in Jacks Creek State Forest. NPWS (2002) and the NSW Scientific Committee (2008a) estimate that the Jacks Creek State Forest population of *B. opponens* is greater than 5 million individuals.

This species is at threat from inappropriate fire regimes, specifically if fire is less than 3 years or greater than 20 years. Other threats include clearing and fragmentation of habitat for agriculture, invasion of habitat by introduced weeds, browsing by feral goats, road and fire trail construction and maintenance, and risk of local extinction because populations are small and distribution is restricted (OEH 2014b).

Bertya opponens within the Project area
This species is known within the Project area, with records occurring primarily along the eastern boundary of the Project area.

Detailed targeted surveys for *Bertya opponens* have been undertaken within the Project area with a total of 6,715 individuals recorded. Based on the frequency of occurrence in specific habitat types, the total population of *B. opponens* within the Project area is likely to be considerably larger.

Given that there are only 4 known populations of *B. opponens*, all can be considered important populations. Therefore, the population within the Project area is also considered to be an important population.

Potential impacts and mitigation
Bertya opponens has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance may result in the removal of *B. opponens* individuals and associated habitat. Additional potential habitat outside of the known population areas may also be removed. This will reduce the size of an important population and the species' area of occupancy within the Project area. The total extent of this direct impact will be determined during the detailed impact assessment phase.

Vegetation clearance may also result in habitat fragmentation. Fragmentation associated with the Project is considered unlikely to disrupt pollen dispersal pathways, but may disrupt the existing seed bank.

Disturbance from the Project may exacerbate the spread of weed species such as *Eragrostis curvula* (African Lovegrass) and *Hyparrhenia hirta* (Coolatai Grass) into areas of known and potential *B. opponens'* habitat. Weeds can impact the species both via direct competition and degradation of habitat. They may also alter fire regimes, which are important for the germination of this species. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.
Invasive herbivore species (e.g. goats) may impact *B. opponens* directly via grazing and trampling and indirectly through habitat degradation. Goats are already present in the Pilliga, however their numbers and extent may be increased due to the Project. These issues will be addressed via the development and implementation of a pest management plan.

Fire is important for the germination of *B. opponens*. A fire risk assessment and management plan is currently being developed, however alterations to the natural burn regime of the region may impact the germination and therefore recruitment of this species.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the *B. opponens* are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains an important population of *Bertya opponens*. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Lepidium aschersonii* (Spiny Peppercress) – Vulnerable**

Background – ecology and distribution
The *Lepidium aschersonii* is listed as vulnerable under the EPBC Act. It is a small perennial herb endemic to mainland southern Australia, where it is widely but patchily distributed from New South Wales to Western Australia. The species grows to about 30 cm tall, with several erect, intricately branched stems arising annually for perennial underground rootstock. Flowering occurs from spring to autumn (Harris and Smith 2000).

Increased numbers of plants have been observed during dry periods, potentially due at least in part to the increased area of bare soil available for seedling establishment (Harris and Smith 2000). The species occurs at some sites that are occasionally flooded, such as gilgai depressions, and shows some adaptation to the seasonal filling and drying of wetlands. Established plants can also apparently withstand some period of submergence.

There are an estimated 25,000–100,000 plants remaining in about 30 wild populations (Carter 2010). Within NSW these plants have a current distribution within the Brigalow Belt South, Darling Riverine Plains, Cobar Peneplain, and Riverina. One population is protected within the Brigalow Park Nature Reserve near Narrabri and the Project area. It is thought to contains many thousands of individuals (Carter 2010) and may be the largest remaining population of *Lepidium aschersonii*.

Much of its habitat has been lost to agriculture, and remaining populations are mostly small, isolated and at risk from a range of threats including grazing, weed invasion, wetland drainage and other forms of habitat destruction.

Lepidium aschersonii within the Project area
Lepidium aschersonii is known from the north-western portion of the Project area, with a large population in Brigalow Park Nature Reserve.

Within the Project area, there are 46 existing records of *L. aschersonii* which corresponds to 3,852 individuals (due to numerous individuals recorded at each location) (OEH 2014a). Recent surveys have identified a further 15 records of *L. aschersonii* totalling 208 individuals. Based on the frequency of occurrence in specific habitat types, the total population of *L. aschersonii* within the Project area is likely to be considerably larger.

Given that there are only 30 known populations of *L. aschersonii*, all can be considered important populations. Therefore, the population within the Project area is also considered to be an important population.

Potential impacts and mitigation
Lepidium aschersonii has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance may result in the removal of *L. aschersonii* individuals and associated habitat. Additional potential habitat outside of the known population areas may also be removed. This will reduce the size of an important population and the species' area of occupancy within the Project area. The total extent of this direct impact will be determined during the detailed impact assessment phase.

Vegetation clearance may also result in habitat fragmentation. Within the Project area, the species currently occurs exclusively in a vegetation community situated in the north of Project area in patches already fragmented by pasture land and roads. This suggests there is at least some tolerance of fragmented landscapes.

Disturbance from the Project may exacerbate the spread of weed species into areas of known and potential *L. aschersonii* habitat. Weeds can impact the species both via direct competition and degradation of habitat. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.

Invasive species (e.g. rabbits and pigs) may impact *L. aschersonii* directly via grazing and trampling and indirectly through habitat degradation. These species are already present in the Project area, however their numbers and extent may be increased due to the Project. These issues will be addressed via the development and implementation of a pest management plan.

Alterations to the hydrological regime of the Project area also has the potential to impact the wetter habitats of *L. aschersonii*. A detailed impact assessment of water resources is currently being prepared as part of the detailed impact assessment phase of the Project, and this will determine impacts to hydrological regimes and flow on effects to species such as *L. aschersonii*.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the *L. aschersonii* are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains an important population of *Lepidium aschersonii*. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Lepidium monoplocoides* (Winged Peppercress) – Endangered**

Background – ecology and distribution
Lepidium monoplocoides is listed as endangered under the EPBC Act. It is a small annual herb growing to about 20 cm tall. Flowering occurs in the spring and summer. Numbers of adult plants fluctuate from year to year with some seed probably remaining dormant in the soil for several years.

Lepidium monoplocoides occurs predominantly in mallee scrub in semi-arid areas (DotE 2014m). Sites are seasonally moist to water-logged with heavy, fertile soils and a mean annual rainfall of around 300 to 500 mm. The predominant vegetation is usually an open-woodland dominated by *Allocasuarina luehmannii* and/or eucalypts, particularly *Eucalyptus largiflorens* (Black Box) or *Eucalyptus populnea* (Poplar Box). The ground layer of the surrounding woodland is dominated by tussock grasses (notably *Rytidosperma* spp. and *Austrostipa* spp.), but the seasonally waterlogged sites preferred by *Lepidium monoplocoides* also support a number of moisture dependent herbs, such as *Marsilea* spp. (Nardoo).

The species is currently known from 13 locations, six in Victoria and seven in New South Wales. These are all considered important populations required for the conservation of *Lepidium monoplocoides*. Total population size is estimated <3,000 plants for each population in Victoria and New South Wales. The inconspicuous nature of the plant may have led to an under-estimation of population sizes. The magnitude of the soil seed store is also unknown, but is likely to be large.

Current major threats to the species include altered hydrology, increasing salinity, weed invasion, grazing, physical damage, and drought and climate change (Mavromihalis 2010).

Lepidium monoplocoides within the Project area
Lepidium monoplocoides is known from the Project area. Records all occur in the north-western portion of the Project area, close to the boundary of Brigalow Park Nature Reserve.

Targeted surveys for *L. monoplocoides* have been undertaken within the Project area with a total of 268 individuals recorded. Based on the frequency of occurrence in specific habitat types, the total population of *L. monoplocoides* within the Project area is likely to be considerably larger.

All currently known populations of *L. monoplocoides* are considered to be important populations (DotE 2014m). Therefore, the population within the Project area are should also be considered an important population.

Potential impacts and mitigation
Lepidium monoplocoides has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance may result in the removal of *L. monoplocoides* individuals and associated habitat. Additional potential habitat outside of the known population areas may also be removed. This will reduce the size of an important population and the species' area of occupancy within the Project area. The total extent of this direct impact will be determined during the detailed impact assessment phase.

Vegetation clearance may also result in habitat fragmentation. Within the Project area, the species occurs in patches already fragmented by pasture land and roads. This suggests there is at least some tolerance of fragmented landscapes.

Disturbance from the Project may exacerbate the spread of weed species into areas of known and potential *L. monoplocoides* habitat. Weeds can impact the species both via direct competition and degradation of habitat. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.

Invasive species (e.g. rabbits and pigs) may impact *L. monoplocoides* directly via grazing and trampling and indirectly through habitat degradation. These species are already present in the Project area, however their numbers and extent may be increased due to the Project. These issues will be addressed via the development and implementation of a pest management plan.

Alterations to the hydrological regime of the Project area also has the potential to impact the wetter habitats of *L. monoplocoides*. A detailed impact assessment of water resources is currently being prepared as part of the detailed impact assessment phase of the Project, and this will determine impacts to hydrological regimes and flow on effects to species such as *L. monoplocoides*.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the *L. monoplocoides* are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains an important population of *Lepidium monoplocoides*. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Rulingia procumbens* – Vulnerable**

Background – ecology and distribution
Rulingia procumbens is listed as vulnerable under the EPBC Act. It is a prostrate trailing shrub endemic to NSW. The species occurs between Dubbo and Gilgandra in northern NSW, where it grows in sandy soil in conjunction with *Melaleuca uncinata* (Broombush) and Mallee Eucalypt scrub with an understory of *Calytrix tetragona*. It is also known to occur with *Eucalyptus fibrosa*, *E. albens* and *Callitris glaucophylla* communities (OEH, 2014b).

The species produces seed which is able to persist in the soil seed bank for some time. It is promoted by fire, which often results in large germination events, and is considered a pioneer species in disturbed areas such as along roadsides, stockpiles and powerline easements (TSSC, 2008).

The main threats to the species include loss and fragmentation of habitat, clearance of roadside vegetation, and inappropriate fire and grazing regimes (TSSC, 2008).

Rulingia procumbens within the Project area
Rulingia procumbens is known to occur within the Project area. Records all occur in the south-eastern portion of the Project area and this species has also been recorded further south within the Pilliga East State Conservation Area.

Detailed targeted surveys for *R. procumbens* have been undertaken within the Project area with a total of 1,389 individuals recorded. Based on the frequency of occurrence in specific habitat types, the total population of *R. procumbens* within the Project area is likely to be considerably larger.

The population of *R. procumbens* within the Project area is considered an important population.

Potential impacts and mitigation
Rulingia procumbens has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance may result in the removal of *R. procumbens* individuals and associated habitat. Additional potential habitat outside of the known population areas may also be removed. This will reduce the size of an important population and the species' area of occupancy within the Project area. This species occurs in roadside areas within the Project area, and these areas will be preferentially developed to reduce overall disturbance of currently intact habitat areas. The total extent of this direct impact from clearing will be determined during the detailed impact assessment phase.

Vegetation clearance may also result in habitat fragmentation. Within the Project area, the species is currently found in the south of Project area, which is less fragmented than other areas.
Frequent fires (more often than 7 years) are considered a threat to this species. A fire risk assessment and management plan is currently being developed, however it is unlikely that an increased frequency of fire will result from the Project.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the *R. procumbens* are detailed in Section 4. These include undertaking rehabilitation and weed management activities.

Summary
The Project area contains an important population of *Rulingia procumbens*. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

***Tylophora linearis* – Endangered**

Background – ecology and distribution
Tylophora linearis is listed as endangered under the EPBC Act. It is a slender, almost hairless twiner, which is known only from NSW and Queensland (OEH 2013b). In NSW, it is found in the Barraba, Mendooran, Temora and West Wyalong districts in the northern and central western slopes. Records include Crow Mountain near Barraba, Goonoo, Pilliga West, Cumbil, and Eura State Forests, Coolbaggie Nature Reserve, Goobang National Park, and Beni Conservation Area.

The species grows in dry scrub and open forest. It has been recorded from low-altitude sedimentary flats in dry woodlands of *Eucalyptus fibrosa*, *E. sideroxylon*, *E. albens, Callitris endlicheri, C. glaucophylla* and *Allocasuarina luehmannii*. It also grows in association *with Acacia hakeoides, A. lineata, Melaleuca uncinata, Myoporum* species and *Casuarina* species. The species flowers in spring, with flowers recorded in November or May with fruiting probably 2 to 3 months later.

Where the species occurs, it has been recorded in very low abundances (OEH 2013b). No data are available to estimate the size of several of the known population and estimates are also complicated by difficulties in positively identifying plants that may not be flowering at the time of survey.

The main identified threats to *Tylophora linearis* include forestry activities, disturbances such as grazing and fire, and invasion of habitat by introduced weeds, such as Lantana (*Lantana camara*) (DECC 2005).

Tylophora linearis within the Project area
Tylophora linearis is known from the Project area. Records occur primarily within the Pilliga and this species has also been recorded within the Pilliga East State Conservation Area and Pilliga East State Forest.

Detailed targeted surveys for *T. linearis* have been undertaken within the Project area with a total of 402 individuals recorded. Individual records of *T. linearis* included all stems within a 5 m radius of the record as *T .linearis* is known to sucker from beneath the ground with shoots in close proximity likely to represent only a few different plants (NSW Scientific Committee 2008). Based on the frequency of occurrence in specific habitat types, the total population of *T. linearis* within the Project area is likely to be considerably larger.

The population of *T. linearis* within the Project area is considered an important population.

Potential impacts and mitigation
Tylophora linearis has the potential to be impacted both directly and indirectly by the Project, and impacts may be significant.

Vegetation clearance may result in the removal of *T. linearis* individuals and associated habitat. Additional potential habitat outside of the known population areas may also be removed. This will reduce the size of an important population and the species' area of occupancy within the Project area. Vegetation clearance may also result in habitat fragmentation. The total extent of these impacts will be determined during the detailed impact assessment phase.

Disturbance from the Project may exacerbate the spread of weed species into areas of known and potential *T. linearis* habitat. Weeds can impact the species both via direct competition and degradation of habitat. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to the *T. linearis* are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains an important population of *Tylophora linearis*. The Project is likely to have direct and indirect impacts to the species. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Ecological Communities

THREATENED ECOLOGICAL COMMUNITY	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Brigalow (*Acacia harpophylla* dominant and co-dominant)	Endangered	Known	Potential
Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions	Endangered	No	No
Weeping Myall Woodlands	Endangered	Known	Potential
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Critically Endangered	No[#]	No
Grey Box (Eucalyptus microcarpa) Grassy Woodlands and Derived Native Grasslands of south-eastern Australia	Endangered	No	No
Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland	Critically Endangered	No	No
Semi-evergreen Vine Thicket in the Brigalow Belt South and Nandewar Bioregions	Endangered	No	No
New England Peppermint (*Eucalyptus nova-anglica*) Grassy Woodlands	Critically Endangered	No	No

The assemblage of species present and associated soils types in the Project area do not support this threatened ecological community

Brigalow (*Acacia harpophylla* dominant and co-dominant)

Background – ecology and distribution
Brigalow (*Acacia harpophylla* dominant and co-dominant) is listed as endangered under the EPBC Act. The Brigalow ecological community is a low woodland or forest community dominated by *Acacia harpophylla* (Brigalow), with pockets of *Casuarina cristata* (Belah) and *Eucalyptus populnea* subsp. *bimbil* (Poplar Box) (DotE 2014o). The canopy tends to be quite dense and the understorey and ground cover are only sparse. The height of the tree layer varies from 9 m in low rainfall areas (averaging around 500mm per annum) to around 25 m in higher rainfall areas (averaging around 750 mm per annum).

The listed Brigalow ecological community extends from south of Charters Towers in Queensland, in a broad swathe east of Blackall, Charleville and Cunnamulla, south to northern New South Wales near Narrabri and Bourke. In NSW, the TEC is found in the Brigalow Belt South Bioregion and as isolated occurrences in the Darling Riverine Plains and Nandewar Bioregions.

Brigalow vegetation is usually associated with deep gilgaied clays, sedentary clays, miscellaneous deep clays and loamy red soils. The soils usually have a clay field-texture throughout the profile, are relatively fertile and tend to have a high salt content. In NSW, Brigalow is associated with red, brown and grey clays, red and grey earths and red-brown earths.

The Brigalow (*Acacia harpophylla* dominant and co-dominant) ecological community retains a national distribution of 804,264 hectares (NPWS 2002). In western NSW (Moree/Narrabri), the Brigalow ecological community is considered to consist of patches generally 100 to 300 hectares in area (NPWS 2002).

The Brigalow ecological community is threatened by any activities that further reduce its extent, cause a decline in the condition of the vegetation, or impede its recovery. The most considerable current threats are clearing, fire, plant and animal pests, and lack of knowledge. Weed invasion and overgrazing by native fauna are both promoted by the high levels of fragmentation (DotE 2014o).

Brigalow (Acacia harpophylla dominant and co-dominant) within the Project area
The presence of the Brigalow (*Acacia harpophylla* dominant and co-dominant) community in the Project area has been confirmed, with a large number of fragmented patches occurring within the north of the Project area. There is currently 2,468 hectares of Brigalow (*Acacia harpophylla* dominant and co-dominant) within the Project area. Of this total 2,468 hectares, 2,447 hectares qualified as EPBC Brigalow within the Brigalow Belt South. The additional 21 hectares did not meet the EPBC requirements, however, still meets the TSC Act requirements, as '*Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregions*'.

Potential impacts and mitigation
Brigalow (*Acacia harpophylla* dominant and co-dominant) has the potential to be impacted both directly and indirectly by the Project, and these impacts may be significant.

Vegetation clearance will result in the removal of Brigalow (*Acacia harpophylla* dominant and co-dominant), and will reduce the area of occupancy and extent of this TEC. The total extent of this direct impact will be determined during the detailed impact assessment phase.

Vegetation clearance will also result in habitat fragmentation. Within the Project area, Brigalow (*Acacia harpophylla* dominant and co-dominant) is highly fragmented in its current form and is comprised of a mix of regrowth and remnant woodland or forest in various condition. Further fragmentation of the community is considered a key threat to the TEC.

The TEC is also currently impacted by edge effects, which are exacerbated by the highly fragmented nature of remnant patches. Disturbance from the Project may exacerbate the spread of weed species into areas of known and potential Brigalow habitat. Weeds can impact the TEC both via direct competition and degradation of habitat. Invasive pasture grasses (e.g. Buffel Grass) also present a major threat to Brigalow, as they alter the fire regime. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to Brigalow (*Acacia harpophylla* dominant and co-dominant) are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains approximately 2,447 hectares of Brigalow (*Acacia harpophylla* dominant and co-dominant). The Project is likely to have direct and indirect impacts to this TEC. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

Weeping Myall Woodlands

Background – ecology and distribution
Weeping Myall Woodland is listed as endangered under the EPBC Act. This community occurs as sparse monotypic stands of *Acacia pendula* (Weeping Myall) on inland alluvial plains west of the Great Dividing Range in NSW and Queensland (DOE, 2014p). The community typically occurs on flat areas with occasional gilgai on black, brown, red-brown or grey clays. While the community is dominated by Weeping Myall, other species of tree and shrub do co-occur on occasion. The understory is usually dominated by an open layer of grasses such as *Rytidosperma spp.*(Wallaby Grasses), *Astrebla spp.*(Mitchell Grass) and *Dichanthium sericeum* (Queensland Blue Grass) as well as an open shrub layer including a range of Chenopod species such as Salt Bushes, Bluebushes and Goosefoots, which form an ecologically important component of the community.

The Weeping Myall TEC was once distributed throughout large portions of western NSW and has been historically cleared across a large portion of its range such that less than 10% of the pre-1750 extent of the community remains (DEWHA 2009). Very few sizable remnants of the community remain across its range, with most patches being highly fragmented. Estimates of the remaining area are thought to be between 190-330,000 hectares (TSSC 2008).

Weeping Myall Woodlands are under threat from continued clearance for cropping and agriculture due to the highly fertile soils that the community occurs on. Continuing threats to the community also include fragmentation, overgrazing, weed invasion and herbivory by the caterpillars *Ochrogaster lunifer* (Bag-Shelter Moth), clearing and lopping for fodder, and dieback of the chenopod shrub layer (TSSC 2008).

Weeping Myall Woodlands within the Project area
The presence of the Weeping Myall Woodlands has been confirmed in the Project area, with a small number of localised patches occurring within the northwest of the Project area. Within the Project area, 33 hectares of vegetation qualified as EPBC Weeping Myall Woodlands. An additional 3 hectares did not meet the EPBC requirements, however, still meets the TSC Act requirements for the Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes bioregions community.

Potential impacts and mitigation
Weeping Myall Woodlands has the potential to be impacted both directly and indirectly by the Project, and these impacts may be significant.

Vegetation clearance may result in the removal of Weeping Myall Woodlands, and if this occurs it will reduce the area of occupancy and extent of this TEC. Vegetation clearance may also result in habitat fragmentation. The total area of Weeping Myall Woodland within the Project area is very small (33 hectares in a total Project area of approximately 98,000 hectares) and impacts to this TEC may be avoided. However, the total extent of this direct impact will be determined during the detailed impact assessment phase.

Disturbance from the Project may exacerbate the spread of weed species into areas of known and potential Weeping Myall Woodlands habitat. Weeds can impact the TEC both via direct competition and degradation of habitat. Weed management measures will be developed and implemented, along with rehabilitation of temporarily impact areas after construction. These measures will reduce impacts of weeds species.

Management and mitigation measures that will reduce potential impacts across the Project area and are applicable to Weeping Myall Woodlands are detailed in Section 4. These include co-locating infrastructure with existing access roads, tracks or other existing linear features or disturbed areas (where possible) and undertaking rehabilitation and weed management activities.

Summary
The Project area contains only 33 hectares of Weeping Myall Woodlands. The Project may have direct and indirect impacts to this TEC. These may be significant, and will be further assessed and quantified in the detailed impact assessment. Avoidance, management and mitigation measures will be implemented throughout construction and operation of the Project to minimise impacts to this species.

3.1 (e) Listed migratory species

Description

A total of 11 listed migratory species were identified from the search undertaken using the DotE PMST as having the potential to occur within the Project area, with 3 additional migratory species included based on previous surveys. A full listing of these species is provided below. All are birds.

Nature and extent of likely impact
In this referral, potential impacts to migratory birds have been considered within the context of two key concepts commonly applied under the EPBC Act for migratory species (DEWHA 2009):

- Important habitat.
- Ecologically significant proportion of the population.

Where neither of these two features of a migratory species are present, impacts are generally not considered an issue under the EPBC Act (DEWHA 2009a).

Five terms for the likelihood of occurrence of species and communities are used and are defined as follows:

"Known"	=	the species has been observed within the project area
"Likely"	=	a medium to high probability that a species uses the project area
"Potential"	=	suitable habitat for a species occurs within the project area, but there is insufficient information to categorise the species as likely to occur, or unlikely to occur
"Unlikely"	=	a very low to low probability that a species uses the project area
"No"	=	habitat within the project area and in the vicinity is unsuitable for the species

There are 14 migratory species which have the potential to occur within the Project area. Of these, seven are known to occur (Fork-tailed Swift, Great Egret, Cattle Egret, White-bellied Sea Eagle, White-throated Needletail, Rainbow Bee-eater, and Satin Flycatcher). The majority of these species may use the Project area in a transient manner.

SCIENTIFIC NAME	COMMON NAME	EPBC LISTING STATUS	LIKELIHOOD OF OCCURRENCE	SIGNIFICANT IMPACT LIKELY?
Anthochaera phrygia	Regent Honeyeater	Endangered, Migratory	Potential	No
Apus pacificus	Fork-tailed Swift	Migratory	Known	No
Ardea modesta	Eastern Great Egret	Migratory	Known	No
Ardea ibis	Cattle Egret	Migratory	Known	No
Calyptorhynchus banksii	Red-tailed Black-Cockatoo	Endangered, Migratory	Unlikely	No
Gallinago hardwickii	Latham's Snipe, Japanese Snipe	Migratory	Potential	No
Haliaeetus leucogaster	White-bellied Sea Eagle	Migratory	Known	No
Hirundapus caudacutus	White-throated Needletail	Migratory	Known	No
Lathamus discolour	Swift Parrot	Endangered, Migratory	Potential	No
Leipoa ocellata	Malleefowl	Vulnerable, Migratory	Unlikely	No
Merops omatus	Rainbow Bee-eater	Migratory	Known	No
Monarcha melanopsis	Black-faced Monarch	Migratory	Unlikely	No
Myiagra cyanoleuca	Satin Flycatcher	Migratory	Known	No
Rhipidura rufifrons	Rufous Fantail	Migratory	Unlikely	No

Each of the migratory species considered has a broad natural distribution and is found in a large variety of areas throughout Australia. Any impacts on these species as a result of the Project are therefore expected to be minor (if any), highly localised and restricted to individual animals. In addition, the Project area does not represent important habitat or support an ecologically significant proportion of any population of the purely migratory species listed below, indicating that the threshold for significant impact will not be met.

Detailed consideration of the potential for significant impact under the EPBC Act for each migratory species considered known or likely to occur within the Project area is provided in below.

The Regent Honeyeater, Swift Parrot and Australian Painted Snipe, which are listed as threatened and migratory, are addressed above in section 3.1 (d).

A number of surveys have been undertaken within the Pilliga region to help understand the values of the area to birds. These surveys varied in methodology and purpose, but as a whole provide an appropriate set of information to understand the potential presence of migratory birds.

The table below provides an analysis of the potential presence of important habitat or an ecologically significant proportion of the population for each species. Key information used to determine the potential importance of the Project area includes:

- General information for each species in relation to distribution, habitat requirements, population and potential threats.
- Site specific information for the Pilliga Project area including the results of surveys and habitat use.

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
White-Bellied Sea Eagle *Haliaeetus leucogaster*	Global distribution from India and Sri Lanka, east to southern China, and south through South-East Asia, the Philippines, Wallacea and New Guinea. Not globally threatened and considered to be a common species throughout much of its range. Estimated global population of more than 10,000 individuals of which approximately 10–20% estimated to occur within Australia. Found in coastal habitats and near to terrestrial wetlands in tropical and temperate regions of mainland Australia. Breeding pairs mainly occur along the east coast. Generally forages over large expanses of open water. Main threats are habitat loss and disturbance from human activity. (DotE 2014q)	Known to occur within the Project area – observed during ecological surveys at a large dam in the north-east of the Project area. Habitat analysis indicates there is approximately 100 hectares of foraging habitat for this species within the Project area.	Important habitat is likely to include known nest sites for the species. Known nest sites are usually located in tall forest bordering a water body which could be used for foraging. Ecologically significant portion of the population in south-eastern Australia is considered to be 4 pairs.	Unlikely
Fork-tailed Swift *Apus pacificus*	Non-breeding visitor. Broad distribution across Australia. Almost exclusively aerial. No known threats in Australia. (DotE 2014r)	Known to occur within the Project area – observed multiple times during ecological surveys. Habitat analysis indicates there is approximately 80,619 hectares of foraging habitat for this species	Abundance of this species has not been quantified within Australia, however, there are records of up to 90,000 individuals occurring in a single flock on rare occasions. As the species is not known to utilise key areas specifically for foraging, and does not breed in Australia, no important habitat or an	Unlikely

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
		within the Project area.	ecologically significant portion of the population can be identified.	
White-throated Needletail *Hirundapus caudacutus*	Non-breeding visitor. Broad distribution across the east coast of Australia. Almost exclusively aerial. No known threats in Australia. (DotE 2014s)	Known to occur within the Project area – observed during ecological surveys. Habitat analysis indicates there is approximately 80,619 hectares of foraging habitat for this species within the Project area.	Abundance of this species has not been quantified within Australia. As the species is not known to utilise key areas specifically for foraging, and does not breed in Australia, no important habitat or an ecologically significant portion of the population can be identified. The species may show an affinity for forested sites.	Unlikely
Eastern Great Egret *Ardea modesta*	Wide spread in Australia in a variety of wetland habitats. Australian population estimated at 25,000 to 100,000. Most important populations occur in the Northern Territory. (DotE 2014t)	Known to occur within the Project area. Habitat analysis indicates there is approximately 9,585 hectares of foraging habitat for this species within the Project area.	Breeding colonies of the species occur throughout the coastal regions of Northern Australia, but are also known to occur in south-west Queensland, the Darling Riverine Plains, the Riverina NSW and Victoria. These populations are considered to be important populations of the species. The species typically breeds in colonies containing hundreds to thousands of pairs. Any site which contains a population of more than one hundred pairs is likely to contain an ecologically significant portion of the population. Using 0.1% of the total population as a threshold that would equate to 250 individuals.	Unlikely

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
Cattle Egret *Ardea ibis*	Highly mobile, wide ranging migratory species that has been recorded throughout most of Australia. Population for Australia, New Guinea and New Zealand is estimated at 100,000 birds . (DotE 2014u) Found in open, grassy areas, such as pastures, meadows, marshes, flood plains and swamps. Has a preference for freshwater and is rarely found near marine environments. A diurnal feeder which commonly associates with native grazing mammals or domesticated livestock (and may follow farm machinery to capture disturbed prey). (Birdlife International 2014a)	Known to occur within the Project area. Habitat analysis indicates there is approximately 9,585 hectares of foraging habitat for this species within the Project area.	Important breeding populations occur between Newcastle and Bundaberg on the east coast as well as within major inland wetlands such as the Macquarie Marshes. The species typically breeds in colonies containing hundreds to thousands of pairs. Any site which contains a population of several hundred pairs is likely to contain an ecologically significant portion of the population. Important habitat for the species is likely to included substantial inundated forests or wooded swamps such as mangroves, *Melaleuca* swamps or eucalypt/lignum swamps known to support a breeding colony of the species as the species utilises inundated trees as nest sites.	Unlikely

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
Rainbow Bee-Eater *Merops ornatus*	Widely distributed throughout Australia and eastern Indonesia. Occurs across most of mainland Australia; although extent of occurrence and areas of occupancy are not well understood. The total Australian population size has not been estimated although it is thought to be reasonably large based on reporting rates (over 30,000 recorded sightings since 1998). Usually occurs in cleared or lightly-timbered areas that are often, but not always, located in close proximity to permanent water. Feeds on insects and less commonly earthworms, spiders and tadpoles. Primary threat in north eastern Australia is the cane toad which feeds on eggs and nestlings and displaces nesting birds. (DotE 2014w)	Known to occur within the Project area – numerous observations during ecological surveys. Habitat analysis indicates there is approximately 66,901 hectares of breeding habitat and an additional 10,887 hectares of foraging habitat for this species within the Project area.	Abundance of this species has not been quantified within Australia. As the species is not known to utilise key areas specifically for forage or breeding, no important habitat or an ecologically significant portion of the population can be identified. The species is known to nest in loose colonies, and the species is known to show some degree of site fidelity returning to the same sites to breed. Important habitat for the species may include areas which are known to contain breeding sites for a large number of individuals (>300), or sites to which the species shows strong site fidelity.	Unlikely

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
Satin Flycatcher *Myiagra cyanoleuca*	Inhabits heavily vegetated gullies in eucalypt-dominated forests and taller woodlands, will use coastal areas on migration flights. (DotE 2014v) Occurs along the east coast of Australia and PNG from far northern Queensland to Tasmania, including south-eastern South Australia. Not a commonly seen species, especially in the far south of its range, where it is a summer breeding migrant. (Birdlife International 2014b)	Known to occur within the Project area – numerous observations during ecological surveys. Habitat analysis indicates there is approximately 66,901 hectares of foraging habitat for this species within the Project area.	The species is known to breed in areas of south-eastern Australia above 600m, and usually nests in loose colonies. The species shows a high site fidelity for breeding and has been known to utilise the same tree on different years, showing a preference for mature forests. Important habitat for the species is considered likely to include mature forests containing heavily vegetated gullies which contain breeding records of the species, and suitable habitat within known migration pathways.	Unlikely

SPECIES	PRESENCE IN AUSTRALIA	PRESENCE WITHIN THE PILLIGA REGION	IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PROPORTION OF A POPULATION	IS THE PROJECT AREA LIKELY TO CONTAIN IMPORTANT HABITAT OR AN ECOLOGICALLY SIGNIFICANT PORTION OF A POPULATION?
Latham's Snipe *Gallinago hardwickii*	Occur in temperate and tropical regions of Australia, as a single, dispersed non-breeding population. Entire global population is thought to migrate to Australia for the Australian summer. Highly mobile and move readily between sites as conditions change. In Australia, Latham's Snipe occur in permanent and ephemeral wetlands, usually in areas of open, freshwater wetlands with low, dense vegetation. Can also occur in habitats with saline or brackish water, in modified or artificial habitats, and in habitats located close to humans or human activity. These habitats are most commonly used when the birds are on migration. The foraging habitats of Latham's Snipe are characterised by areas of mud (either exposed or beneath a very shallow covering of water) and some form of cover (e.g. low, dense vegetation). The species roost on the ground near and sometimes in their foraging areas.	Potential to occur within very small portions of the Project area. Habitat analysis indicates there is approximately 100 hectares of potential foraging and breeding habitat for this species within the Project area.	Important habitat for the Latham's Snipe is defined as habitat that supports greater than 18 individuals, and which is a naturally occurring freshwater wetland with suitable adjacent vegetation cover such as tussock grasses, lignum or macrophytes.	Unlikely

3.1 (f) Commonwealth marine area

Description

N/A

Nature and extent of likely impact

The Project is not in or near a Commonwealth Marine Area.

3.1 (g) Commonwealth land

Description

There are five (5) Commonwealth lands in the vicinity of the Project area:

- Commonwealth Trading Bank of Australia.
- Communications, Information Technology and the Arts – Australian Telecommunications Commission.
- Communications, Information Technology and the Arts – Australian Postal Corporation.
- Communications, Information Technology and the Arts – Telstra Corporation Limited.
- Education, Science and Training – CSIRO.

Nature and extent of likely impact

The above properties do not fall within the Project area, and the Project would not impact on these Commonwealth lands.

3.1 (h) The Great Barrier Reef Marine Park

Description

N/A

Nature and extent of likely impact

Not applicable. The Great Barrier Reef Marine Park is located approximately 700 kilometres to the north-east of the Project area.

3.1 (j) Water resources in relation to coal seam gas and large coal mining development

The EPBC Act was amended in June 2013, to provide that water resources are a matter of national environmental significance, in relation to coal seam gas and large coal mining development. This is directly relevant to the Project and as such impacts to water resources within the Project area have been addressed below.

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*).

Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources state that an action is likely to have a significant impact on a water resource if there is a real or not remote chance or possibility that it will directly or indirectly result in a change to the hydrology or water quality of a water resource that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring. 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. It also depends upon the intensity, duration, magnitude and geographic extent of the impacts.

An assessment of water resources within the Project area was undertaken to assess impacts from Santos' Coal Seam Gas Exploration Appraisal Program. The description of water resources and nature of impacts below is based on this assessment. A further, more detailed assessment of the intensity, duration, magnitude and geographic extent of impacts to water resources within the Project area is currently underway and will be completed as part of the detailed impact assessment phase of the Project.

Description

Surface water resources

The Project is located within the Namoi River Catchment which forms part of the Murray-Darling Basin and covers an area of approximately 42,000 square kilometres 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 Project is mainly located in the Lower Namoi sub-catchment which commences at Narrabri.

Details of the surface water resources within the Project area, their sensitivity and current condition (as currently known) are provided below.

FEATURE	SENSITIVITY	DESCRIPTION
Namoi River	High – feature has high quality and rarity on a regional or national scale	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 Project area suggests that it contributes to the groundwater within the Namoi Alluvium.
Bohena Creek	Medium – feature has high quality and rarity on a local scale	The ephemeral nature of Bohena and Jacks 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		
Mollee Creek	Low – feature has medium quality and rarity on a local scale	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 – feature has medium quality and rarity on a local scale	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 – feature has medium quality and rarity on a local scale	These tributaries are headwaters of the Bohena Creek. They are minor ephemeral creek systems, which include very limited remnant pools. They have very low value ecologically or for water supply purposes
Spring Creek		
Yellow Spring Creek		
Bibblewindi Creek		
Un-named minor tributaries	Very low – feature has low quality and rarity on a local scale	

The Namoi State of the Catchment Report (2010) identifies one surface water dependent ecosystems (SWDE) within the Project area, namely Yarrie Lake which occurs in the north-west of the Project area. The next nearest SWDEs are:

- The Lagoons (wetland billabong) approximately 17 km to the east of the Project area.
- Narrabri Lagoon (wetland billabong) approximately 6 km to the north-east of the Project area.

There are no other large standing water bodies within the Project area.

Groundwater resources
The Project area 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 Project is underlain directly by unconsolidated alluvium overlying outcrops of the Jurassic and Cretaceous strata. These strata consist of the Keelindi Beds which overly Pilliga Sandstone and form part of the Coonamble Embayment, a southerly extension of the Surat Basin, and consequently the lowest intake beds of the Great Artesian Basin (GAB). These GAB sediments are underlain by the Gunnedah Basin strata including the Triassic Deriah, Napperby and Digby Formations.

The groundwater sources of highest value (significant transmissive units) within the Project area are:

- Superficial sediments of unconsolidated alluvium primarily the Namoi alluvium although other thinner alluvium does exist.
- 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.
- The Late Permian Clare Sandstone (of the Black Jack Group).

The coal seams (including the target coal seams) will also be included in the full impact 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.

FEATURE	SENSITIVITY	DESCRIPTION
Bohena Creek Alluvium	Medium – feature has high quality and rarity on a local scale	Groundwater from this source may be abstracted for local use Supports Pilliga Terrestrial GDE Groundwater will have moderate recharge rates however recovery periods are likely to be relatively short as the aquifer is unconfined
Namoi alluvium	Medium – feature has high quality and rarity on a local scale	Locally this groundwater source is used predominantly for stock and domestic abstractions within the Project area. Regionally the Namoi alluvium is targeted directly by the irrigation industry and large volumes are extracted annually.
Pilliga Sandstone	Medium – feature has high quality and rarity on a local scale	This groundwater source is used predominantly for stock and domestic abstractions within the Project 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

FEATURE	SENSITIVITY	DESCRIPTION
Garrawilla Volcanics	Low – feature has medium quality and rarity on a local scale	Water quality generally unknown but considered likely to be unsuitable 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 – feature has low quality and rarity on a local scale	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 – feature has low quality and rarity on a local scale	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 Ecosystems, springs and wetlands	High – feature has high quality and rarity on a regional or national scale	High priority GDEs exist at Eather, Hardys and Mayfield springs GDEs are likely to be used by threatened/migratory species, as described in relevant sections above Adopting the precautionary principle, it is assumed that these GDEs are of high sensitivity
Stygofauna populations	High – feature has high quality and rarity on a regional or national scale	Stygofauna communities may exist in the unconsolidated alluvium within the Project area. Given the depth of the proposed CSG wells, their separation from the alluvium, geological features between, the significant irrigation extraction directly from the alluvium, their sensitivity has been designated as low

Groundwater use within the Project area is limited. This is attributed both to land use constraints arising from the Project area largely coinciding with the footprint of the Pilliga and lower bore yields associated with the consolidated rock units.

It is understood from the NSW Office of Water (NOW) bore database PINEENA 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 Project 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, poor water quality and availability of better quality groundwater near the surface.

Compared with the assessment conducted in accordance with the Significant Impact Guidelines for the Exploration and Appraisal Program, an assessment of the Project indicates that the duration and wider geographic extent of depressurisation of groundwater head within the coal seams and adjacent strata will cause a significant impact to the groundwater resources of the Gunnedah-Oxley Basin. However, due to the depth of the target coal seams, low hydraulic conductivity of the target strata and poor hydraulic continuity with overlying strata, the overlying groundwater features of greater sensitivity (Pilliga Sandstone, alluvium) are highly unlikely to experience significant impact.

3.2 Nuclear actions, actions taken by the Commonwealth (or Commonwealth agency), actions taken in a Commonwealth marine area, actions taken on Commonwealth land, or actions taken in the Great Barrier Reef Marine Park

3.2 (a)	**Is the proposed action a nuclear action?**	X	No
			Yes (provide details below)

If yes, nature & extent of likely impact on the whole environment

3.2 (b)	**Is the proposed action to be taken by the Commonwealth or a Commonwealth agency?**	X	No
			Yes (provide details below)

If yes, nature & extent of likely impact on the whole environment

3.2 (c)	**Is the project to be taken in a Commonwealth marine area?**	X	No
			Yes (provide details below)

If yes, nature and extent of likely impact on the whole environment (in addition to 3.1(f))

3.2 (d)	**Is the proposed action to be taken on Commonwealth land?**	X	No
			Yes (provide details below)

If yes, nature & extent of likely impact on the whole environment (in addition to 3.1(g))

3.2 (e)	**Is the proposed action to be taken in the Great Barrier Reef Marine Park?**	X	No
			Yes (provide details below)

If yes, nature & extent of likely impact on the whole environment (in addition to 3.1(h))

3.3 Other important features of the environment

3.3 (a) Flora and fauna

The results of all environmental assessments undertaken in the Project area since 2005 have been used to describe the existing environment.

In addition to EPBC Act listed species, a number of threatened species listed on the NSW *Threatened Species Act 1995* (TSC Act) have been recorded in the Project area:

- *Calyptorhynchus lathami* (Glossy Black-cockatoo).
- *Cercartetus nanus* (Eastern Pygmy-possum).
- *Chalinolobus picatus* (Little Pied Bat).
- *Chthonicola sagittatus* (Speckled Warbler).
- *Circus assimilis* (Spotted Harrier).

- *Daphoenositta chrysoptera* (Varied Sittella).
- *Falco subniger* (Black Falcon).
- *Glossopsitta pusilla* (Little Lorikeet).
- *Grantiella picta* (Painted Honeyeater).
- *Hieraaetus morphnoides* (Little Eagle).
- *Hoplocephalus bitorquatus* (Pale-Headed Snake).
- *Lophoictinia isura* (Square-tailed Kite).
- *Macropus dorsalis* (Black-striped Wallaby).
- *Melanodryas cucullata cucullata* (Hooded Robin (south-eastern form)).
- *Merops ornatus* (Rainbow Bee-eater).
- *Miniopterus schreibersii oceanensis* (Eastern Bentwing Bat).
- *Neophema pulchella* (Turquoise Parrot).
- *Ninox connivens* (Barking Owl).
- *Petaurus norfolcensis* (Squirrel Glider).
- *Pomatostomus temporalis temporalis* (Grey-crowned Babbler (eastern subspecies)).
- *Saccolaimus flaviventris* (Yellow-bellied Sheathtail-Bat).
- *Stagnopleura guttata* (Diamond Firetail).
- *Tyto novaehollandiae* (Masked Owl).
- *Vespadelus troughtoni* (Eastern Cave Bat).

Several exotic fauna species have also been recorded, including: *Vulpes vulpes* (Red Fox), *Felis catus* (Feral Cat), *Oryctolagus cuniculus* (European Rabbit), *Sus scrofa* (Feral Pig), *Lepus europaeus* (Brown Hare) and *Capra hircus* (Goat).

In addition to EPBC Act listed species, the following threatened flora species listed on the TSC Act have been recorded in the Project area:

- *Diuris tricolor* – vulnerable (under TSC Act).
- *Myriophyllum implicatum* – critically endangered (under TSC Act).
- *Polygala linariifolia* – endangered (under TSC Act).
- *Pomaderris queenslandica* – endangered (under TSC Act).
- *Pterostylis cobarensis* – vulnerable (under TSC Act).

A small number of invasive exotic flora species have been identified in the Project area, including *Xanthium occidentale* (Noogoora Burr) and *Hyparrhenia hirta* (Coolatai Grass).

3.3 (b) Hydrology, including water flows

Details of the hydrology are provided in Section 3.1(j), in relation to impacts to water resources from coal seam gas and large coal mining development.

3.3 (c) Soil and Vegetation characteristics

PEL 238 is located in the central portion of the Gunnedah Basin where Jurassic and Cretaceous Surat Basin sediments unconformably overlie Permo-Triassic Gunnedah Basin sediments. The Gunnedah Basin covers an area of more than 15,000 square kilometres and is defined in structural terms as being bounded to the east by the Hunter-Mooki Thrust Fault System and the New England Fold Belt, and to the west by the Lachlan Fold Belt onto which the Gunnedah Basin sediments gradually onlap.

The Gunnedah Basin consists of Early Permian to Late Triassic aged consolidated sediments of shallow marine and fluvial origin. These sediments are underlain by basement rocks of the Lachlan Fold Belt. Basement rocks of the New England Fold Belt abut the eastern boundary of the Gunnedah Basin.

The most important Gunnedah Basin structure within the Project area is the Bohena Trough. The Bohena Trough contains two well-developed coal measures, which are the primary natural gas targets for the Project.

The Project area is dominated by sandy soils associated with undifferentiated alluvium and deeper weathered sandstone. It is situated within outcropping Pilliga Sandstone recharge zones of the Great Artesian Basin. Due to the sandy soils, and subsequent high infiltration rates, precipitation would infiltrate the soil and then into the underlying sediments. Most stream sediment within this landscape is derived from Pilliga Sandstone plateaus, or as a result of reworking of the broad outwash plain.

Soil nutrient mapping by NSW OEH confirms the low fertility in the Project area, with the bulk of the Project area showing 'moderately low' as the inherent soil fertility classification, with areas to the north of the forest being of 'moderate' inherent soil fertility.

3.3 (d) Outstanding natural features

The Project area spans several state forests including the Pilliga East State Forest, Bibblewindi State Forest, and Jacks Creek State Forest. It is also located within improved and irrigated pasture, cropping and grazing land. The Pilliga as a whole is recognised as an important area for biodiversity in NSW west of the Great Dividing Range.

3.3 (e) Remnant native vegetation

Biometric Vegetation Types (BVTs) are a higher order vegetation class used in regional biodiversity planning in NSW. 13 BVTs have been mapped in the Project area (Table 1).

Table 1: Biometric Vegetation Types within the Project area

BVT ID	BVT	Total area mapped (hectares)
NA102	Belah woodland on alluvial plains in central-north NSW (Benson 55)	685.45
NA117	Brigalow - Belah woodland on alluvial often gilgaied clay soil mainly in the Brigalow Belt South Bioregion (Benson 35)	6,696.48
NA121	Broombush shrubland of the sand plains of the Pilliga region, subtropical sub-humid climate zone (Benson 141)	1,402.3
NA124	Brown Bloodwood - cypress - ironbark heathy woodland in the Pilliga region of the Brigalow Belt South Bioregion	30,951.37
NA126	Carbeen woodland on alluvial soils (Benson 71)	15.03
NA141	Fuzzy Box on loams in the Nandewar Bioregion and northern Brigalow Belt South Bioregion (Benson 202)	590.35
NA143	Green Mallee scrub on sandstone rises in the Brigalow Belt South Bioregion (Benson 179)	20.33
NA160	Mugga Ironbark - Pilliga Box - pine- Bulloak shrubby woodland on Jurassic Sandstone of outwash plains (Benson 255)	367.4
NA179	Pilliga Box - Poplar Box- White Cypress Pine grassy open woodland on alluvial loams mainly of the temperate (hot summer) climate zone (Benson 88)	6,891.91
NA193	River Red Gum riverine woodlands and forests in the Nandewar and Brigalow Belt South Bioregions (Benson 78)	10.49
NA197	Rough-barked Apple riparian forb/grass open forest of the Nandewar Bioregion	8,691.25
NA219	Weeping Myall open woodland of the Darling Riverine Plains and Brigalow Belt South Bioregions (Benson 27)	209.26
NA227	White Cypress Pine - Bulloak - ironbark woodland of the Pilliga area of the Brigalow Belt South Bioregion	23,986.89
Other	Includes cleared, creek bed, dams and improved pasture	14,718.13
Total		**95,236.64**

Within these BVTs, there are four endangered ecological communities (as listed under the TSC Act), and two threatened ecological communities (as listed under the EPBC Act). These are shown below in Table 3.

Table 2: Endangered and Threatened Ecological Communities

EEC	TSC ACT AREA (HECTARES)#	EPBC ACT AREA (HECTARES)
Weeping Myall Woodlands (EPBC Act) Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes bioregions (TSC Act)	36.00	32.52
Brigalow (*Acacia harpophylla* dominant and co-dominant) (EPBC Act) Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregions (TSC Act)	2,467.97	2,447.35
Fuzzy Box Woodland on alluvial Soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South Bioregions (TSC Act)	590.35	N/A
Carbeen Open Forest community in the Darling Riverine Plains and Brigalow Belt South Bioregions (TSC Act)	15.03	N/A
Total	3,109.35	2,479.87

TSC Act area includes the EPBC Act area

3.3 (f) Gradient (or depth range if action is to be taken in a marine area)

The land has been described as gently undulating around 280 metres (Australian Height Datum).

3.3 (g) Current state of the environment

The vegetation within the Project area has been variously affected by a long history of forestry, fires and small-scale agriculture. Forestry tracks (both formal and informal) form a fragmented network across the Project area; however, there are large patches (>1,000 hectares) of contiguous vegetation which have not been dissected by forestry. Areas which have remained long unburnt (>10 yrs) generally support large hollow-bearing trees.

Currently eight land use classes have been mapped within the Project area. The predominant land use is native vegetation/forestry, constituting 75 % of the total Project area. The second most dominant land use is 'grazing' with a combined 24 %. Notably of this 24 %, DNG constitutes 10 % and the remainder consists of cropping or improved pasture.

Table 3: Land use within the Project area

LAND USE	TOTAL AREA MAPPED (HECTARES)
Cleared	1,425.25
Creek Bed	148.35
Dam	100.1
Grazing - DNG	9,484.83
Grazing - Other - Cropping	4,972.18
Grazing - Other - Improved Pasture	3,627.2
Grazing - Other - Previous Evidence of Pasture Improvement	4,445.05
Native Vegetation / Forestry	71,033.68
Total	95,236.64

The vegetation within the Project area is generally considered to be in good condition. Few weeds are present within the area (refer to 3.3 (a)), and mainly occur within riparian zones. Generally, vegetation around the existing well pads, areas that have undergone logging and existing access road shows a higher level of disturbance.

The Project area supports a number of introduced fauna species (refer to 3.3 (a)) which are variously affecting the biodiversity values in the Project area through predation and competition.

Riparian zones show low levels of erosion.

3.3 (h) Commonwealth Heritage Places or other places recognised as having heritage values

There are no Commonwealth heritage places located within the Project area and there are no other known places of heritage value.

3.3 (i) Indigenous heritage values

The Project is located within the boundaries of the Narrabri and Wee Waa Local Aboriginal Land Councils (LALCs), and wholly within the area of the Registered Native Title Claimants - the Gomeroi People.

During the development of the Preliminary Environmental Assessment (GHD 2014) a search of the Office of Environment and Heritage Aboriginal Heritage Information Management System (AHIMS) database was undertaken in September 2013 to determine whether there are any Aboriginal sites within the Project area or vicinity (i.e. within 5 kilometres of the Project area boundary).

The database search results indicate that 160 registered Aboriginal sites have been recorded in the vicinity of the Project area. The database search results are presented in Table 4.

Of these 160 Aboriginal sites, 22 are located within the Project area. These include 14 modified trees, 7 artefacts and 1 grinding groove site. There are likely to be Aboriginal heritage sites within the Project area that have not been recorded within the AHIMS.

Table 4: AHIMS database search results

ITEM	NO. RECORDED IN VICINITY OF PROJECT
Aboriginal ceremony/dreaming	1
Artefact	135
Burial	1
Grinding groove	2
Habitation structure	2
Hearth	2
Modified tree	16
Shell	1
Total	160

The surface and sub-surface disturbance may have the potential for direct and indirect impacts on items of Aboriginal cultural heritage. The strategy for the protection and management of Aboriginal cultural heritage is to work with the relevant Aboriginal parties to develop an integrated and comprehensive management framework for cultural heritage that will apply for the life of the Project.

Additionally, Santos is currently undertaking an audit of all Aboriginal cultural heritage, including information held by the Narrabri LALC. An analysis of the information identified through the audit will be undertaken in collaboration with the Registered Native Title party, Narrabri LALC and OEH. The audit will provide key information for the zone mapping.

In addition to the data audit, Santos proposes to undertake the following activities as part of the impact assessment phase:

- Identification, notification and registration of Aboriginal people who hold cultural knowledge relevant to the Project area.
- Provide registered Aboriginal parties with information about the scope of the Project and the proposed cultural heritage assessment process.
- Undertake consultation in regards to gathering cultural information, research methods and management options. This information will inform zone mapping to guide field development, construction and operation during production.
- Targeted field surveys to ground-truth historic site data, and assessment of locations of potential cultural heritage significance.
- Assessment of potential impacts and appropriate mitigation measures in relation to the Project.

In contrast to many local resource developments which are required to clear and excavate large areas of land in specific locations, the Project has greater flexibility in siting of infrastructure, and in particular, wells and gas and water gathering lines. As such, consultation with key Aboriginal stakeholders will focus on the development of a robust cultural heritage management framework that will guide the micro-sitting of infrastructure at the time of construction. Field development would be undertaken in consultation with the relevant Aboriginal stakeholders and would seek to minimise impacts, as far as practicable, on Aboriginal heritage.

The Santos Cultural Heritage Standards and supporting systems would ensure compliance with:

- The management framework developed with the Aboriginal stakeholders.
- All legislative requirements, in a manner that is comprehensive, documented and auditable.

The Cultural Heritage Management Framework will include appropriate response management protocols and systems for landscapes, sites and objects as identified in the mapping and will be finalised prior to construction commencing.

3.3 (j) Other important or unique values of the environment

The Project area is located within Pilliga East State Forest, Jacks Creek State Forest, Bibblewindi State Forest and private freehold land.

3.3 (k) Tenure of the action area

The Project area is held under a number of different tenures including:

- Crown land including State Forest, travelling stock reserves (TSRs) and State Conservation Area.
- Crown Land Road Reserve (both Crown Roads and Narrabri Shire Council).
- Private land (freehold) owned by Santos and other land holders.

3.3 (l) Existing land/marine uses of area

The Project would be wholly located within the Narrabri LGA. Land use in the Narrabri LGA is dominated by primary production, including agriculture and forestry (54.7%). Other land uses comprise rural residential development (18.7%), native vegetation (14.6%), irrigated plants consisting predominantly of cotton (11.1%), intensive animal husbandry (0.2%) and extractive industries (0.1%).

The majority of the Project would be located in an area designated as either RU1 (Primary Production) or RU3 (Forestry) under the Narrabri Local Environment Plan 2012. Brigalow Park Nature Reserve, which is surrounded by the Project area though excluded from the Project footprint, is designated E1 (National Parks and Nature Reserves). Land designated as RU1 (Primary Production) consists predominantly of agricultural land supporting dry-land cropping and pastoral (livestock) activities. Land designated as RU3 (Forestry) includes the Pilliga East State Forest, Bibblewindi State Forest and Jacks Creek State Forest. These state forests are designated Crown Lands under the Forestry Act 1916.

State forests and conservation areas in the region are administered under the *Brigalow and Nandewar Community Conservation Area Act 2005*, which designates the area into Community Conservation Areas (CCAs). The purpose of CCAs is to reserve land for conservation, protect areas of natural and cultural heritage significance to Aboriginal people, sustainable forestry and mining and other appropriate uses. Pilliga East State Forest, Bibblewindi State Forest and Jacks Creek State Forest located within the Project area are managed as Zone 4 CCAs, in accordance with the *Forestry Act 2012*. Zone 4 CCAs are managed specifically for forestry, recreation and mineral extraction (NSW EPA 2013). State forests within the Project area and vicinity are also used for recreational activities such as bird watching and bushwalking, and hunting.

The New England North West SRLUP (DPI, 2012) represents one component of the NSW Government's broader Strategic Regional Land Use Policy which comprises multiple initiatives to address land use conflict in regional areas, particularly focused on managing coal and natural gas issues. The SRLUP maps areas of strategic agricultural land. Strategic agricultural land includes both land with unique natural resource characteristics, known as BSAL, and clusters of significant agricultural industries that are potentially impacted by natural gas or mining development, known as Critical Industry Clusters (CICs).

The Project falls within the area regulated by the New England North West SRLUP. However, regional broad scale mapping of strategic agricultural land within the SRLUP indicates that the Project would not fall within any mapped BSAL (DPI 2012 and 2013). Further, the Project would not be located on or near any mapped CICs, as no CICs have been identified in the New England North West region (DPI, 2012). Due to the regional scale of the mapping, it is important that site-specific verification is undertaken. Therefore, a site verification application would be prepared to determine if the Project area meets the BSAL site criteria as defined by the SRLUP Interim protocol for site verification and mapping of biophysical strategic agricultural land (GHD 2014).

Open cut coal mines including Maules Creek, Narrabri, and Boggabri exist in the Narrabri LGA. There are also a number of petroleum titles within and around the Project, all held by Santos.

3.3 (m) Any proposed land/marine uses of area

There are no other proposed uses of the Project area, other than those that currently occur and the referred action.

4 Measures to avoid or reduce impacts

A number of avoidance, mitigation and management measures will be undertaken as part of the Project in order to minimise potential impacts to MNES, as outlined below.

Avoidance measures

The design and location of infrastructure for the Project will make maximum use of areas within or adjacent to existing disturbance. This strategy will continue to reduce the overall extent of clearing required and to date has substantially avoided increasing the level of existing fragmentation and edge effects within the landscape. This strategy includes:

- Preparation of a field development protocol which considers threatened species, ecological communities and their potential habitats and prioritising them for avoidance.
- The development of field clearance procedures for all necessary project clearing to ensure that all infrastructure is appropriately located for minimal impact on MNES.
- The lateral well design has minimised surface disturbance and helped avoid the need for hydraulic fracturing (fracking).
- Routes for linear infrastructure such as gas and water gathering systems will use existing roads, access tracks and disturbance corridors wherever possible. Further micro-alignment may be undertaken to minimise impacts on known ecological constraints such as threatened species and hollow-bearing trees, if practicable.
- Construction of the gas and water gathering systems will use a 'plough-in' technique where possible as this reduces the width of the corridor required for construction, minimises disruption to top soil, and minimises the need for traditional trenching and dewatering of open trenches.

Mitigation and management measures

The following key measures will be implemented to mitigate and manage potential impacts to MNES potentially occurring within the Project area:

- A weed and pest management plan will be developed and implemented to address issues of weed introduction and feral animal infestations within the Project area.
- A feral animal control strategy will be developed which will address feral animal control at a landscape scale.
- A water management plan will be developed and implemented, to address issues associated with hydrological changes and water quality impacts for both surface and groundwater.
- A bushfire hazard and risk assessment will be developed and implemented.
- Pre-clearance surveys of areas of potential habitat for all MNES described in Section 3.1(d) will be undertaken by suitably qualified ecologists to re-locate (where possible) fauna and habitat features prior to clearing.
- Appropriate construction and operational controls will be developed and implemented (i.e. construction and operational management plans) to address issues such as sediment and erosion control, exclusion fencing, signage and site inductions.
- Development and implementation of protocols to record vegetation clearance and ensure it is within the approved overall limits.

Rehabilitation

Rehabilitation of the impacted areas will occur as soon as practicable and in a number of stages:

- Following the construction and installation of infrastructure, portions of the sites will undergo immediate rehabilitation. More than half of the clearing associated with the well pads and the gas and water gathering systems will be rehabilitated.

- Following the decommissioning of infrastructure, full rehabilitation of sites will be undertaken.

The areas rehabilitated will be determined by a range of factors including safety, security and bush fire asset protection requirements. Along the gas and water gathering systems, up to 60% of the corridors will be rehabilitated as soon as practicable following the installation of infrastructure to reduce the level of habitat fragmentation.

Current rehabilitation of previous exploration activities

Rehabilitation of existing exploration and appraisal activities is currently being undertaken. These activities provide a benchmark for understanding the potential reduction in impact as a result of rehabilitation works identified for the Project.

Santos has commenced a program of rehabilitation works throughout PEL 238 and PAL 2. Rehabilitation works include:

- Reducing the size of existing well leases back to the minimum area required for operations.
- Plugging and abandoning, according to legislative requirements, wells that are no longer required for exploration and appraisal and rehabilitating associated well leases.
- Rehabilitating a number of water storage ponds that are no longer required for exploration and appraisal activities.

Actions undertaken during the clearing of vegetation include stockpiling ‘waste’ timber from felled trees not suitable for forestry activities, fallen logs and bush rock for later use in habitat restoration; low vegetation is slashed and mulched on site; and topsoil is striped and stockpiled. Rehabilitation actions include replacing topsoil, re-installing habitat features such as fallen timber and bush rock, natural re-establishment of slashed and cleared native vegetation, and direct seeding where required.

Monitoring of rehabilitation activities has shown an overall site value close to 45% of nearby reference sites after two years. The replacement of topsoil is producing encouraging results, with sites showing a high number of native species when compared to reference sites. Rehabilitation measures undertaken have been considered using adaptive management principles with monitoring informing future modifications to works and methodology.

Rehabilitation works associated with the Project will follow the methods developed for the existing exploration and appraisal activities.

Santos has identified approximately six hectares of vegetation dieback which has resulted from the actions of the previous operator (Eastern Star Gas). The affected areas occur within the White Cypress Pine – Bulloak – Ironbark woodland of the Pilliga area of the Brigalow Belt South Bioregion BVT adjacent to areas cleared for infrastructure. Santos has progressed rehabilitation of these areas in consultation with the NSW Government.

To date, rehabilitation of approximately 28 hectares of land, including the vegetation dieback areas, has commenced.

Offsetting

Following the application of all reasonable measures to avoid and mitigate impacts to MNES, any residual significant impacts to the species/communities will be offset in a single consolidated biodiversity offset package developed in accordance with the NSW Biodiversity Offsets Policy for Major Projects.

5 Conclusion on the likelihood of significant impacts

5.1 Do you THINK your proposed action is a controlled action?

	No, complete section 5.2
X	Yes, complete section 5.3

5.2 Proposed action IS NOT a controlled action.

NA

5.3 Proposed action IS a controlled action

	Matters likely to be impacted
	World Heritage values (sections 12 and 15A)
	National Heritage places (sections 15B and 15C)
	Wetlands of international importance (sections 16 and 17B)
X	Listed threatened species and communities (sections 18 and 18A)
	Listed migratory species (sections 20 and 20A)
	Protection of the environment from nuclear actions (sections 21 and 22A)
	Commonwealth marine environment (sections 23 and 24A)
	Great Barrier Reef Marine Park (sections 24B and 24C)
	Protection of the environment from actions involving Commonwealth land (sections 26 and 27A)
	Protection of the environment from Commonwealth actions (section 28)
	Commonwealth Heritage places overseas (sections 27B and 27C)
X	Water resources, in relation to coal seam gas and large coal mining developments (‘water trigger’) (sections 24D and 24E)

As detailed above, the Project has the potential to impact on several threatened flora and fauna species, TECs, as well as water resources. Consequently, Santos believes the Project is a controlled action.

The total extent to which impacts will be realised depends on a number of factors, which will be determined during a detailed impact assessment phase. Santos is committed to minimising impacts to MNES as much as practicable during the construction and operation of the Project and where complete avoidance is not possible, management and mitigation measures will be implemented.

6 Environmental record of the responsible party

		Yes	No
6.1	**Does the party taking the action have a satisfactory record of responsible environmental management?** See also further information in section 6.2 below.	X	
6.2	**Has either (a) the party proposing to take the action, or (b) if a permit has been applied for in relation to the action, the person making the application - ever been subject to any proceedings under a Commonwealth, State or Territory law for the protection of the environment or the conservation and sustainable use of natural resources?** Santos Limited acquired Eastern Star Gas Limited (ESG) on 17 November 2011. The applicant, Santos NSW (Eastern) Pty Ltd, is a subsidiary of ESG and became a wholly owned subsidiary of Santos Limited on its acquisition of ESG on 17 November 2011. In July 2012 ESG was issued two penalty infringement notices (PINs) for pollution incidents which occurred at the Bibblewindi Water Treatment Facility prior to November 2011. The details of these PINs are as follows: • Pollution of Bohena Creek on 11 March 2010 due to discharge of permeate, from the reverse osmosis (RO) plant at Bibblewindi, with electrical conductivity levels above background • Pollution of Bohena Creek on 25 November 2010 due to discharge of permeate, from the RO plant at Bibblewindi, with electrical conductivity levels above background. In June 2013 proceedings were commenced in the Land and Environment Court against Santos NSW (Eastern) Pty Ltd for breaches of the *Petroleum (Onshore) Act 1991* (NSW) for past reporting failures in relation to natural gas operations in the Pilliga in north west NSW. Santos NSW (Eastern) Pty Ltd is a subsidiary of ESG and became a wholly owned subsidiary of Santos Limited on its acquisition of ESG on 17 November 2011. Santos NSW (Eastern) Pty Ltd was fined $52,500 after pleading guilty to the charges.. On 11 February 2014, Santos NSW (Eastern) Pty Limited was issued with a PIN in respect of water pollution from Bibblewindi Pond 3. The RO plant at Bibblewindi Water Treatment Facility ceased operation on 15 December 2011. Santos has been progressively rehabilitating the areas affected by the incidents and progressing alternative arrangements for managing existing produced water stored at Bibblewindi Pond 3. State approval has been granted to transfer water currently stored at this facility to the Leewood Produced Water Facility. With respect to proceedings relating to other Santos entities, on 10 September 2003, the Moonie Pipeline Company Pty Ltd, a Santos controlled entity, pleaded guilty to a charge under Section 437(2) of the Queensland Environmental Protection Act 1994 related to an oil spill at Lytton on 18 March 2003. The Moonie Pipeline Company Pty Ltd was fined $300,000 with no	X	

conviction recorded.

6.3	**If the party taking the action is a corporation, will the action be taken in accordance with the corporation's environmental policy and planning framework?** The Project will be planned and carried out in accordance with Santos' Environmental Policy (attached).	X	
6.4	**Has the party taking the action previously referred an action under the EPBC Act, or been responsible for undertaking an action referred under the EPBC Act?**	X	

Santos NSW (Eastern) Pty Ltd referred the Energy NSW Coal Seam Gas Exploration and Appraisal Program under the EPBC Act in June 2013. The outcome of this referral was not a controlled action if undertaken in a particular manner decision (Reference number 2013/6918)

ESG also referred a number of actions which were subsequently withdrawn. These include:

- Eastern Star Gas Limited/Energy generation and supply (non-renewable)/25 km SW of Narrabri, 80km NNE of Coonabarabran/NSW/Narrabri Coal Seam Gas Field Development (Reference number 2011/5914)
- Eastern Star Gas Limited/Energy generation and supply (renewable)/Coolah to Newcastle/NSW/Gas Transmission Pipeline (Reference number 2011/5917)
- Eastern Star Gas Limited/Energy generation and supply (non-renewable)/43 and 45 Greenleaf Road, Kooragang Island, Newcastle/NSW/Newcastle LNG export facility (Reference number 2011/5915)
- Eastern Star Gas Limited/Energy generation and supply (non-renewable)/Pipeline extends 285-294 km between Wellington and Narrabri/NSW/Narrabri to Wellington gas transmission pipeline (Reference number 2011/5913).

With respect to other Santos entities, a number of actions involving onshore and offshore petroleum exploration and production activities have been referred under the EPBC Act including:

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- Santos Limited/Energy generation and supply (non-renewable)/Central Southern Queensland/QLD/Santos GLNG Gas Field Development Project, QLD (Reference number 2012/6615)
- Santos Ltd/Energy generation and supply (non-renewable) area around Emerald, Injune, Taroom and Roma townships/WLD/Coal Seam Gas Field Development for Natural Gas Liquefaction Park Curtis Island (Reference number 2008/4058)
- Santos Ltd/Energy generation and supply (non renewable)/Curtis Island, Near Gladstone/QLD/Development of a Natural Gas Liquefaction Park (Reference number 2008/4057)
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- Santos Ltd/Exploration (mineral, oil and gas - marine)/Browse Basin/WA/Offshore Gas Exploration Drilling Campaign (Reference number 2012/6384)

- Santos Offshore Pty Ltd /Exploration (mineral, oil and gas - marine)/Within Commonwealth Waters of the Joseph Bonaparte Gulf/WA/Fishburn2D Marine Seismic Survey (Reference number 2012/6659)
- Santos Limited/Energy generation and supply (non-renewable)/152km North of Dampier, Western Australia/Commonwealth Marine/Fletcher-Finucane Development, WA26-L and WA191-P (Reference number 2011/6123)
- Santos Limited/Exploration (mineral, oil and gas - marine)/76km north of Barrow Island, WA/Commonwealth Marine/Santos Winchester three dimensional seismic survey- WA-323- P & WA-330-P (Reference number 2011/6107)
- Santos QNT Pty Ltd/Energy generation and supply (non-renewable)/40km South of Gunnedah/NSW/George's Island Pilot Wells Development (Reference number 2011/6022).

7 Information sources and attachments

(For the information provided above)

7.1 References

Australian Energy Market Operator (AEMO). 2013. *2013 National Electricity Forecasting Report.* 68pp.

Australian Pipeline Industry Association (APIA) 2011. *APIA Code of Practice Upstream PE Gathering Networks CSG Industry*, version 1.1

Belcher, C. Burnett, S. and Jones, M. 2008 "Spotted-tailed Quoll, Dasyurus maculus". In: *The Mammals of Australia* (Third Edition). Ed. Van Dyke, S. and Strahan, R. Reed New Holland

Biolink 2013. *Koala habitat & population assessment: Ballina Shire Council LGA.* Final report to Ballina Shire Council.

BirdLife International (2014a) *Species factsheet: Bubulcus ibis*. Downloaded from http://www.birdlife.org on 11/04/2014. Recommended citation for factsheets for more than one species: BirdLife International (2014) IUCN Red List for birds. Downloaded from http://www.birdlife.org on 11/04/2014.

BirdLife International (2014b) *Species factsheet: Myiagra cyanoleuca*. Downloaded from http://www.birdlife.org on 11/04/2014. Recommended citation for factsheets for more than one species: BirdLife International (2014) IUCN Red List for birds. Downloaded from http://www.birdlife.org on 11/04/2014

Churchill, S. 2008. *Australian Bats*. Second Edition. Allen and Unwin, Crows Nest

Carter, O. 2010. *National Recovery Plan for the Spiny Peppercress Lepidium aschersonii*. Department of Sustainability and Environment, Melbourne.

Department of Environment & Climate Change New South Wales (DECC) 2005a, *Tylophora linearis – Profile*, viewed 8 May 2008, available at http://www.threatenedspecies.environment.nsw.gov.au /tsprofile/profile.aspx?id=10815

Department of Trade, Investment, Regional Infrastructure and Services (DTIRIS) 2012. *NSW Code of Practice for Coal Seam Gas Well Integrity*

Department of the Environment (DotE) 2014a. *Anthochaera phrygia* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:42:34 +1100

Department of the Environment (DotE) 2014b. *Botaurus poiciloptilus* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:43:41 +1100

Department of the Environment (DotE) 2014c. *Lathamus discolor* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:44:26 +1100

Department of the Environment (DotE) 2014e. *Polytelis swainsonii* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:46:04 +1100

Department of the Environment (DotE) 2014f. *Dasyurus maculatus maculatus* (SE mainland population) in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:46:32 +1100

Department of the Environment (DotE) 2014g. *Nyctophilus corbeni* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:46:57 +1100

Department of the Environment (DotE) 2014h. *Chalinolobus dwyeri* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:47:16 +1100

Department of the Environment (DotE) 2014i. *Phascolarctos cinereus* (combined populations of QLD, NSW and the ACT) in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:47:34 +1100

Department of the Environment (DotE) 2014j. *Pseudomys pilligaensis* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:47:55 +1100

Department of the Environment (DotE) 2014k. *Dichanthium setosum* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:48:31 +1100

Department of the Environment (DotE) 2014l. *Homopholis belsonii* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 14:59:10 +1100

Department of the Environment (DotE) 2014m. *Lepidium monoplocoides* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 28 Mar 2014 16:45:16 +1100

Department of the Environment (DotE) 2014n. *Rostratula australis* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 09:59:03 +1000.

Department of the Environment (DotE) 2014o. Brigalow (*Acacia harpophylla* dominant and co-dominant) in Community and Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 2014-04-11T13:39:49EST.

Department of the Environment (DotE) 2014p. Weeping Myall Woodlands in Community and Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed 2014-04-11T13:44:24EST.

Department of the Environment (DotE) 2014q. *Haliaeetus leucogaster* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:03:50 +1000.

Department of the Environment (DotE) 2014r. *Apus pacificus* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:06:21 +1000.

Department of the Environment (DotE) 2014s. *Hirundapus caudacutus* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:08:13 +1000

Department of the Environment (DotE) 2014t. *Ardea modesta* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:09:47 +1000.

Department of the Environment (DotE) 2014u. *Ardea ibis* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:11:03 +1000.

Department of the Environment (DotE) 2014w. *Merops ornatus* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:14:29 +1000.

Department of the Environment (DotE) 2014v. *Myiagra cyanoleuca* in Species Profile and Threats Database, Department of the Environment, Canberra. Available from: http://www.environment.gov.au/sprat. Accessed Fri, 11 Apr 2014 14:15:31 +1000.

Department of Primary Industries, Parks, Water and Environment (DPIPWE) 2010. *Threatened Species, Swift Parrot, Lathamus discolour.* Available from http://www.parks.tas.gov.au/file.aspx?id=7019. Accessed 9 April 2014.

Department of the Environment, Water, Heritage, and the Arts (DEWHA) (2009a). *Weeping Myall Woodlands Policy Statement*. Available from http://www.environment.gov.au/system/files/resources/a887e6ec-f4db-4476-8e72-977085028dbd/files/weeping-myall-woodlands.pdf. Accessed 2014-04-11T13:44:24EST.

Department of the Environment, Water, Heritage and the Arts (DEWHA) 2009b. *Draft EPBC Act Policy Statement 3.21 – Significant Impact Guidelines for 36 Migratory Shorebird Species*. Commonwealth Department of the Environment, Water, Heritage and Arts, Canberra.

Garnett, S.T. & G.M. Crowley 2000. *The Action Plan for Australian Birds 2000*. [Online]. Canberra, ACT: Environment Australia and Birds Australia. Available from: http://www.environment.gov.au/biodiversity/threatened/publications/action/birds2000/index.html.

GHD. 2014. *Narrabri Gas Project – Preliminary Environmental Assessment*, Santos NSW (Eastern) Pty Ltd. http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=6456

Harden, G.J. (ed) 1990. *Flora of New South Wales Volume 1*. Royal Botanic Gardens and New South Wales University, Sydney.

Harris, S. and Smith, S. 2000. *Flora and Fauna Guarantee Action Statement No 111: Spiny Pepper-Cress Lepidium aschersonii*. Department of Natural Resources and Environment, Melbourne.

Mavromihalis, J. 2010. *National Recovery Plan for the Winged Peppercress Lepidium monoplocoides*. Department of Sustainability and Environment, Melbourne.

Menkins, I 1998, *Draft report for survey of Homopholis belsonii C.E. Hubb. on the Darling Downs*, Toowoomba and Region Environment Council Inc, Toowoomba.

Milledge, D. 2012. *National significance – the ecological values of Pilliga East Forest and the threats posed by coal seam gas mining 2011-2012*. A report prepared for the Northern Inland Council for the Environment and the Coonabarabran and Upper Castlereagh Catchment and Landcare Group.

National Parks and Wildlife Service (NPWS) 1999a. *Threatened Species Information for Regent Honeyeater* (Xanthomyza phrygia). National Parks and Wildlife Service

National Parks and Wildlife Service (NPWS) 1999b. *Threatened Species Information for Spotted-tailed Quoll* (Dasyurus maculatus). National Parks and Wildlife Service.

National Parks and Wildlife Service (NPWS) 2000. *Brigalow Belt South: Regional Assessment (Stage 1) - Report on Preliminary Fauna Survey of Pilliga and Goonoo Forests, November 1999 to January 2000*. Report prepared for the Resource and Conservation Assessment Council, NSW Western Regional Assessments

National Parks and Wildlife Service (NPWS) 2002. *Bertya sp. Cobar-Coolabah (Cunningham & Milthorpe s.n., 2/8/73) Recovery Plan*. NSW National parks and Wildlife Service.

National Parks Association (NPA) 2002. *Pilliga State Forest Flora and Fauna Survey, 14th – 19th November 2001*. Report prepared for National Parks Association of New South Wales

NSW Chief Scientist & Engineer 2013. *Initial report on the Independent Review of Coal Seam Gas Activities in NSW*. Report prepared for the NSW Premier.

NSW Scientific Committee 2008a. *Final determination to list Bertya opponens as a vulnerable species*.

NSW Scientific Committee 2008b. *Tylophora linearis P.I.Forst (Apocynaceae) Review of Current Information in NSW*.

Office of Environment and Heritage (OEH). (2014a). *Atlas of NSW Wildlife*. Available: http://wildlifeatlas.nationalparks.nsw.gov.au/wildlifeatlas/watlas.jsp

Office of Environment and Heritage (OEH). (2014b). *Threatened species profiles*. Available, http://www.environment.nsw.gov.au/threatenedspecies/

Paull, D. C. and Date, E. M. 1999. P*atterns of Decline in the Native Mammal Fauna of the North-west Slopes of New South Wales*. *Australian Zoologist*. 31: 210 – 224

Paull, D.C. & D. Milledge (2011). *Results of the survey for the Pilliga Mouse Pseudomys pilligaensis in Pilliga East State Forest (October 2011) and review of habitat requirements*. Unpublished report.

Santos and Eco Logical Australia (2013). *Referral of proposed action - Santos NSW (Eastern) Pty Ltd, Energy NSW Coal Seam Gas Exploration and Appraisal Program, Gunnedah Basin, NSW.* Available from: http://www.environment.gov.au/cgi-bin/epbc/epbc_ap.pl?name=current_referral_detail&proposal_id=6918

Schulz, M. and Lumsden, L. 2010. (Draft) *National Recovery Plan for the South-eastern Long-eared Bat* Nyctophilus corbeni. Victorian Department of Sustainability and Environment

Trémont, RM & Whalley, DB, 1993, *Final Report for Survey for Homopholis belsonii*, Toowoomba and Region Environment Council Inc, Toowoomba

Threatened Species Scientific Committee (TSSC) (2003). NON-CURRENT *Commonwealth Listing Advice for Rostratula australis (Australian Painted Snipe).* [Online]. Available from: http://www.environment.gov.au/biodiversity/threatened/species/r-australis.html.

Threatened Species Scientific Committee (TSSC) (2008). *Advice for Weeping Myall Woodlands*. Available from: http://www.environment.gov.au/biodiversity/threatened/communities/pubs/98-listing-advice.pdf

Threatened Species Scientific Committee (TSSC) (2010). *Advice for Dichanthium setosum (bluegrass).* Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/14159-listing-advice.pdf

Turbill, C. Lumsden, L. F. and Ford, G. I. 2008. "South-eastern and Tasmanian Long-eared Bats (*Nyctophilus* sp.)". Pp. 527-528. In: *Mammals of Australia* (Third Edition). Ed by S. Van Dyke and R. Strahan. Reed New Holland.

7.2 Reliability and date of information

All information relied on in the compilation of this document has been sourced from reliable, established sources, such as reputable specialist consulting firms and government agencies. The most up-to-date information available has been provided.

7.3 Attachments

		✓ attached	Title of attachment(s)
You must attach	figures, maps or aerial photographs showing the Project locality (section 1)	✓	Included in section 2
	figures, maps or aerial photographs showing the location of the Project in respect to any matters of national environmental significance or important features of the environments (section 3)		Detailed mapping of the location of MNES is currently underway. This will be provided during the detailed impact assessment phase.
If relevant, attach	copies of any state or local government approvals and consent conditions (section 2.5)		N/A
	copies of any completed assessments to meet state or local government approvals and outcomes of public consultations, if available (section 2.6)		Currently under preparation.
	copies of any flora and fauna investigations and surveys (section 3)		Numerous flora and fauna investigations have been used to prepare this referral. A comprehensive ecological impact assessment document will be prepared during the detailed impact assessment phase which will detail the results from surveys undertaken within the Project area from 2005 to date.
	technical reports relevant to the assessment of impacts on protected matters that support the arguments and conclusions in the referral (section 3 and 4)		Numerous technical reports have been used to prepare this referral. A comprehensive ecological impact assessment and water resources assessment will be prepared during the detailed impact assessment phase which will assess the potential impacts of the Project on MNES.
	report(s) on any public consultations undertaken, including with Indigenous stakeholders (section 3)		N/A

8 Contacts, signatures and declarations

Project title:

8.1 Person proposing to take action

Name	Neale House
Title	Manager Environment and Water - Energy New South Wales
Organisation	Santos NSW (Eastern) Pty Ltd
ACN / ABN (if applicable)	009 321 662 / 11 009 321 662
Postal address	Level 16, 40 Creek Street, Brisbane QLD 4000
Telephone	07 3838 3861
Email	Neale.House@santos.com
Declaration	I declare that to the best of my knowledge the information I have given on, or attached to this form is complete, current and correct. I understand that giving false or misleading information is a serious offence. I agree to be the proponent for this action. I acknowledge that I may be liable for fees related to my proposed action following the introduction of cost recovery under the EPBC Act.
Signature	[signature] Date 28/10/14

8.2 Person preparing the referral information

Name	Martin Sullivan
Title	Manager Hunter Region
Organisation	Eco Logical Australia Pty Ltd
ACN / ABN (if applicable)	87 096 512 088
Postal address	PO Box 1056, Newcastle NSW 2300
Telephone	02 4910 0125
Email	martinsullivan@ecoaus.com.au
Declaration	I declare that to the best of my knowledge the information I have given on, or attached to this form is complete, current and correct. I understand that giving false or misleading information is a serious offence.
Signature	[signature] Date 28/10/14

FEATURE	SENSITIVITY	DESCRIPTION
Garrawilla Volcanics	Low – feature has medium quality and rarity on a local scale	Water quality generally unknown but considered likely to be unsuitable 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 – feature has low quality and rarity on a local scale	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 – feature has low quality and rarity on a local scale	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 Ecosystems, springs and wetlands	High – feature has high quality and rarity on a regional or national scale	High priority GDEs exist at Eather, Hardys and Mayfield springs GDEs are likely to be used by threatened/migratory species, as described in relevant sections above Adopting the precautionary principle, it is assumed that these GDEs are of high sensitivity
Stygofauna populations	High – feature has high quality and rarity on a regional or national scale	Stygofauna communities may exist in the unconsolidated alluvium within the Project area. Given the depth of the proposed CSG wells, their separation from the alluvium, geological features between, the significant irrigation extraction directly from the alluvium, their sensitivity has been designated as low

Groundwater use within the Project area is limited. This is attributed both to land use constraints arising from the Project area largely coinciding with the footprint of the Pilliga and lower bore yields associated with the consolidated rock units.

It is understood from the NSW Office of Water (NOW) bore database PINEENA 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 Project 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, poor water quality and availability of better quality groundwater near the surface.

Compared with the assessment conducted in accordance with the Significant Impact Guidelines for the Exploration and Appraisal Program, an assessment of the Project indicates that the duration and wider geographic extent of depressurisation of groundwater head within the coal seams and adjacent strata will cause a significant impact to the groundwater resources of the Gunnedah-Oxley Basin. However, due to the depth of the target coal seams, low hydraulic conductivity of the target strata and poor hydraulic continuity with overlying strata, the overlying groundwater features of greater sensitivity (Pilliga Sandstone, alluvium) are highly unlikely to experience significant impact.

Tony Pickard

From: "Tony Pickard" <deere@activ8.net.au>
Date: Saturday, 14 March 2015 2:13 PM
To: <nwalliance@healthyland.com.au>; <narrabri@pilliga.com.au>; <coalcommunities@lists.nsw.greens.org.au>
Attach: r b2a Bohena2b leakingwell soileffectebysalts 21-07-2011.jpg; r b2b Bohena2b notcental-cementmissing 14-1-2012.JPG; r b2c Bohena2b 8-4-2012.JPG; r b2dBohena2b cut-offwellheadof2ndwell leakingwater 13-04-12.JPG; r b2e Bohena2b returnedplugcement veryweak 30-10-2011.JPG; r b4a Bohena4L on 4-4L 14-1-2012.JPG; r b4b Bohena4 on 4-4L 21-1-12.JPG; r b4c on Boh 4-4L plugcementseemstonothavenotattachedtowellbore 8-4-12.JPG; r b5a Bohena5 innercasingsnotcentraltooutercasing 14-1-2012.JPG; r b5b Bohena5 innercasingnotcentral 21-1-2012.JPG; r b5c Bohena5 inner casingnotcentral 22-2-2012.JPG; r d5a Dewhurst5 corroded casingnowater-cellarhas waterinit 17-9-2011.JPG; r d5b Dewhurst5 corrodedconditioncementwillnotseal 17-09-2011.JPG; r D6ca Dewhurst6c casingnotcentreandnocement 22-1-12.JPG; r D6cb Dewhurst6c notcentralandnocement 28-3-2012.JPG; r d10a Dewhurst10 NO CEMENT betweencasings NOTEWATERbetweencasings 17-09-2011.JPG; r d10b Dewhurst10 NO CEMENT betweencasings 12-5-12.JPG; r LastCentury OilExplorWells whoismonitoringthese 6-8-2011.JPG; r lastCentury OilExplorWells whoismonitoringthese 6-8-2011.JPG
Subject: My Presentation to the March 2015 Narrabri Gas Project CCC.

To All
Attached are the photographs that formed the presentation that I was allowed to give the Narrabri Gas Project CCC on Gas Well Integrity. This presentation was in response to the Office of Coal Seam Gas presentation on the same subject the month before.
At the start of the presentation I explained the time frame and current status of the wells in the presentation.
I explained that the first lot up until Dewhurst 6c were now plugged and abandoned and these photos showed why the Community were concerned about well Integrity from the older gas wells as well as some newer wells that are not plugged and abandoned one even being part of the Dewhurst 22-25 Pilot that being Dewhurst 6c.
Dewhurst 10 is at this stage just siting there not far from Dewhurst 26-29 Pilot.
There are also photos of earlier Oil Well drillings which raise the question as to who actually is responsible for their condition monitoring. and there were videos at the end (never got to show these).

The first photo drew a few gasps, but it was not until the 4th photograph came up that Santos started to get upset, and when I say upset that is being polite, and asked questions of the Chair as to why I was showing photographs of wells put in by previous companies which had now been plugged and abandoned. I replied that these photographs showed wells that were not central, poor cementing and poor quality of plugging returned cement (pond shot and sample) and that when the wells were cut off who were they going to be monitored for casing and cementing condition, deterioration of either could lead to cross contamination of aquifers and if the wells were like this at the top then what were they like further underground, this all went to show the community concerns about old and new Well Integrity, something that the OCSG presented on last month.

The presentation continued on until the view of the cement coming away from the down-hole shot on Bohena 4. When Santos again got agitated and the Chair then indicated that these were all plugged and abandoned and did I have recent photos, I replied yes and moved through the photos at a speed that was slow enough for all to see the condition (remarks thrown in as often as possible). Until we arrived at Dewhurst 6c with its off-centre casing and Dewhurst 10 with the missing cement.
The Chair inquired as to when these wells went in to which I replied 2009/2010.
These two really hurt Santos and the OCSG because I informed the Chair that these two well cellars were now filled with large sized rail ballast rock thus making it almost impossible to check if Santos had fixed or hidden the problems, but they were photographed just prior to being filled in and the problems were still there then. This then presents a recent case for wondering the condition of the well further down.
The Chair asked the representative representing OCSG if he knew anything about this and could the OCSG look into the monitoring of these wells.
Santos then jumped in and asked me if I had seen their recent wells to which I replied “no”, I have not jumped the fence, but then corrected my statement and said that I had jumped the fence at Dewhurst 10 to take a another photo of the missing cement and that is how I know about the rocks in the cellars, but not their recent wells
We moved onto the Oil Wells and I asked the question as to who was monitoring these wells for their condition.
By this time the Committee was silent and I resummoned my seat.

Quote from my minutes of the meeting: ***"After the photo presentation Santos was adamant this was before their time and was Eastern Star Gas. Many of the CCC members said that Eastern Star Gas was not a good operator – some comments were not flattering to ESG at all -- Russell Stewart and the Chair".***

Almost at the end of the meeting the Chair was asked a question as to who was responsible to monitor the wells of all ages and who was responsible if something were to happen.
The Spokeswoman for the EPA answered that the current holder of the Licence was that person or body and that the responsibility for all previous actions was passed on with the Licence.

Santos was not happy at all.

Tony Pickard

MGPA.001.001.2202.pdf

Summary of Comments on MGPA.001.001.2202 my bore URS Bacteria testing see 0027 .pdf

Page: 1

Number: 1 Author: Tony Subject: Sticky Note Date: 15/05/2017 4:35:21 PM

See page 5.
Santos was advised that if my bore had E'Coli Bacteria in it Santos was advised to assist in locating the source.
Santos never came back to try and locate the source of the contamination, all Santos did was to make statements to the media.

URS

Memorandum

Date: 23 April 2012

To: Stephen Tapsall

From: Julian Long, Principal Water Quality Scientist

Subject: Heterotrophic plate count results for sample NAR_7525_BORE_W

This memorandum has been prepared to provide an interpretation of the significance of the heterotrophic plate counts recorded in a sample of bore water recently collected by URS during the bore survey being undertaken for Santos in the Narrabri area. This memo has been structured in four parts these being:

- The role of heterotrophic plate counts in drinking water safety
- Guidelines for heterotrophic place counts in drinking water
- Heterotrophic plate count results and interpretation
- Recommendations

The role of heterotrophic plate counts in drinking water safety

Heterotrophs can be broadly defined as microorganisms that require organic carbon for growth and include bacteria, yeasts and moulds. The culture-based tests that are intended to recover heterotrophs from water are referred to as heterotrophic plate counts.

HPC testing has a long history of use in water quality assessment. By the end of the 19th century, HPC tests were employed to assess the functioning of water treatment processes and thereby as indirect indicators of water safety. Use of heterotrophs as a safety indicator declined during the 20th century with the adoption of specific faecal indicator bacteria.

There is no evidence in the available literature that HPC values alone directly relate to health risk. They are therefore considered to be unsuitable as basis for the setting of water quality targets for public health or as the sole justification for issuing "boil water" advisories. Abrupt increases in HPC levels may sometimes be attributable to faecal contamination but tests for *E. coli* or other faecal-specific indicators and other information are essential for determining whether a health risk exists.

Guidelines for heterotrophic place counts in drinking water

Guidelines for drinking water in Australia are specified under the National Health and Medical Research Council Australian Drinking Water Guidelines 2011.

The guidelines do not specify a guideline value for heterotrophic plate counts in drinking water. HPCs are endorsed for operational use as a measure of water disinfection effectiveness and in distribution systems to assess whether a chlorine residual has been maintained. Heterotroph concentrations would be expected to be low following successful disinfection of drinking water.

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GPO Box 302, QLD 4001
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URS

Heterotrophic plate count results and interpretation

A water sample was collected from the subject bore on 22nd March 2012. The sample was delivered to the laboratory for analysis on 26th March 29 and was delivered to the laboratory packed in ice. The sample was analysed for heterotrophs which could be cultured at 20°C and also for heterotrophs which be cultured at 37°C using heterotrophic plate count methods. The heterotrophs which could be cultured at 20°C are indicative of microorganisms which can replicate under ambient conditions whilst those that can be cultured at 37°C may be indicative of microorganisms which can replicate within animal hosts since this temperature is equivalent to body temperature..

The results of the HPC analysis are provided in Table 1 below.

Table 1 HPC Results

Sample	Sample Date	Heterotrophic Plate Count 48hr@37°C (cfu/100mL)	Heterotrophic Plate Count 72hr@20°C (cfu/100mL)
NAR_7525_BORE_W	22nd March 2012	54,000	136,000

There is no guidance available in the Drinking Water guidelines by which the significance of these results can be assessed. Heterotrophs however are known to be associated with unpleasant tastes in drinking water.

The results do indicate that heterotrophs were present at concentrations of 54,000 colony forming units per 100mL which are capable of being cultured at 37°C and would therefore be capable of reproducing at human body temperatures. This may be indicative of faecal pollution of the bore but this is not necessarily the case. Confirmation of this would require follow up sampling for *E. coli* or other faecal-specific indicators to determine whether faecal contamination had occurred and whether a health risk exists.

In the absence of addition microbiological information an assessment of the nutrient results for the sample was undertaken since elevated nutrient concentrations are often associated with water contamination by animal and human faeces. The nutrient results for the sample are provided Table 2.

Table 2 Nutrient Results for Bore Sample

Nutrient	Concentration (mg/L)
Ammonia	0.08
Nitrite	<0.01
Nitrate	0.15
Total Kjeldahl Nitrogen	<0.1

URS

Nutrient	Concentration (mg/L)
Total Nitrogen	0.20
Total Phosphorus	<0.01

Ammonia in particular is generally accepted to be an indicator of potential faecal pollution but the ammonia results for the bore sample are well below guideline values. The other nutrient results comply with water quality objectives for a range of environmental values and are lower than would be expected if faecal contamination of the bore had occurred.

Summary of findings

In summary the HPC results show that heterotrophs were present in the bore that were capable of reproduction at 37°C. Available nutrient data does not confirm that the source of the heterotrophs is a consequence of contamination of the bore with animal or human faeces. Follow up testing should be undertaken to confirm the HPC results and this should be accompanied by testing for *E. coli* and other faecal-specific indicators to determine whether a health risk exists. In the event that subsequent testing indicates that the heterotroph concentrations detected were due to faecal contamination of some kind it is highly unlikely that such contamination would be attributable to CSG activity unless there is wastewater treatment plant associated with the CSG operation in the near vicinity that is malfunctioning.

Recommendation

There is considerable ambiguity regarding the significance of the heterotrophic plate counts recorded for the bore sample particularly in the context of the low nutrient concentrations present in the sample. In order to establish whether the heterotrophic plate counts recorded are indicative of a potential health risk associated with the consumption of water from the bore the following recommendations should be implemented:

- Re-sample the bore for heterotrophic plate count, and the following indicators of potential faecal contamination
    - E. coli
    - Enterococci
    - Aeromonas
    - Pseudomas aeruginosa
    - Chlostridium perfringens
    - Campylobacter
    - Cryptosporidium
    - Giardia

URS

- Interpret the results of the additional microbiological data to assess the health risk posed by consumption of the bore water in terms of faecal contamination and advise the landholder of the outcome.
- 1 In the event that faecal contamination is detected assist the landholder in undertaking an investigation to identify the source of the contamination. 2

It is further recommended that the HPC test should be removed from the analytical suite for further analysis of bore samples collected during the bore survey. This should be replaced with *E. Coli*.

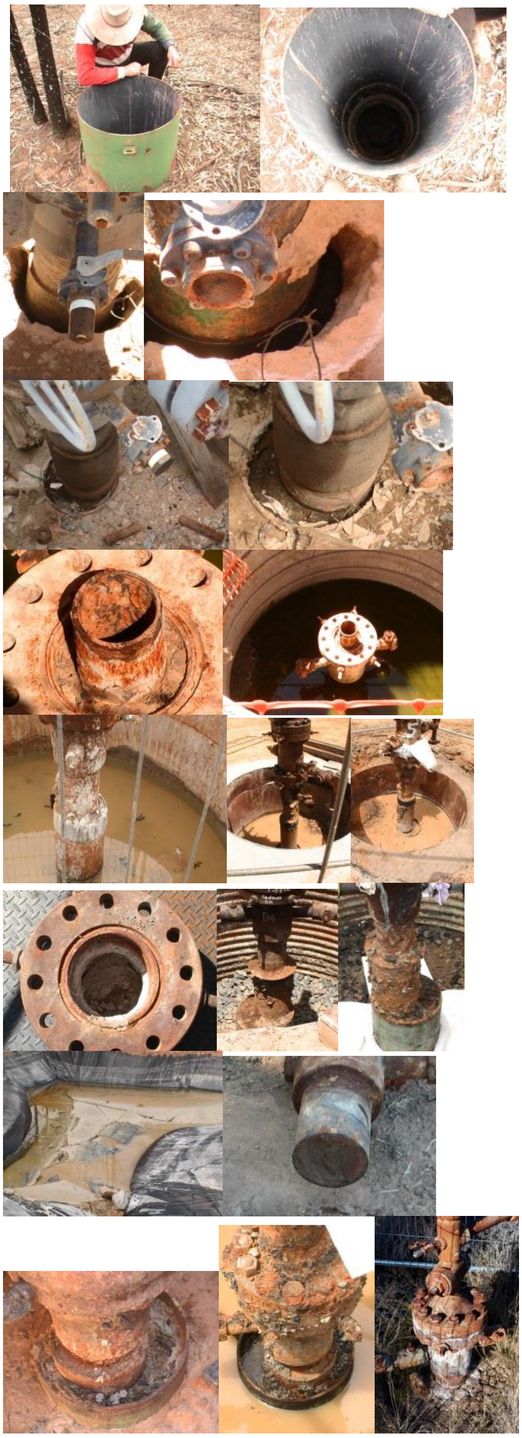
Page: 5

Number: 1 Author: Tony Subject: Highlight Date: 15/05/2017 4:32:28 PM

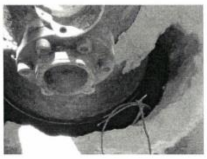
Number: 2 Author: Tony Subject: Sticky Note Date: 15/05/2017 4:32:20 PM

Santos advised to assist in locating source of contamination by URS.
Santos never assisted just made remarks to the media based on no actual "ground work".

Attachment 1



Dewhurst 10 + VIDEO



THIS Shows The lack of cement between the two casings at the very top where it should not be.

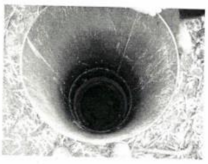
THE DISTURBING Factor here is it looks like there may have been a better cement Seal (by the tongue of Cement on the inner casing) !

So what happend, Did the Cement weaken off due to being passed through water and eventually erroded away. Note water in between casing

What ever the reason this is a perfect example why the public do not trust the So called Well Integrity Policy or the CSG Industry to do the correct thing.

THIS IS AT THE Very Top Of The Well - So what are the conditions underground.

Oil Wells from the last Century.



Some examples of the new outer upper protection casings of these wells.

THIS Well itself is about 3 meters down.

- Who is Monitoring the Condition of these wells
- Are they plugged?. if So will that plug last.
- Who is going to carry out the conditions of correct abandoning or is there a reason why this will not be done

5

Dewhurst 5 + VIDEO..
Plugged and abandonded.

Casing covered by water and has been since 2009.

Corrosion both inside & outside the casing
No Aquifer casing visiable.

Note heavy Scale on inside and outside of casing. What damage to the outer casing has occured further down.
Will the plugging cement stick and Seal the insides of this Well.
and Was the inside cleaned out & how.
does Santos have photos to prove their answer?

Dewhurst 6c (video)
Well is now part of the Dewhurst 22-25 Pilot.

Note the poor casing centralisation and lack of Cement.

Now this IS AT The very top of the well, so what are conditions like in regards to cementing and Centralisation of Casings below the grounds Surface

Santos has filled this collar with large Rail ballast type rocks
why?

There is a short Video.

4.

Bolena 5 + Video

Note the poor casing Centeralisation between an inner and outer casing.

Bolena 5

Note the poor centralisation between the 2 inner casings.

Bolena 5

another photo showing the poor centralisation between the two inner casings

THIS Well was plugged and abandonded.

If THIS Centralisation ISSUE IS here why Not also Down Wel

Bolena 2b.

There were 2 wells on the Bolena 2 well pad. THIS is ONE OF THEM

We will be following this Well

I have No actual photographic Record of the Second wells plugging and abandoning Only a photo that shows its Existence.

Bolena 2b

Note that the casings are not central.

THE Outer casing is supposed to protect the upper aquifers of the GAB.

Bolena 2b

a better shot showing how all the casings are not central, the lack of Cement between the casings.

This lack of Cement is really evident due to the fresh cement added between the outer casing & the 2nd Inner.

If it's like this here why not down well?

Bolena 2b

this is the cutoff well head and calls into question exactly how many casing there actually were to start with.

There is produced water still dripping from the cut-off Section. THIS Well was plugged in late October 2011 and cut-off in April 2012

So why is there produced Salty Water, if the plugging was done correctly?

3

Bolena 2

THIS is A Lined Pond containing the "returned" plugging cement from Bolena 2b

A Sample of this cement can be seen in the plastic bag - IT IS very light and can easil be crushed to dust. The reason for this is that it has been passed through water (down well) and this f has removed many of the cements properties. - THERE is A SHORT VIDEO.

Bolena ~~4~~-4L (video)

There were two wells on this site known as Bolena 4-4L

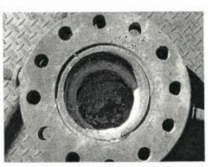
THIS is 4L - L= Longitudional and linked up with Bolena 2b. THIS was The first Longitudion well drilled by ESG. There is more to this Story Now is not the time.

Note that the Casings are together and are not central. If it is here at the top why not in Other locations down well?

This is Bolena 4 (The other well on the 4-4L

As you can see this well is Not central either.

THERE is A Short Video following this slide



This is looking down Bolena 4 after it was plugged

Note that the plugging cement is not adhearing to the inside of the casing

If it is like this at the top where else has the same problem.

THIS is A Perfect environment for SRBs to live thrive and attack the casing from the inside.

No – do not worry. Glad to help.

Just to put you in the know. I am currently advising some CSG developers in Queensland on the same issue and they ask similar question – like “where does the salt in groundwater come from” and “what is the salt that is found in coal seam deposits?” etc. So it seems from both sides people want answers and wants to understand these issues. Hopefully after all is said and done the environment remains the winner.

OK – your question I guess refers to potassium mud which drillers use to try and stabilise clays by preventing them to swell.

To tell you the truth I do not think they use a formula. The amount of stabilizing additives like KCl or liquid polymer or even bentonite will depend on the driller and the formation he is drilling into. If he is running into drilling problems with the clays keep swelling or his hole keep collapsing he will keep adding his additives. In America they have some standard limiting concentrations of KCl to below ±5600mg/l. The potential risk of additives should be accessed based on the context of the environment even though it is always claimed it is non-toxic or biodegradable.

Loss of drilling fluid – from nothing to 100%. The drillers do not want to lose any drilling fluid and part of the additives purpose is to prevent this from happening but I think they would probably loose at least 50% of their fluids on a drilling
program targeting permeable formations with water in it.

Regards

Adriaan

Adriaan du Toit Hon. BSc Geol, PrSciNat
Senior Hydro- & Environmental Consultant

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Hi [redacted]

No – do not worry. Glad to help.

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Regards
Adriaan

Adriaan du Toit *Hon. BSc Geol, PrSciNat*
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From: [redacted]
Sent: Monday, 8 March 2010 6:24 PM
To: Du Toit, Adriaan
Subject: CSG

Hi Adriaan,
Many thanks for your help. Could you tell me how much potassium chloride is used per drill hole or a formula on how to work it out - for CSG exploration and extraction? Also - how much drilling fluid is lost down a hole ie what percentage is

never recovered? Sorry to bother you as I know that you must be very busy.
Kind Regards
[redacted]

.com.au

Australian Museum

Turbidity

Why measure turbidity?

Streamwatch volunteers at Myles Dunphy Reserve
Photographer: I. Kingsley © Australian Museum

Turbidity is a measure of the cloudiness of water. It is caused by tiny particles, such as silt and clay, organic matter and microscopic plants and animals suspended or floating in the water.

High turbidity reduces the penetration of sunlight into water and can limit photosynthesis and hence the growth of aquatic plants. It therefore affects the animals that rely on these plants for food and shelter.

Turbidity can make it difficult for animals to breathe by clogging or damaging their gills, or making it difficult for animals that filter-feed to collect food. As the suspended particles settle to the bottom they can also smother animal habitats, eggs and larvae.

Turbid water also heats up more than clear water, which can reduce the amount of dissolved oxygen available for animals to breathe. Over time, unatural levels of turbidity can reduce the biodiversity in a waterway.

Causes of turbidity:

- soil erosion due to heavy rainfall or floods
- erosion of the banks of a waterway
- sediments from building sites
- stormwater
- loss of vegetation cover especially within the riparian zone

Karen Player , Manager Museum Outreach
Hayley Bates
Last Updated: 7 October 2015

Tags Streamwatch, citizen science, turbidity, soil erosion,

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Baseline Project Ref: 86828a
September 9th, 2012.

Samples Collected August 6th 2012.
Samples Received 12:10h August 8th, 2012. Temperature at receipt 10.1°C.
All seals intact at receipt.
Sample Analyses commenced 08/07/2012, 16.00h.
Re: Assays Total Coliforms, Faecal Coliforms, *E.coli, Sulphate Reducing Bacteria, Heterotrophic Plate Counts*

		Sulphate Reducing Bacteria (SRB) adapted from APHA (1995) in house MPN 14d @ 28°C		Heterotrophic Plate Count AS 4276.3.1 48h @ 37°C	Heterotrophic Plate Count AS 4276.3.1 72h @ 22°C	Total Coliforms 48h @ 35.0°C MMG medium	Faecal Coliforms 24h@ 44.5°C MMG medium
		Positive *Desulfovibrio* sp Baseline Lab Isolate	Negative *P.aeruginosa* NCTC 6749	Positive *E.coli* ACM 845	Positive *Serratia* sp Baseline Lab Isolate	Positive *E.Coli* ACM 845	Positive *E.Coli* ACM 845
Sampler Description	Baseline Sample No	Most Probable Number*	95% Confidence Limits			Total Lactose acid @ 35.0°C *E.coli* EMB sheen + Indole	Faecal Lactose acid @ 44.5°C *E.coli* EMB sheen + Indole
120562-BcO Water with heavy orange precipitate)	12814	160 000 SRB/100mL	54 000 to 480 000 SRB/100mL	37 000 CFU^/mL	870 000 CFU^/mL	MPN 400 Coliform/100mL 95% 140 to 1200 Coliform/100mL; MPN 8 *E.coli* /100mL 95% 2 to 40 Coliform/100mL	MPN 78 Faecal Coliform/100mL 95% 25 to 240 Coliform/100mL; MPN 27 *E.coli* /100mL 95% 8 to 100 Coliform/100mL
		Iron Precipitating Bacteria (IPB) adapted from British Environment Agency 1998		Iron Reducing Bacteria (IRB) MPN Method adapted from Gould (2003)		Hydrocarbon Utilizing Bacteria (HUB) Pour Plate Assay	Naphthalene Utilizing Bacteria NUB Pour Plate Assay
		Positive Baseline "MB5" Bore sample Baseline Lab Isolate Pure culture		Positive *P.aeruginosa* NCTC 6749	Negative *E.agglomerans* Baseline Lab Isolate	14d @ 28oC	14d @ 28oC
Sampler Description	Baseline Sample No	Most Probable Number*	95% Confidence Limits	Most Probable Number*	95% Confidence Limits	Positive *P.aeruginosa* #34 Baseline Lab Isolate	Positive *Bacillus* sp. Baseline Lab Isolate
120562-BcO Water with heavy orange precipitate)	12814	>160 000 IPB/100mL Delayed positive reaction for last MPN tube indicated many different forms principally including *Ochrobium* -like & another non-flexuous filamentous form (Photographed)	> 54 000 IPB/100mL	>160 000 IRB/100mL	> 54 000 IRB/100mL	10 600 CFU HUB/mL	335 000 CFU NUB/mL

Notes:
*MPN Most Probable Number
~SRB Sulphate Reducing Bacteria
^CFU Colony Forming Units
SRB Medium Controls:- Negative: *Pseudomonas aeruginosa* NCTC 6749; Positive: *Desulfovibrio* sp. Baseline Isolate.
IPB Control Inidentified Baseline Bore water isolate of Iron Oxidizing Bacteria and previous sample Bore MB5.
IRB Positive Control *Pseudomonas aeruginosa* NCTC 6749; Negative Control *E.aglomerans* Baseline Isolate
HUB Positive Control P.aeruginosa #34; NUB Positive Control *Bacillus* sp
Total Coliform & Faecal Coliform Positive *E.coli* ACM 845; HPC growth @ 22°C Positive *Serratia* sp. Baseline isolate.
Limits of Detection:Total Coliform, Faecal Coliform *E.coli*, SRB, IRB IPB 4CFU/100mL; HPC, HUB & NUB 1 CFU/mL;

Laboratory work undertaken by S. Nearhos August 2012. September (Micro-exams) 2012.

Report checked & authorized: S.P.Nearhos Ph.D. MASM September 9th, 2012.

Steven Nearhos

Senior Microbiologist

Prepared for

Santos Limited

Bibblewindi Water Treatment Plant

Preliminary Remediation Plan

Final Report

March 2012

Reference: 920534 / J8XAPT0FS

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Project No: 920534 / J8XAPT0FS

Report No: 01

Original Date of Issue: 2 March 2012

Project Manager: Mark Favetta (Halcrow)

REPORT DETAILS

Title:	**Preliminary Remediation Plan – Bibblewindi Water Treatment Plant**
Author(s):	**Ben Farmer, Michael Leviton, Jim Jordahl, Vivienne Wilson, Emma Walsh, Max Porter**
Client:	**Santos Limited**
Client Contact:	**Neale House**
Client Reference:	**920534 / J8XAPT0FS**
Synopsis:	**This preliminary remediation plan has been prepared to provide planning guidance and information regarding remediation and restoration of the impacted areas down gradient of the Bibblewindi Water Treatment Plant (BWTP). The objective of this preliminary remediation plan is to present the regulatory requirements, immediate response actions and potential remedial works associated with the management of the source contamination and the restoration of the impacted bushland at the BWTP based on the current data and known history of the site.**

REVISION / CHECKING HISTORY

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				Santos	Halcrow	NSW ORE	CH2M File
A	28 Feb 2012	B. Farmer	--	--	1(e)	--	1(e)
B	28 Feb 2012	M. Porter	--	--	1(e)	--	1(e)
C	29 Feb 2012	P. Wilkinson	--	--	1(e)		1(e)
0	29 Feb 2012	M. Favetta	M.Favetta	1(e)	1(e)	--	1(e)
1	2 Mar 2012	Santos Ltd	M. Favetta	1(e)	1(e)	--	1(e)
2	2 Mar 2012	Santos Ltd	M. Porter	1 (e)	1 (e)	1 (e)	1(e)
3	16 Mar 2012	NSW ORE (M&ED)	M. Porter	1 (e)	1 (e)	1 (e)	1(e)
4	22 Mar 2012	Santos Ltd	M. Porter	1 (e)	1 (e)	1 (e)	1 (e)
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Executive Summary

Santos Limited (Santos) – acquired Eastern Star Gas Limited (now a Santos Limited company) (ESG) in November 2011. A detailed review into ESG's operations in the Pilliga East State Forest is currently occuring. During this review, Santos identified that ESG had failed to advise the relevant Regulators of the uncontrolled discharge of process water from the Bibblewindi Water Treatment Plant (BWTP) on 25 June 2011. In addition to that incident, Santos discovered a further significant discharge that is likely to have occurred during 2010 along with a number of smaller incidents during the operational life of the BWTP. It appears that the uncontrolled discharges have impacted the native bushland located down gradient of the BWTP.

In February 2012, Santos commissioned Halcrow Pacific Pty Ltd (Halcrow) (a CH2M HILL company) to develop this preliminary remediation plan, which outlines the plan for management of the source of contamination and the restoration of the impacted bushland. The following are the remediation and restoration objectives for the BWTP:

- Prevent further degradation of the area; and
- Return the impacted area down gradient of the BWTP to a self-sustaining native forest condition, typical of adjacent reference forest ecosystems.

As part of the rehabilitation of the impacted bushland at the BWTP, this preliminary remediation plan has been developed to provide the following information:

- Site description, including site status and the surrounding environment;
- Summary of the site history and existing information;
- Description of the contamination that has been identified;
- Description of potential immediate response actions;
- Identification of data gaps and subsequent data collection activities;
- Discussion of potential remediation options, documenting the various remedial options that have been considered for each of the impacted media (groundwater, surface water, soil and vegetation); and
- Identification of regulatory compliance requirements.

The BWTP is located within the Pilliga State Forest and is approximately 36 kilometres (km) south south-east of Narrabri, New South Wales (NSW) and 8 km east of the Newell Highway. An area (15,500 m^2) of vegetation die-back and visually stressed vegetation, along with black residue across the ground surface, is located immediately down gradient and to the south of the BWTP, identified as the 'impacted area'. Further down gradient and to the south east of the 'impacted area', is another area where the black residue is also present on the ground surface, however the vegetation does not appear to be stressed.

Golder Associates Pty Ltd (Golder) undertook a soil investigation in January 2012, which consisted of a site inspection to visually assess the extent of the impacted and affected areas and to collected soil samples to assess the contamination status. Halcrow/CH2M HILL assessed the data set and concluded that contamination in the soil samples does not present a human health risk, but that elevated levels of sodium have resulted in sodic soil conditions. Sodic soils are typical characterised by poor stability, very low permeability, formation of a surface crust and often water logging, all of which have been visually observed at the site.

After review of background information and completion of a site walkover, Halcrow/CH2M HILL have developed a preliminary remediation plan, which consist of the following components:

- Immediate Response Actions
  - Groundwater – isolate groundwater flow, if present, into the impacted and affected areas to promote drying of water logged soils and to reduce the likelihood of further impact from potentially contaminated groundwater migrating into the impacted area.
  - Surface Water – short term diversion of surface water away from the impacted area to assist in maintaining integrity of the soil structure and allowing the impacted area to dry
  - Preliminary Restoration – preparatory restoration works in the impacted area to remove dead or fallen vegetation for stockpiling. The vegetation can be used during the restoration works to provide habitat, slow release food source and to assist with minimising erosion.
  - Soil Restoration Trials – preliminary trials of identified remedial techniques in the impacted and affected area to assess their feasibility for full scale implementation.
- Investigation and Characterisation Program
  - Contaminated Land Assessment - to address several identified data gaps which will involve identification of the presence of shallow groundwater, groundwater quality and flow direction; assessment of the integrity of the water storage ponds; assessment of soil contamination at the BWTP inlet manifold; and vertical and horizontal delineation of contaminants in soil within the impacted and affected areas.
  - Baseline Flora/Fauna Surveys - to characterise soil fauna, and tree, shrub and forb species including plant community structure and to identify a reference ecosystem nearby or adjacent to the affected area to characterise the same ecosystem components and provide a guide for revegetation work and a basis for monitoring of the restored system.
  - Soil Assessment - to determine the extent of saline impacts and/or the suitability of the current soil quality to support restoration and revegetation of the impacted and affected areas.

Completion of the above tasks will provide the necessary data to select a preferred remediation technique and enable development of a remediation, restoration and revegetation plant for the BWTP.

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Abbreviations	
bgl	Below ground level
BWTP	Bibblewindi Water Treatment Plant
CLA	Contaminated land assessment
CH2M HILL	CH2M HILL Australia Pty Ltd
DP	Deposited plan
EIL	Ecological Investigation Level
EPA	Environmental Protection Authority
ESG	Eastern Star Gas Limited (a Santos Limited company)
ESP	Exchangeable Sodium Potential
Golder	Golder Associates Pty Ltd
ha	Hectares
Halcrow	Halcrow Pacific Pty Ltd
HIL	Health based investigation level
km	Kilometres
m	Metres
mm	Millimetres
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NSW	New South Wales
ORE	Office of Resource and Energy
RO	Reverse osmosis
Santos	Santos Limited
SEPP	State Environment Planning Policy
SVOC	Semi volatile organic compounds
TOC	Total organic carbon
TRH	Total recoverable hydrocarbons
VOC	Volatile organic compounds

1 Introduction

1.1 General

Santos Limited (Santos) – acquired Eastern Star Gas Limited (now a Santos Limited company) (ESG) in November 2011. A detailed review into ESG's operations in the Pilliga East State Forest is being undertaken. During this review, Santos identified that ESG had failed to advise the relevant Regulators of the uncontrolled discharge of process water from the Bibblewindi Water Treatment Plant (BWTP) on 25 June 2011. In addition to that incident, Santos discovered a further significant discharge that is likely to have occurred during 2010. Santos has been unable to identify exactly when that spill occurred or the volume of water released. A number of smaller incidents have also occurred during the operational life of the BWTP. The location of the BWTP is presented on **Figure 1.** It appears that the uncontrolled discharges have impacted the native bushland located down gradient of the BWTP. Preliminary results of environmental investigations carried out around the BWTP indicate that the impact to vegetation is from elevated salt and alkalinity levels.

As a result of the concerns about operations at the BWTP, Santos scaled back operations in the Pilliga, including ceasing operations at the BWTP pending a full review of the BWTP adequacy and integrity.

In February 2012, Santos commissioned Halcrow Pacific Pty Ltd (Halcrow) (A CH2M HILL company) to develop this preliminary remediation plan, which outlines the plan for management of the source of contamination and the restoration of the impacted bushland. The preliminary remediation plan will be submitted to Forests New South Wales (Forests NSW) and the NSW Office of Resources and Energy (ORE).

1.2 Remediation and Restoration Objectives

Santos is committed to the rehabilitation of the impacted areas down gradient of the BWTP and is implementing immediate improvements to operational practices at ESG's former sites. The following remediation and restoration objectives are proposed to:

- Prevent further degradation of the area; and
- Return the impacted area down gradient of the BWTP to a self-sustaining native forest condition, typical of adjacent reference forest ecosystems.

1.3 Outline of the Preliminary Remediation Plan

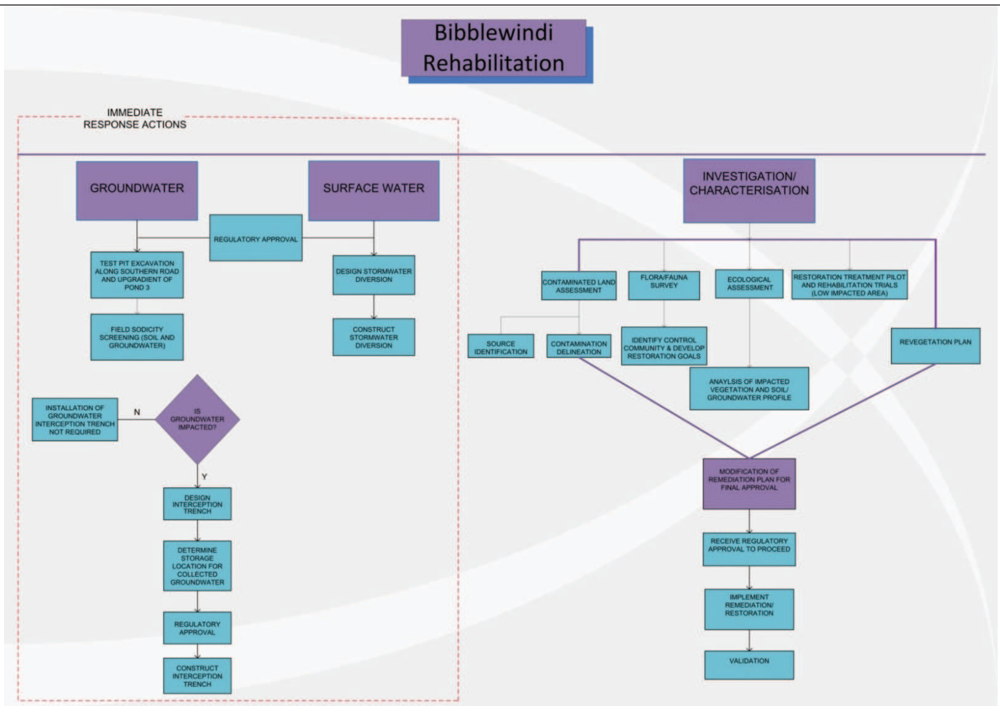
The objective of this Preliminary Remediation Plan (PRP) is to clearly present the regulatory requirements, immediate response actions and potential remedial works associated with the management of the source contamination and the restoration of the impacted bushland at the BWTP based on the current data and known history of the site. The preliminary remediation plan includes the following:

- Site description, including site status and the surrounding environment;
- Summary of the site history and existing information;
- Description of the contamination that has been identified;
- Description of potential immediate response actions;

- Identification of data gaps and subsequent data collection activities;
- Discussion of potential remediation options, documenting the various remedial options that have been considered for each of the impacted media (groundwater, surface water, soil and vegetation); and
- Identification of regulatory compliance requirements.

A process flow diagram presenting an overview of the preliminary remediation plan is presented as **Figure 1-1**. Details pertaining to the flow diagram are provided within this plan.

Figure 1-1 - Remediation Process Flow Diagram



1.4 Limitations

This preliminary remediation plan is provided strictly in accordance with, and subject to, the following limitations:

- The preliminary remediation plan was prepared for Santos Limited – ("the Client") in accordance with the Scope of Work agreed between Halcrow and the Client.
- Halcrow and CH2M HILL assumes no responsibility for conditions we were not authorised to investigate.
- This report is based, in part, on unverified information supplied to Halcrow and CH2M HILL from several sources during the project research. Therefore, Halcrow and CH2M HILL does not guarantee its completeness or accuracy, and assumes no responsibility for errors or omissions related to this externally supplied information.
- An understanding of the site conditions depends on the integration of many pieces of information; some regional, some site specific, some structure-specific and some experienced-based.
- The previous investigations reviewed during the preparation of this preliminary remediation plan identified actual surface and subsurface conditions only at those locations where samples were taken and when they were analysed. This data has been interpreted and an opinion rendered regarding the overall environmental conditions.
- Because of the inherent uncertainties in sub-surface evaluations, changed or unanticipated sub-surface conditions may occur that could affect total project cost and execution. Halcrow and CH2M HILL do not accept responsibility for the consequences of variations in the site conditions.
- This report should not be altered, amended or abbreviated, issued in part and issued incomplete in any way. Halcrow and CH2M HILL accepts no responsibility for any circumstances that arise from the issue of the report which has been modified as outlined above.
- This report has been prepared for the exclusive use of the Client relating to the property as described in the report. No warranty, expressed or implied, is made. There are no beneficiaries to this report other than the Client, and no other person or entity is entitled to rely upon this report without the written consent of Halcrow and CH2M HILL, and a written agreement limiting Halcrow and CH2M HILL's liability.

2 Site Description

The following section provides identification details and a summary of the current condition of the BWTP and the surrounding area.

2.1 Site Identification

The BWTP is located within the Pilliga State Forest and is approximately 36 kilometres (km) south south-east of Narrabri, New South Wales (NSW). The BWTP is positioned at the junction of Garland and X Line Road, approximately 8 km east of the Newell Highway. The location of the BWTP is shown on **Figure 1**.

Table 2-1 summarises the site identification.

Table 2-1 - Site Identification

Item	Description
Street Address	Garlands Road, Pilliga State Forest, NSW
Area	Approximately 2 hectares (ha)
Local Government Area	Narrabri
Current Zoning	Crown Land State Forest
Current Land Use	Coal Seam Gas Exploration

The BWTP does not lie within a registered Lot and Deposited Plan (DP) number. However, part of the affected area, described below in **Section 2.2**, is located within Lot 7 of DP 757126.

2.2 Site Status

The layout of the BWTP and the surrounding area is presented on **Figure 2**. There are nine coal seam gas well pads (Bibblewindi 1-9) located in the immediate vicinity. Numerous other exploration and lateral wells are located in the Narrabri area. The gathered gas is piped to Wilga Park via a pipeline with the groundwater produced during the gas extraction piped to the BWTP for treatment. Three ponds surround the BWTP and are used to store groundwater extracted from the coal formation, produced brine from the treatment process, surface water run-off from the bunded site and drilling fluid. There is an existing approval for the discharge of treated water 'permeate' from the BWTP to Bohena Creek.

An area of vegetation die-back and visually stressed vegetation, along with black residue across the ground surface, is located immediately down gradient and to the south of the BWTP, identified as the 'impacted area' on **Figure 2**. The 'impacted area' has an area of approximately 15,500 square metres (m^2). Further down gradient and to the south east of the 'impacted area', is another area where the black residue is also present on the ground surface, however the vegetation does not appear to be stressed. This area is identified as the 'affected area' on **Figure 2** and has an area of approximately 8,295 m^2.

2.3 Surrounding Land Use and Potential Receptors

The BWTP is surrounded by the Pilliga State Forest. The type of vegetation found surrounding the BWTP is a White Cypress Pine- Bulloak- Ironbark Forest (RPS, *Bibblewindi*

Spill Incident, Matters of National Environmental Significance Assessment, 2012) and typical of the vegetation in the Pilliga State Forest.

Given the location of the BWTP, potential human receptors for contamination at the BWTP are predominantly the workers at the BWTP. There may be occasional recreational users of the Pilliga State Forest who would have limited exposure to any potential contamination.

Potential ecological receptors are the surrounding bushland and down-gradient surface water bodies. The surrounding bushland is within the Pilliga State Forest.

A natural drainage channel is located approximately 600 metres (m) to the south west of the BWTP. This channel flows to the north for approximately 1 km, where it flows into Bohena Creek. Bohena Creek is a well defined, planar sand channel capable of accepting significant volumes of surface runoff during periods of high surface flow. Bohena Creek has a large sandy river bed, with only base surface flow.

2.4 Topography, Drainage and Hydrology

The BWTP site is relatively flat, however the ponds have been built up above the natural elevation and provide relief across the site. Regional topography is gently undulating, and the BWTP is located at one of the higher elevation points. The land slopes gently away from the BWTP in all directions.

The impacted and affected areas slope gently away from the BWTP towards the south-west. The approximate elevation change between BWTP and the natural drainage channel is 6 m.

Surface water at the BWTP flows in a general south west direction towards the natural drainage channel. Observations during a recent site walkover by Halcrow / CH2M HILL appeared to indicate the surface water flows follow the path of the ‘impacted’ and ‘affected’ areas to the south west.

2.5 Lithology

The 1:250,000 Narrabri geological sheet indicates that the BWTP and surrounding area is situated on Quaternary sand with minor silty sands.

Based on borelogs from adjacent groundwater wells, it is believed that the area is underlain by the Pilliga sandstone formation at an approximately depth of 2.0 m below ground level (bgl). Visual observations during the recent site walkover identified outcropping sandstone at several locations nearby to the BWTP.

2.6 Hydrogeology

A search of registered groundwater bore records from the NSW Natural Resource Atlas was reviewed by Halcrow / CH2M HILL on the 27 February 2012. Four registered groundwater bores are located within 5 km of the BWTP. The bores are utilised for mixed usage, including industrial, oil exploration and domestic stock.

Table 2-2 - Summary of Registered Groundwater Bores

Bore ID	Total Depth (m)	Standing Water Level (mbgl)	Approx. Dist. from BWTP (km)	Date Installed	Purpose
GW021998	73.8	--	4.9 km SW	Jul 1964	Oil Exploration
GW968789	84.0	26.0	4 km NE	Oct 2008	Domestic Stock
GW967935	93.0	--	1 km N	Aug 2006	Industrial
GW967923	90.0	36.0	At BWTP	Aug 2006	Industrial

Lithology descriptions from the bores indicate that sandstone or compacted sand is present at approximately 2.0 mbgl. This is consistent with site observations of sandstone outcropping in the area surrounding the BWTP. Shallow groundwater was not noted in the borelogs, however due to the depth wells and construction techniques, identification of shallow groundwater would have been difficult.

As described in **Section 2.3**, the nearest water course to the BWTP is an unnamed natural drainage channel, located approximately 600 m to the south east. This unnamed natural drainage channel is a tributary to Bohena Creek. It is not known whether shallow groundwater in the vicinity of the BWTP would discharge into the unnamed natural drainage channel and then into Bohena Creek or flow beneath the unnamed drainage channel and contribute to the baseflow of Bohena Creek.

3 Site History and Contamination Status

The results of a review of previous investigations in relation to the contamination status of the BWTP and surrounding area are discussed below.

3.1 Site History

Santos has been unable to determine whether previous titleholders cleared the land for construction of the BWTP (Santos, *Report into Eastern Star Gas Limited*, 2012). The BWTP comprises three separate water storage ponds and a reverse osmosis (RO) water treatment plant. The BWTP RO plant processes the groundwater extracted from the gas wells. The groundwater produced from the gas wells contains elevated levels of salts (total dissolved solids - TDS). The BWTP removes TDS from the produced water and creates a stream of water with low levels of TDS (permeate) and a waste stream of brine which has much higher TDS concentrations.

Santos acquired ESG on 17 November 2011. A review undertaken since that time indicated that the BWTP appears to have given rise to a number of issues. The plant suffered from apparently multiple leaks and incidents. Given the passage of time, Santos has been unable to determine the volume of water released as a result of these incidents (Santos, 2012).

Following identification of these incidents in December 2011, Santos has ceased operation at the BWTP, pending Santos' review of the operation and operating practices.

3.2 Golders (2012) Soil Investigation

Golder Associates Pty Ltd (Golder) undertook a soil investigation in the vicinity of the BWTP in January 2012, with the results reported in February 2012 (Golder, *Bibblewindi Water Treatment Facility, Soil Investigation*, 2012) (**Appendix A**). Golder undertook a site inspection to visually assess the extent of the area affected by the discharge of process water from the BWTP and collected soil samples to assess the contamination status of the impacted and affected areas.

Golder reported that a black residue, which comprised of a dry, black crust, covered the surface of the impacted and affected areas. The residue was approximately 50 mm thick adjacent the BWTP in the impacted area and thinned to 1-2 mm towards the south-western extent of the affected area. A black / grey silty substance was encountered directly beneath the residue to depths of up to 0.15 mbgl. The underlying natural soils were described as fine to medium grain clayey sand with low to medium plasticity.

The majority of analytical results were reported to be below either the adopted assessment criteria (for both human health and ecological risk from the National Environment Protection Measure), or below the laboratory limit of reporting (LOR) where no criteria existed. The only exceptions were limited minor exceedences of the barium and vanadium ecological investigation limit (EIL).

Levels of total recoverable hydrocarbons (TRH) were reported above the LOR, but below the adopted criteria, in several samples of the black residue. These samples were re-analysed following a silica gel clean-up, which is designed to remove polar organic compounds (i.e. those not associated with petroleum products). Each of the samples that were re-analysed reported TRH concentrations below the LOR, indicating that the black residue is likely attributable to natural organic matter.

Comparison of soil analytical results indicated that the concentrations of heavy metals, TRH, nutrients, salts and pH were generally higher in the surface samples from both the deeper samples collected from the impacted / affected areas and to background concentrations from non-impacted areas. Golder reported that this pattern was most pronounced for barium, strontium, manganese, iron and exchangeable sodium, which Golder noted are generally characteristic of coal seam gas water.

Golder concluded that that the soil in the impacted and affected areas does not appear to represent a human health risk and that the major contributing factor to the observed vegetation stress is most likely the higher concentrations of salts, particularly sodium salts.

3.3 RPS (2012) Ecological Survey

RPS conducted an assessment of the impacted and affected areas at BWTP for Matters of National Environment Significance (MNES) relating to the process water discharge event. The assessment consisted of a desktop review of available information and an on-site vegetation and habitat survey of the impacted/affected areas and surrounding areas.

RPS reported that the vegetation community at the BWTP is a 'White Cypress Pine – Bulloak – Ironbark Forest'. The vegetation was described as a dry shrubby open forest dominated by *Eucalyptus crebra* (Ironbark) *Callitris glaucophylla* (White Cypress Pine) with a shrubby understorey of *Gahnia*, *Leptospermum* and *Acacia* species. The ground cover is primarily native grasses with *Lomandra sp*. occurring regularly. RPS did not identify any endangered ecological communities within or close to the impacted area.

A desktop review of the NPWS Atlas of NSW Wildlife and EPBC Protected Matter indicated the potential for five threatened flora species to be present in the area. RPS did not identify any of these threatened species during the on-site survey.

An assessment of the degradation of habitat in the impacted determined that a reduction in shelter and foraging resources has occurred through impact to foliage, pollen and nectar sources.

The assessment of MNES identified the following species, which had the potential to exist or transit the local area:

- Regent Honey-eater (*Anthochaera Phrygia*);
- Swift Parrot (Lathamus discolour);
- Malleefowl (Leipoa ocellata);
- Superb Parrot (Polytelis swainsonii);
- Pilliga Mouse (Pseudomys pilligaensis)
- Rainbow Bee-eater (*Merops ornatus*); and
- South-eastern Long-eared Bat (*Nyctophilus corbeni*).

A significant impact assessment (as defined by the EPBC Act significant impact criteria) was completed for each of the species listed above. The assessment determined that significant impact had not occurred for each of the species, with the exception of the Pilliga Mouse. RPS concluded that the incident has the potential to have a temporary or permanent impact on the Pilliga Mouse, due to a reduction in population size or decrease in the extent of habitat. While the impact is likely to be small due to the size of the impacted area, the potential impact still exists. It was recommended that any restoration of the impacted area consider the habitat requirements of the Pilliga Mouse. The report also concluded that further investigations into either the possible presence of a local population of the Pilliga Mouse or the long-term effects of the contaminant on the potential habitat, would assist in more accurately assessing the significance of impacts upon this species, if required.

3.4 Site Contamination Status

Known contamination is defined by the impacted and affected areas down gradient of the BWTP. As discussed in **Section 3.2**, Golder collected surface, near surface and subsurface soil samples across the impacted and affected areas and analysed the samples for a wide range of contaminants (**Appendix A**). Sample locations are presented on **Figure 2**.

The soil samples collected by Golders were analysed for the following analytes:

- pH;
- Conductivity;
- Sulphur;
- Exchangeable cations (calcium, magnesium, potassium, sodium, aluminium);
- Bicarbonate extractable potassium and phosphorous;
- Extractable and heavy metals;
- NOx, TKN and total Nitrogen;
- Total organic carbon (TOC);
- Volatile organic compounds (VOC);
- Semi-volatile compounds (SVOC); and
- Total recoverable hydrocarbons (TRH).

Halcrow / CH2M HILL has completed an independent assessment of the Golder data set. Due to the location of the Site within the Pilliga State Forest, assessment of analytical results against NSW Environmental Protection Authority (EPA) human health based (HIL) and ecological investigation levels (EIL) was completed to provide an indication of potential impacts. However, HILs and EILs are only available for a restricted suite of analytes, principally heavy metals and SVOCs and VOCs, and do not provide investigation levels for nutrient, geochemical or ecological parameters for soil. Therefore, average background concentrations were calculated and used to assess the results of soil samples collected within the impacted and affected areas. The following sections provide a summary of the assessment of soil sample results against HIL, EIL and background levels. **Table A** at the end of the report presents the soil sample results for the impacted area, affected area and background locations along with the adopted assessment criteria.

Human Health Investigation Levels

Due to the sensitive nature of the Site, soil sample results were compared to the most conservative NSW EPA endorsed health based investigation level. The NSW Department of Environment and Climate Change (DECC), *Contaminated Sites: Guidelines to the Site Auditor Scheme (2nd edition)*, 2006 presents HIL values for a range of land use scenarios. The most conservative values are for residential land use with assessable soil (HIL A). Therefore the HIL A values have been adopted as the default health based assessment criteria for the Site. The NSW DECC (2006) guidelines do not provide assessment criteria for TPH and several VOC, including benzene, toluene, ethylbenzene and xylene (BTEX), therefore criteria for these analytes has been adopted from NSW EPA, *Contaminated Sites: Guidelines for the Assessment of Service Station Site*, 1994. The criteria listed in the NSW EPA (1994) guideline provide values for protection of human health at sensitive sites.

The concentrations of heavy metals, volatile and semi volatile organic contaminants have been assessed against the HIL A and NSW EPA (1994) criteria, with all results less that adopted assessment criteria.

Ecological Investigation Levels and Background Ranges

Ecological investigation levels presented in National Environment Protection Council (NEPC), *National Environment Protection (Assessment of Site Contamination) Measure (NEPM)*, 1999 are for urban environments in Australia and not applicable for assessment of ecological risk from soil contamination in a regional undeveloped environment. The NEPM (1999) also presents background concentration ranges for several heavy metals. The background ranges are stipulated as generic values that can be applied as a first screening of soil sample results. The NEPM (1999) indicates that site specific values should be determined by collection of uncontaminated samples at the site to determine whether soil quality could negatively impact ecological receptors at the Site.

The concentrations of heavy metals have been assessed against the NEPM (1999) background ranges, with results less than the upper limit of the background ranges.

Site Background Levels

Soil sample results were compared against average background concentrations, which were calculated using results of soil samples collected from locations WTP9, WTP12, WTP16 and WTP19 (**Figure 2**). Background concentrations for three depth intervals were calculated to allow a more detailed assessment.

The majority of heavy metals in surface soil samples (~0 – 0.05 mbgl) exhibited concentrations exceeding the average site specific background concentration. However, the majority of the heavy metal analytes only marginally exceeded the background concentration or were within one order of magnitude. Generally concentrations of heavy metals were greatest in the impacted area with concentrations decreasing at locations further away from the BWTP, with the exception of manganese. Concentrations of manganese at locations WTP10, WTP11 and WTP13 were greater than manganese concentrations at WTP4 and WTP5 located within the central portion of the 'impacted area'. Heavy metal exceedances of background heavy metal concentrations were less common in near surface (i.e. 0.1 – 0.2 mbgl) and subsurface samples (0.4-0.5 m bgl) It is noted the concentrations of heavy metals at location WTP17, located up gradient of the impacted area, are comparable with concentrations of corresponding heavy metal analytes within the impacted area. **Table 3-1** summaries the comparison of heavy metal results with average background concentrations. The data indicates that there is generally a decreasing maximum concentration of heavy metals at depth in the impacted / affected zone.

Table 3-1 - Summary of Heavy Metal Results

Analyte	Units	Background Average - Surface (~0.0-0.05 m)	Background Average - Near Surface (~0.05-0.2 m)	Background Average - Sub Surface (~0.2-0.5 m)	Impacted / Affected Zone Maximum Surface Concentrations / Location	Impacted / Affected Zone Maximum Near Surface Concentration / Location	Impacted / Affected Zone Maximum Sub Surface Concentration / Location
Barium	mg/kg	37.5	20.0	30.0	510 @ WTP3	360 @ WTP3	280 @ WTP7
Chromium (total)	mg/kg	6.0	8.5	12.0	25 @ WTP3	23 @ WTP3	16 @ WTP7
Cobalt	mg/kg	<2.0	2.0	3.0	14 @ WTP7	6 @ WTP3 & WTP17	9 @ WTP17
Copper	mg/kg	<5.0	<5.0	<5.0	8 @ WTP17	--	5 WTP7
Lead	mg/kg	5.0	6.0	6.0	11 @ WTP17	9 @ WTP3	7 @ WTP17, WTP7 & WTP8
Manganese	mg/kg	93.5	9.0	<5.0	344 @ WTP7	216 @ WTP17	13 @ WTP8
Nickel	mg/kg	2.0	2.5	3.0	10 @ WTP3 & WTP17	6 @ WTP17	6 @ WTP17
Strontium	mg/kg	6.3	3.5	4.0	55 @ WTP3	40 @ WTP3	12 @ WTP7
Vanadium	mg/kg	17.5	24.0	35.0	52 @ WTP17	68 @ WTP3	42 @ WTP2 & WTP17
Zinc	mg/kg	<5	<5	<5	22 @ WTP3	8 @ WTP3	--

Concentrations of heavy fraction TRH (C_{10}-C_{36}) were detected in surface soil samples at locations WTP1, WTP2, WTP3, WTP4, WTP5 and WTP13 and near surface samples at locations WTP4, WTP5 and WTP15. Although detections of TRH (C_{10}-C_{36}) were noted, all concentrations were less than the NSW EPA endorsed health based trigger level of 1000 mg/kg for sensitive land use. Several samples were selected for re-analysis for TRH with silica gel cleanup to identify whether detection of TRH were influenced by biological sources within the soil profile. Results of the TRH silica gel cleanup analysis were below the laboratory detection limit, indicating that the detections of TRH (C_{10}-C_{36}) are not attributed to petroleum based contamination. **Table 3-2** summarises the TPH/TRH (C_{10}-C_{36}) detections.

Table 3-2 - Summary of TPH / TRH Sample Results

Sample ID	Depth Interval (mbgl)	Laboratory LOR	TRH (C_{10}-C_{36}) Result (mg/kg)	TRH (C_{10}-C_{36}) Silica Gel Result (mg/kg)
NSW EPA (1994) Criteria	--	--	*1,000*	*1,000*
WTP1A	0.0-0.05	<50	260	<50
WTP2A	0.0-0.05	<50	530	<50
WTP3A	0.0-0.05	<50	270	<50
WTP4A	0.0-0.05	<50	150	<50
WTP4B	0.05-0.1	<50	120	<50
WTP5A	0.0-0.05	<50	890	<50
WTP5B	0.1-0.2	<50	580	<50
WTP13A	0.0-0.05	<50	240	--
WTP15B	0.2-0.3	<50	160	--

Conductivity or salinity levels are significantly greater than background levels from surface samples collected in the 'impacted area', which are up to two orders of magnitude greater than background levels. Similar to heavy metal concentrations, conductivity levels decrease with further distance down gradient from the WTP and increasing depth, with a few minor exceptions.

Concentrations of sodium (Na) within the impacted and affected areas are significantly greater than background levels. Typically, healthy soils have an exchangeable sodium percentage (ESP) of less than 6% (consistent with background levels), with levels of 15% considered extremely sodic. ESP is calculated by dividing the concentration of sodium (meq/100g) by the total concentration of exchangeable cations (i.e. aluminum, calcium, magnesium, potassium and sodium). Many of the samples within the impacted and affected areas have ESP levels >50%. These high ESP values combined with elevated pH levels (8 – 10 pH) appear to indicate that the soil is extremely sodic. Physical symptoms of sodic soils are poor stability, very low permeability, formation of a surface crust and often water logging. These symptoms have been visually observed at the site and along with analytical results appear to indicate that the impacted and affected areas have extremely high sodium concentrations, which has contributed to impacts to vegetation and the soil characteristics.

3.5 Data Gaps

Several data gaps have been identified after review of existing site information, completion of an initial site walkover and assessment of soil sample results from Golder. Prior to selection of a preferred remedial approach and design of the remedial and restoration work plan, closure of the data gaps is required. The identified data gaps are listed below and will be addressed following completion of the items presented in **Section 5**:

- Validation of the presence of shallow groundwater and flow direction.
- Detailed assessment of shallow groundwater quality to determine whether groundwater is transporting contaminants into the impacted and affected areas.
- Detailed assessment of the integrity of the water storage ponds and associated infrastructure at the Site to determine whether leakage from the ponds may have contributed contamination to the impacted and affected areas.
- Assessment of soil contamination at the WTP inlet manifold to determine whether anecdotal evidence of significant leaks at this location have resulted in an ongoing contamination source.
- Vertical delineation of impacts in soil within the impacted and affected areas. It is assumed that surficial soils extend to approximately 2.0 mbgl with current soil sample results only available in the top 0.5 m of the surficial soil profile.
- Detailed ecological assessment of impacted and control community.
- Confirm that the existing data set is representative of site conditions and appropriate for selection of a remedial technique or whether additional sampling is required..

4 Immediate Response Actions

The sections below outline potential immediate response actions, or interim remedial actions, to prevent further degradation of the impacted area. The potential immediate response actions are:

- Stormwater diversion around the impacted area;
- Identification and interception of potentially contaminated groundwater;
- Removal of dead wood lying on the surface of the impacted and affected area to be re-used after site rehabilitation; and
- Restoration Treatment Pilot (Affected Area) and Rehabilitation trials.

Other response actions will be implemented as part of the proposed data collection activities detailed in **Section 5.**

4.1 Surface Water

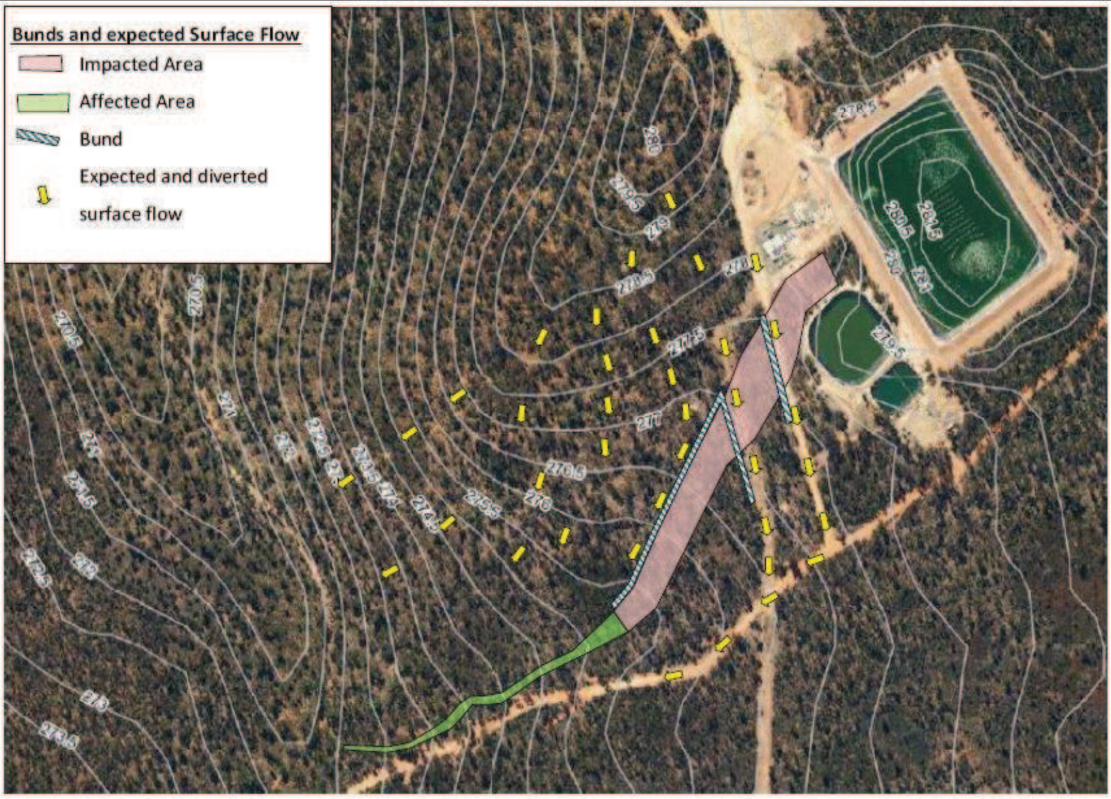
As discussed in **Section 3.4**, sodic soils are highly impermeable due to the dispersion of clay particles within the soil matrix. The soil often becomes water logged as water fills the pore spaces vacated by the dispersive clay. As a result, the following often occurs:

- Ponding of surface water in depressed areas.
- Surface water does not infiltrate into the soils and run across the surface, increasing erosion and washing of nutrients and topsoil into down gradient receptors.

Therefore, short term diversion of surface water away from the impacted area will assist in maintain integrity of the soil structure and allow the impacted area to possibly dry. Construction of surface water flow barrier is typically done by altering levels and creating a berm (or embankment) around which the water flows, or a ditch through which the water flows.

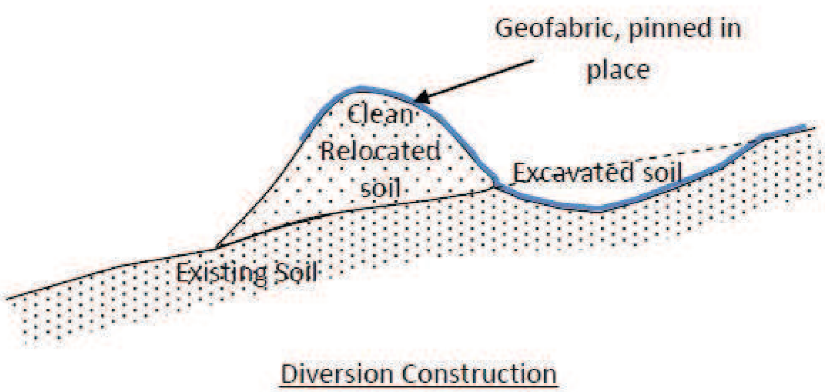
Subject to approval, a surface water flow barrier is proposed up gradient and possibly through the impacted area to divert a high proportion of the water away or from running through the impacted area. Based upon our current knowledge and the local topography, the barrier may be installed as indicated in **Figure 4-1**.

Figure 4-1 - Proposed Surface Water Diversion Layout



As the barrier is a temporary structure, it will not be engineered to withstand ongoing scouring and severe rainfall events, and it may require inspection and maintenance after every heavy rainfall event. However, to prevent excessive maintenance and scouring, a geofabric will be placed over the soil and pinned in place, as shown in **Figure 4-2**.

Figure 4-2 - Surface Water Barrier Schematic Diagram



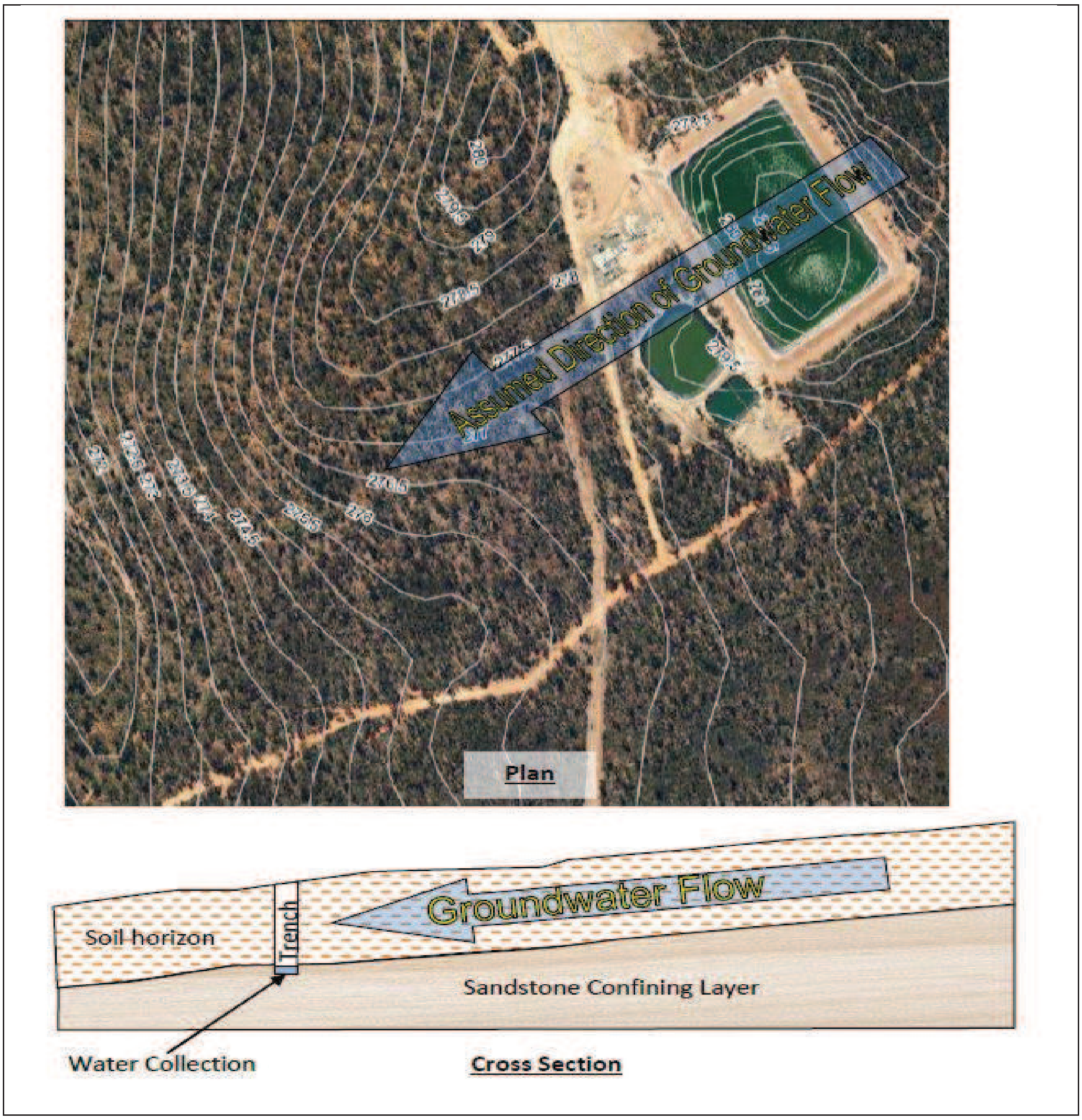
It is anticipated that the surface water barrier could be constructed using hand tools, thus minimise the potential to further damage the vegetation through use of an excavator or backhoe.

4.2 Groundwater

To isolate groundwater flow into the impacted and affected areas an interception trench may be required to promote drying of water logged soils and to reduce the likelihood of further impact from potentially contaminated groundwater migrating into the impacted area.

The shallow groundwater at the BWTP is assumed to flow generally in a north-west to south-east direction (**Figure 4-3**), following to localised topography of the area. It is unlikely that shallow groundwater will be present within the shallow clayey sand soil horizon overlying the Pilliga sandstone formation, however confirmation is required to determine whether groundwater interception is required. As discussed in **Section 2.6**, the Pilliga sandstone is expected to be present approximately 1.8 to 2.0 mbgl.

Figure 4-3 - Inferred Groundwater Flow Direction

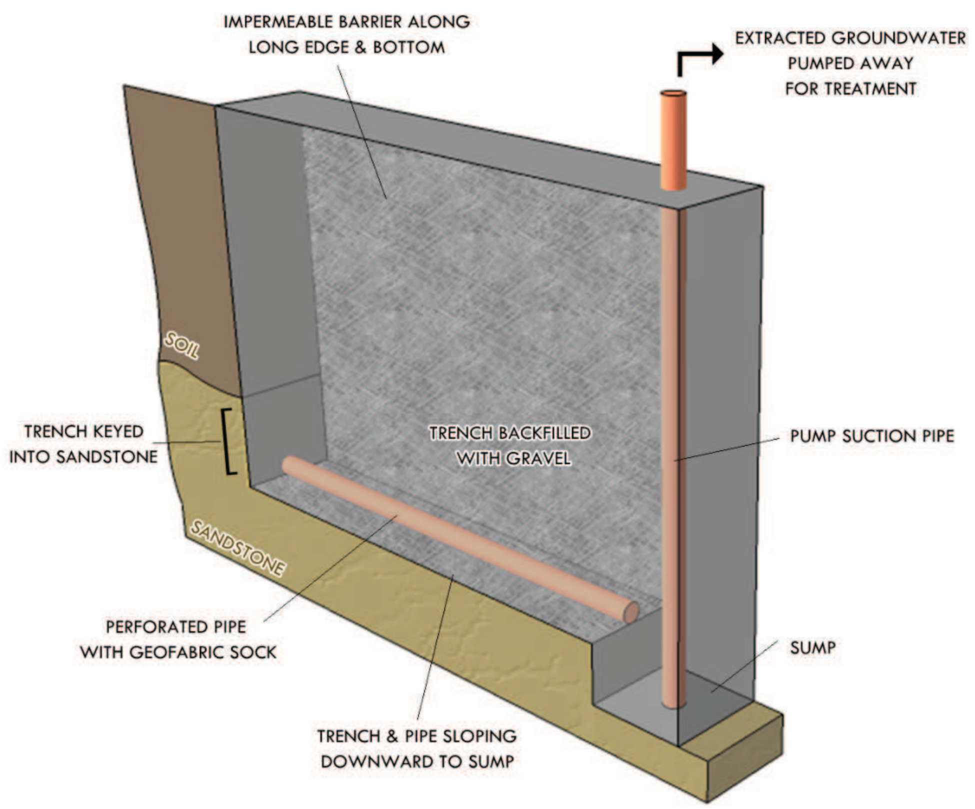


To determine if shallow groundwater is present and impacted, it is proposed that test pits will be excavated to the top of the Pilliga sandstone formation along the proposed location of the trench. Soil samples will be analysed at incremental depths for chemical and geochemistry analytes, with intercepted groundwater assessed as a transport mechanism for salinity and heavy metals into the impacted area. An additional test pit will be excavated up hydraulic gradient of the ponds, as a background location. The test pits will be backfilled immediately after sampling and compacted using the bucket of the excavator.

Once the samples have been analysed, a decision can be made as to whether the soil and groundwater is impacted and a trench needs to be installed. In addition, design specifications for the interception trench will be determined along with how the intercepted groundwater will be managed.

Dissolved salts within the groundwater can be raised by capillary action to the surface and can precipitate onto the surface. Should the groundwater be contaminated with salt, a possible approach to isolate the impacted area is to excavate the interception trench to capture the impacted groundwater. A typical interception trench consists of a slotted PVC pipe within gravel backfill. The gravel keeps the trench open and provides a highly permeable pathway for collection of the groundwater. The groundwater is transported to a collection sump and pumped away for treatment or storage. A schematic interception trench construction is shown in **Figure 4-4**.

Figure 4-4 - Indicative Interception Trench Schematic



Based upon the current site configuration, the possible preferred position of a trench would be along the eastern side of the BWTP western site access road as shown on **Figure 4-5.**

Figure 4-5 – Proposed Location of Interception Trench

Intercepted contaminated groundwater would be collected and pumped to one of the storage ponds pending treatment. However, storage and subsequent treatment of the groundwater may require further design to ensure it can be integrated with the ongoing operations.

4.3 Impacted Area Restoration

Preparatory restoration works could commence in the impacted area in parallel with the further soil assessments. There is currently a significant quantity of dead vegetation present on the surface of the impacted area. This material contains valuable nutrients that are slowly released into the soil profile through natural decomposition. To avoid damage to these potential nutrient sources during subsequent assessment of restoration works, it is recommended that the material is collected and stockpiled off the impacted site for later use during the revegetation works. As well as providing a nutrient source during the revegetation process, the large fallen drunks or branches could provide a habitat to small mammals and other animals.

4.4 Restoration Treatment Pilot and Bench Scale Trials

Other possible immediate actions may be the investigation and completion of a soil treatment pilot in the affected area and a bench scale trial of the impacted area material. There are number options that are currently being considered, with the selection to be made after completion of initial soil testing.

The options for a suitable pilot trial are discussed in detail in **Section 5.4**. In summary, the options are:

- Application of dry gypsum and irrigation by natural rainfall;
- Application of dry gypsum and controlled irrigation;
- Application of dry gypsum, followed by tillage and controlled irrigation;
- Application of a wet slurry of gypsum then tilled into the soil; or
- Multiple applications of gypsum.

The decision regarding which pilot trial is adopted will be based upon some soil tests, which include:

- Dispersion jar test results
- Saturated hydraulic conductivity
- Sodium adsorption ratio
- pH
- Reduced soil moisture.

The short term response action could be to use additions of gypsum to the affected area to minimise any further impact of sodicity on the vegetation.

The bench scale trials will focus on the soil material from the impacted area to evaluate the effectiveness of ex-situ treatment. The bench scale trial could be completed on site or at the Santos office/warehouse in Narrabri. The potential components of a bench scale trial are detailed in **Section 5.5**. In summary, the components are:

- Collection of soil from three locations within the impacted area:
- Construction of treatment trays with underlying drainage layer;
- Pre-treatment testing of the soil as per soil tests detailed above;
- Addition of gypsum in varying dosages and bulking agents;
    - Application of dry gypsum and mechanical mixing followed by one-time water addition (i.e. rainfall event);
    - Application of dry gypsum and mechanical mixing with continuous mist irrigation;
    - Application of dry gypsum and a coarse bulking agent with mechanical mixing and continuous mist irrigation.

  - Application of gypsum slurry and mechanical mixing followed by one-time water addition (i.e. rainfall event); and
  - Application of gypsum slurry and mechanical mixing with continuous mist irrigation;
- Post-treatment testing of soil and leach water to determine effectiveness of treatment process; and
- Geotechnical testing of treated soil to assess suitability for beneficial reuse as backfill material at other sites.

5 Data Collection Activities

5.1 Contaminated Land Assessment

A contaminated land assessment (CLA) will be developed to address several of the data gaps identified in **Section 3.5**. The CLA will focus on the following items:

- Identification of the presence of shallow groundwater, groundwater quality and flow direction;
- Assessment of the integrity of the water storage ponds at the Site;
- Assessment of soil contamination at the WTP inlet manifold; and
- Vertical delineation of impacts in soil within the impacted and affected areas.

Development of a work plan for the CLA will be completed after review of available background information. However, sufficient information has been reviewed to allow presentation of a preliminary work plan, which may be amended as further information becomes available (i.e. information on groundwater from test pit excavation and interception trench installation). The objective of the CLA is to identify potential sources of contamination, whether historical or on-going, and to collect the necessary data to allow development of a remediation and restoration plan for the Site.

The following sections provide further detail on the planned CLA work associated with the data gap items listed above.

Groundwater Well Installation and Storage Pond Integrity

Upon approval by NSW Office of Water, installation of shallow groundwater monitoring wells up gradient and down gradient of ponds, adjacent to the BWTP and at select distances down gradient from the BWTP and within the impacted area will assist in determining whether surficial impacts from the discharged process water have impacted the local shallow groundwater.

Installation and monitoring of groundwater wells up gradient, as background, and down gradient of the ponds and BWTP will establish shallow groundwater flow direction and assist in determining whether shallow groundwater is transporting contaminants down gradient from the BWTP or from potential leaking of the ponds.

A hydrogeological assessment of shallow groundwater flow patterns at the site will also assist in determining whether groundwater mimics the topographic drainage patterns of surface water, which appears to be along the corridor defined by the impacted bushland.

It is anticipated that a geoprobe drill rig can be used due to potential access restrictions and requirements to minimise impact to vegetation. The boreholes will be drilled using hollow flight augers or hammer due to the unconsolidated nature of the surface lithology and underlying sandstone. The groundwater wells will be constructed using 50 mm uPVC screen and casing and will be completed at the surface with a lockable monument cover. In each groundwater well, a sand pack will be installed from the base of the well to above to top of the screen with a bentonite plug set on top of the sand. Each well will be grouted to the surface to further stop the infiltration of surface water. **Figure 5-1** provides a schematic diagram of a typical groundwater well construction.

Figure 5-1 - Groundwater Well Schematic Diagram and Surface Completion

BWTP Inlet Manifold

Based on discussions with site personnel, anecdotal evidence indicates that leaks and spills of process water at the three BWTP RO manifold may have occurred over an extended period of several years. This may have resulted in more extensive subsurface migration of contaminants down gradient of the BWTP. Investigation of soil at the BWTP manifold will allow the presence or absence of an ongoing contamination source at this location to be determined. Should a source be identified at this location, remediation of the source would be required to reduce the potential for continued impacts to the impacted and affected areas, which could inhibit proposed restoration and revegetation works.

Delineation of Soil Impacts

To better define the vertical and lateral extent of impacted soils and to further characterise the soil quality, additional collection and analysis of soil samples will be completed. It is likely that samples will be collected along a central transect running the length of the impacted and affected areas. Several cross sections, perpendicular to the central transect, will be selected to allow further definition of the lateral extent of contamination. In addition, several background locations will selected to provide a control sample set.

At each location, samples will be collected from the following depth intervals:

- Surface;
- 0 – 300 mm;
- 600 – 900 mm;
- 1200 – 1500 mm; and
- 1700 – 2000 mm or at the interface between the overlying unconsolidated material and the underlying sandstone.

Additional background samples will be collected and analysed to increase the robustness of the background data set. As with samples in the impacted area, background samples will be collected at deeper intervals and in locations outside of the impacted area..

The soil samples will be analysed for a broad suite of analytical tests to delineate the impacted and affected area. In addition, the soil samples will be analysed for specific soil chemistry and physical properties to determine whether the soil is suitable to support revegetation of whether restoration works will be required. Refer to **Section 5.3** for details on the ecological assessment analytical program.

5.2 Ecosystem Baseline Survey

Ecosystem Baseline surveys such as a vegetation baseline are proposed to allow development of a revegetation plan for the impacted and affected areas.

Vegetation Baseline Survey

Typically vegetation baseline surveys for the affected and reference area(s) will comprise similar components. Sample plots will be set up within the areas to determine the attributes of tree species; site, soil types, plants and successional status; coarse woody debris and duff layers; and other site resources.

In general, the following steps are undertaken to characterise the vegetation baseline:

- tree attributes (variable and/or fixed area plot);
- top height tree (fixed area plot);
- wildlife tree attributes (variable or fixed area plot);
- small trees and stumps (fixed area plot);
- vegetation species and percent;
- coverage (fixed area);
- ecological site (centre point);
- soils (point);
- old growth designation (point);
- coarse woody debris and duff layers (line transect); and
- range resources (line transect and fixed area).

5.3 Soil Assessment

In combination with the delineation sampling detailed in **Section 5.1,** soil samples will be analysed for a suite of analytes to determine the extent of salinity impacts and/or the suitability of the current soil quality to support restoration and revegetation of the impacted and affected areas.

Soil Chemistry

The below analysis will be conducted on selected samples to assess the soil chemistry within the impacted and affected areas. Results of the analysis will be used to define the extent of impacts and develop the restoration plan in support of revegetation. Much of this analysis has been conducted on surface samples by Golder, however assessment of deeper samples especially into the root zone is a key component of the additional assessment.

- Electric conductivity (EC 1:5 [soil water]) (test for free carbonates and remove if present prior to analysis);
- Saturation extract EC;
- pH (1:5);
- Chloride (1:5);
- Organic carbon (test for free carbonates and remove if present prior to analysis);
- Boron ($CaCl_2$ extractable);
- Sulphur ($Ca(H_2PO_4)2*H_2O$ extractable);
- Effective cation exchange capacity (CEC);
- Exchangeable bases (Ca, Mg, Na, K);
- Exchangeable bases with soluble salt pretreatment;
- Saturation extract (Ca, Mg, Na, K, B, SO_4, Cl and HCO_3/CO_3);
- Gravimetric moisture content; and
- Total gypsum.

Soil Physical Properties

Representative samples from affected soils and reference areas will be tested to confirm the existence of a dispersed condition, hydraulic conductivity, in-situ permeability and particle size distribution.

Dispersion field testing (Rengasamy and Bourne Method) will involve the following methodology and will be completed on select soil samples:

- 100 g of soil placed in a 600 ml glass jar with secure lid;
- Slowly add 500 ml (1:5) of distilled water down the side of the jar to minimise disturbance of soil material;
- Invert jar slowly once, then return to upright position; and
- Let jar stand for 4 hours and qualitatively document turbidity in the supernatant (sodium dispersed soils will remain cloudy).

Undisturbed cores will be collected from the impacted area and at background locations for evaluation of soil permeability (hydraulic conductivity) (ASTM D2434-68: Standard Test Method for Permeability of Granular Soils (Constant Head).

In-situ measurements of permeability differences between the impacted area and background locations may be conducted with standard tools such as the Guelph Permeameter. However, due to the saturation of the soil within the impacted area, success of these measurements may be difficult.

Extensive data on gradation (particle size, texture) were collected on the affected area in the Golder investigation. Some supplemental data will be collected for background locations and and a subset of samples from the current investigation (% silt, sand, clay, and coarse fragments (% >2 mm)).

5.4 Restoration Treatment Pilot (Affected Area)

Potential remedial approaches could be evaluated in the affected area on a pilot scale basis. Soils from this area would be tested before the trial using the procedures outlined in **Section 5.3**. Success indicators may include improved dispersion jar test results, improved saturated hydraulic conductivity, reduced SARe (sodium adsorption ratio in soil saturation extract), reduction in soil pH and reduced soil moisture.

Dosage rates are expected to be approximately 5 ton/ha, or 0.5 kg/m^2. It is likely that multiple applications will be required as the effectiveness of each dose is evaluated. Due to the impermeable nature of sodic soils, reaction of the added Ca with the Na often requires multiple applications. As the soil structure and permeability increases after the initial gypsum addition, further doses of gypsum will allow complete reaction with the bound Na. Evaluation of the requirement for further doses will be evaluated after each addition of gypsum. The benefit of gypsum addition is the minimal impact on total soil pH even if significant dosage is required (i.e 10ton/ha). Dissimilar to lime or limestone addition which can significantly raise the soil pH, gypsum has minimal impact on the soil pH, which in this case is important as the soil pH within the impacted area is already alkaline (approximately 8.0 – 10 pH units).

The specific design of the pilot test will be further evaluated, but the general options being considered are described in the sections below.

Drainage, Bulk Application of Dry Gypsum and Natural Rainfall

To isolate the soil being treated from surrounding soil, affected soil would be placed in a constructed in-situ cell or bin such that surface drainage and possibly subsurface drainage could be provided. Excess surface water would be removed to the extent possible. Approximately 5 to 10 tonnes/Ha of finely ground gypsum would be applied to the soil surface, and would be incorporated into the surface of the soil using garden tools. This would alleviate the visual impact of dry gypsum on the ground surface and leaves of surface vegetation. In addition, tillage of the gypsum will increase the contact of gypsum with the soil matrix and maximise the reaction of Ca with Na. A control cell would also be installed, but have no soil amendments applied. Native herbaceous species tolerant of elevated sodium, salinity, and excess moisture could be planted to help remove excess water, promote aggregation of soil particles, and provide organic matter which will also improve soil structure.

Subsurface drainage (e.g., perforated plastic tile or PVC pipe with drilled holes) would be incorporated into the design to remove excess water, soluble salts, and Na that has been replaced by Ca on the soil exchange surfaces. Success indicators would be re-evaluated after a predetermined time period.

Irrigation with Gypsum Solution

This pilot option would be very similar to that described in **Section 5.4**, except a gypsum slurry would be irrigated onto the affected soil before being mixed through tillage. Possible salt tolerant vegetation could also be used to promote aggregation of the soil and removal of excess water. Success indicators would be re-evaluated after a predetermined time period.

Excavation and Ex-situ Treatment

This pilot option would be somewhat similar to the approach described in **Section 5.3**, except the treatment cell would be designed to allow multiple applications of gypsum with tillage, irrigation and more aggressive drainage.

5.5 Bench Scale Trials (Impacted Area)

It is possible that in-situ treatment of the soil within the impacted area is not feasible. Due to the level of impacts, excavation and ex-situ treatment of the soil may be the only treatment option that will allow beneficial reuse of the soil and eliminate the requirement for off-site disposal and importation of clean soil. To evaluate the effectiveness of ex-situ treatment of the soil from the impacted area, it is proposed to complete a bench scale trail. The bench scale trial would evaluate the effect that gypsum (bulk and slurry) addition, aggregate addition, mechanical mixing, natural rainfall and manual irrigation have on improving the quality of the soil matrix.

Any treatment of the impacted soil is a two stage process. Firstly addition of a cation, namely Ca or Mg, to react with the Na bound to the soil particles and secondly, leaching of the formed salts out of the soil matrix. The addition of a coarse bulking agent; such as leaves, sticks, gravel and/or inert mulch; will increase the porosity and permeability of the soil matrix, which will assist in leaching of the salts out of the matrix.

The bench scale trial would involve collection of representative samples from several areas of the impacted area followed by varying treatment techniques and evaluation. As listed in **Section 4.4**, it is proposed that the following treatment techniques would be evaluated:

- Application of dry gypsum and mechanical mixing followed by one-time water addition (i.e. rainfall event);
- Application of dry gypsum and mechanical mixing with continuous mist irrigation;
- Application of dry gypsum and a coarse aggregate with mechanical mixing and continuous mist irrigation;
- Application of gypsum slurry and mechanical mixing followed by one-time water addition (i.e. rainfall event); and
- Application of gypsum slurry and mechanical mixing with continuous mist irrigation.

After mixing of the gypsum and/or bulking agent, the material would be placed in constructed trays with an underlying drainage layer that would allow capture of any leachate water. The mixed material would be irrigated either continuously (mist irrigation) or by a one-time water addition (rainfall). A control tray would be evaluated along with the test mixes to provide a benchmark for analysis. In addition, one duplicate tray would be assessed to provide quality control of the data received.

At the completion of the mixing and irrigation, samples of the soil and leachate will be analysed to determine the effectiveness of the treatment techniques. The following details the soil and leachate analysis:

- Soil Analysis
    - pH;

  - moisture content;
  - dispersion jar test;
  - sodium absorption rate (SAR); and
  - Cations (Ca, Mg, Na, K) and ESP.
- Leachate (Water) Analysis:
  - pH
  - SAR;
  - TDS; and
  - Cations (Ca, Mg, Na, K).

Varying concentrations of gypsum dosage may be trialled; however the initial dosage will be determined after collection of the initial soil samples. In addition, the use of permeate water from the RO plant may be trialled along with potable water. Utilisation of permeate would contribute to the overall sustainability of the remediation program.

A second component of the treatment trial would be to evaluate the reuse of the impacted soil onsite as possible fill for pond bases. This material could be covered with local soil and topsoil for subsequent revegetation. This trial could involve the possible addition of quantities of a binding agent such as cement or blast furnace slag to enhance the physical properties of the soil and also reduce the possibility of leaching. This option would be reviewed after soil analytical data is available.

6 Potential Remedial Options

This section presents an overview and appraisal of potential suitable remedial options to determine the most appropriate remedial option or combination of options for the remediation and restoration of the impacted areas based on the current knowledge of the site.

6.1 Source Remediation

After completion of the contaminated land assessment (**Section 5.1**), remediation and/or management of contamination sources may be required. Several historic and potentially existing contaminant sources have been identified during review of background information and discussion with Santos personnel. The below list presents a preliminary list of the identified historic and unidentified potential existing contamination sources:

- Identified Historic Sources of Contamination
  - Uncontrolled discharges of process water
  - Leaking above ground pipes and valves
- Unidentified Potential Existing Sources of Contamination
  - Salt impacted soil located at the inlet manifold
  - Leaking storage ponds due to poor construction or liner breach

Identified historic above ground sources of contamination have been rectified after Santos obtained control of the BWTP in November/December 2011. Through implementation of strict operational protocols and environmental management procedures, the potential for uncontrolled discharges of process water have been minimised. In addition, maintenance or replacement of above ground faulty values and other water treatment infrastructure has eliminated the potential for ongoing leaks through infrastructure at the BWTP.

The below points summarise potential remedial options for the potential existing sources of contamination listed above:

- Salt Impacted Soil at Inlet Manifold
  - Excavate and remove impacted soil
  - Install interception trench around RO plant to capture infiltrated water and impacted groundwater
- Leaking Storage Ponds
  - Empty pond and repair liner
  - Install interception trench along down gradient edge of pond to collect impacted water

Results of the contamination land assessment will guide development of remedial plans for identified sources of contamination.

6.2 Impacted and Affected Area Remediation

This section provides a brief summary of potential remedial options under the assumption that excessive sodium and soil dispersion are the primary issues for the impacted and affected areas. The major techniques involve introduction of large quantities of soluble Ca to replace Na in the soil, controlled application of supplemental water (irrigation) with a water chemistry that won't promote dispersion, drainage of excess water, mixing of amendments, growing vegetation to promote soil aggregation and continued removal of excess water.

The feasibility of each option will be influenced by additional data from the soils assessment (**Section 5.3**) and treatment trials. For example, gypsum will not be effective as an amendment if the existing soils are already high in gypsum or high in sulphate, in which case alternate sources of soluble calcium may be required, such as $CaCl_2$.

Surface Drainage, Bulk Application of Dry Gypsum, Natural Rainfall

In this approach, excess surface water would be removed to the extent possible with drainage channels. Drainage channels may be needed along the side of the impacted and affected area and periodically extending into the two areas. Existing dead trees would be removed, followed by the application of a 5 to 10 tonnes/Ha of gypsum to the soil surface. A finely ground gypsum or pelletized product will be applied to maximise the available surface area and rate of reaction. Special low ground pressure equipment may be required to apply the gypsum if the soil remains saturated. The applied gypsum would be incorporated into the upper part of the soil if possible.

No supplemental irrigation would be used with this approach. Native herbaceous species tolerant of elevated sodium and salinity could be planted to help remove excess water, promote aggregation of soil particles, and provide organic matter which will also improve soil structure.

The remedial process would likely continue over a period of several years, with additional application and incorporation of gypsum and reseeding. The remedial process would proceed from the surface downward, until a sufficient soil depth had been reclaimed to support normal drainage patterns and reestablishment of vegetation typical of the area. Subsurface drainage (e.g., perforated plastic tile) may be incorporated into the design to remove excess water, soluble salts, and Na that has been replaced by Ca on the soil exchange surfaces, but the drainage tile would likely provide little benefit until some restoration of soil structure has occurred.

Irrigation with Gypsum Solution

An alternative means of delivering gypsum to the affected area is through a spray, drip or mist irrigation system. This method is less intrusive than bulk application of dry gypsum and if feasible would greatly reduce the potential impact to vegetation within the affected area. This method is commonly used in vineyards, where either Ca is deficient in soils or there is a concern with excess Na, is through application with what is sometimes referred to as a "gypsum machine". A tank with paddles or other agitation is coupled with an injection pump. Finely ground gypsum is added to the tank, and mixing produces the gypsum solution. The pump injects the gypsum solution into the irrigation flow. This approach could be used to deliver gypsum to a affected area, where accessibility and minimising impact to vegetation are key issues. If the alkalinity of the water is high, an acid or scaling inhibitor may also need to be injected to prevent the formation of lime ($CaCO_3$) scale in the distribution system. The concentration that could be injected would be a function of the chemistry of the irrigation water and the solubility products (Ksp for $CaSO_4$ @ 25°C = 2 x 10^{-5}). A $CaCl_2$ solution could also be injected, but the potential formation of lime scale in the system would need to be addressed.

Bulk application of dry gypsum would likely be more cost effective given the large quantity of exchangeable Ca required. However, minimising the impact to vegetation in the affected area and the subsequent accessibility issues for machinery, if feasible, the drip irrigation of a gypsum solution may be the preferable solution for the affected area.

Excavation and Ex-Situ Treatment

It may be possible to accelerate the remediation process by excavating the affected soils to an area where surface water run-on and possibly even rainfall can be excluded. The purpose would be to facilitate mixing of the affected soil with high Ca amendments such as gypsum or $CaCl_2$, and to then leach the soils with irrigation water with a controlled level of salinity to maximise flocculation of soil particles. Remediated soils would be placed back in the affected area, and revegetation efforts would proceed. The excavated area would need to be protected from soil erosion while soils were being remediated. Excess sodium and other salts leached from the soils during the remediation process would be captured and returned to the process ponds for treatment. The soil treatment area would be lined to prevent localized impacts.

Excavation and Disposal, Replacement with Unaffected Soil

This approach is more applicable to highly impacted sodic soils in the impacted areas. These soils would be removed from the site, and replaced with soil of a similar texture and chemistry to the native soil. Revegetation would then follow placement of unaffected soil. Difficulties with this approach include handling of existing saturated soils, relatively high impact from excavation equipment on soils surrounding the affected area, finding a source of suitable soil without having adverse effects on the borrow site (and difficulty of obtaining required permits) and finding a suitable location to dispose of the affected soils which may include a landfill licensed to accept general solid waste.

Restoration Using Proprietary Products

There are commercial products available for remediation of sodium affected soils, and these products could potentially provide more rapid remediation of affected soils. One such product is DeSalt Plus™ (Advanced Microbial Services Inc.), that provides a proprietary mixture of cations (Ca, NH_4^+), proprietary additives and surfactants. These types of products would likely be much more costly than gypsum, and the impacts of additional nitrogen and unknown additives and surfactants into a natural area would need to be evaluated.

6.3 Revegetation

Revegetation planning is dependent on two key sources of information:

- Results of the soil assessment and the selection of the soil restoration technique; and
- Results of the vegetation baseline information that will guide species selection for replanting and seeding activities.

Revegetation Objectives

The Society for Ecological Restoration lists the following attributes of a restored ecosystem that need to be considered in development of a revegetation plan for the site (SER 2004):

- The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure;
- The restored ecosystem consists of indigenous species to the greatest practicable extent;
- All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the potential to colonise by natural means;
- The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory;
- The restored ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent;
- The restored ecosystem is suitably integrated into a larger ecological matrix or landscape;
- Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible;
- The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem;
- The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions.

Revegetation Planning

Revegetation planning will be carried out in detail once more is known about the soil conditions, but will generally consist of the following steps:

- Grading and contouring of the site to pre-impact levels if soils materials have been moved or removed;
- Identification of suitable “nurse” species that can be seeded onto the site to control erosion due to wind and water, and provide initial organic material for soils. “Nurse” species are typically pioneer successional species that respond positively to exposed soil conditions;
- Identification of suitable mulch materials to add organic material to the soil – this may consist of wood and bark from dead trees stockpiled and mulched, or an alternative source of an ecologically inert mulch (i.e. a mulch that will not contribute foreign seeds or fauna to the area);

- Development of a planting plan that mimics successional processes in reference ecosystems. The planting plan may require multiple planting events to introduce all native species back to the site, as some species require support from already developed tree canopy or soil layers to be successfully reintroduced. This plan will be developed after collection of baseline data and as soil remediation is underway;
- Tree and shrub species will be identified that prefer early site development conditions, and these will need to be sourced from nursery stock, or grown from seed collected in nearby reference ecosystem sites;
- Revegetation plan drawings may include plant locations, grading, irrigation system (if used), access routes, and protective measures such as fencing and signage;
- Plans for maintenance, including pest and erosion control, weeding, replanting, maintenance of irrigation (if needed), and maintenance of fencing and signage will be included; and
- Development of a monitoring plan and success criteria for the restored ecosystem. These will be developed from analysis of baseline data and the remediation and restoration goals stated for the project.

7 Estimated Remediation Schedule

A proposed project schedule has been developed based on estimated task durations. The actual schedule for the remediation will be highly dependent on the findings of the CLA and regulatory approval requirements, which are yet to be confirmed. Therefore, the proposed schedule presented in **Table 7-1** is an estimate only, but provides a guide for the sequencing of tasks and their estimated duration.

Table 7-1 - Estimated Remediation Schedule

Task	Start Week	End Week	Duration
Immediate Action Items			
Surface Water (SW) Diversion Design and Preliminary Trench Test Pitting	1	2	2
Preparatory Restoration Works	2	2	1
Review of Test Pit Data, Design Trench and Procure Trench Supplies	3	4	2
Installation of Surface Water Diversion and Interception Trench	5	6	2
Treatment Pilot	8	9	2
Data Collection Activities			
Develop Contamination and Ecological Assessment Plan	3	4	2
Install Groundwater Wells and Collect Soil Samples	5	5	1
Sample Groundwater Wells	7	7	1
Complete Flora/Fauna Surveys	5	7	3
Modify and Finalise Remediation Plan	6	9	4
Approvals for Remediation [1]	10	13	4
Tender and Procurement for Remediation	14	19	6
Complete Remediation and Restoration Works	20	31	12
Complete Initial Revegetation	32	35	4
Monitoring of Revegetation	36	--	--

Table Notes: 1 – assumed approvals process for remediation is 4 weeks.

8 Planning Pathway

Below is a summary of the potential regulatory regime that may impact the intrusive investigations and remedial option approvals for the site. The exact planning pathway will have to be discussed with regulators before a final pathway can be finalised.

Preliminary discussions with the Division of Resources and Energy (DRE) who are part of the Department of Trade and Investment, Regional Infrastructure and Services (TIRIS, formerly Department of Industry, and Investment) have been undertaken. It is understood from this consultation that DRE will impose conditions on Santos' existing petroleum title in regard to rehabilitation requirements. The implication of this is detailed further in **Section** Error! Reference source not found. below.

8.1 Petroleum (Onshore) Act 1991

The remediation works will fall within Santos Petroleum Exploration Title (PEL) 238 and Petroleum Assessment Lease (PAL) 2, granted under the *Petroleum (Onshore) Act 1991*. S76 (1a) of the Act states that conditions can be imposed on a petroleum title relating to, "the rehabilitation, levelling, regrassing, reforesting or contouring of any part of the land the subject of the title that may have been damaged or adversely affected by operations" and "the filling in or sealing of excavations and drill holes, as may be prescribed by the regulations or as the Minister may, in any particular case, determine" (s76(1)b). If such conditions are not contained within a petroleum title, they can be imposed at a later date (s76(2)). However, prior to granting such an amendment to title conditions for the purpose of s76(1)a, they must be in a form approved by the Commissioned of the Soil Conservation Service (within DPI) and imposed only after consultation with the Director General of National Parks and Wildlife (within OEH)(s76 (4)).

Under s77 of the Act, Santos is required to take the specified steps to, "give effect to any conditions included in the petroleum title". Failure to comply with these conditions can result in a penalty. As such, ORE can amend Santos' existing titles to direct them to undertake rehabilitation activities (after consulting with OEH and DPI). Santos would then be required to comply with these conditions.

However, it is understood that environmental planning provisions may still apply to rehabilitation works, despite the requirement for Santos to undertake rehabilitation activities in accordance with their petroleum title. Potentially relevant planning provisions and environmental legislative requirements are outlined below.

8.2 State Environmental Planning Policy 55

The State Environmental Planning Policy No 55 - Remediation of Land (SEPP 55) provides the planning framework for the remediation of contaminated land in NSW and provides details on whether remediation works require development consent. Category 1 remediation works are works that require consent, while Category 2 works do not require consent.

Clause 14 states that remediation works are considered to be Category 2 when the remediation work is not a work of a kind described in Clause 9 (a)-(f),". Clause 9 (a)-(f), describes Category 1 remediation as:

(a) designated development, or

(b) carried out or to be carried out on land declared to be a critical habitat, or

(c) likely to have a significant effect on a critical habitat or a threatened species, population or ecological community, or

(d) development for which another State environmental planning policy or a regional environmental plan requires development consent, or

(e) carried out or to be carried out in an area or zone to which any classifications to the following effect apply under an environmental planning instrument:

(i) coastal protection,

(ii) conservation or heritage conservation,

(iii) habitat area, habitat protection area, habitat or wildlife corridor,

(iv) environment protection,

(v) escarpment, escarpment protection or escarpment preservation,

(vi) floodway,

(vii) littoral rainforest,

(viii) nature reserve,

(ix) scenic area or scenic protection,

(x) wetland.

Once it can be determined that the remedial work is not being undertaken under any of the above areas then the work can be classed as Category 2 remediation and will not require consent (it will however require notification to Narrabri Council). Further consultation with Narrabri Council and Forests NSW will assist in determining whether the land is located in any of the above areas, specifically in an environmental protection area.

8.3 SEPP (Mining, Petroleum Production and Extractive Industries) 2007

The aims of this Policy are:

- to provide for the proper management and development of mineral, petroleum and extractive material resources for the purpose of promoting the social and economic welfare of the State;
- to facilitate the orderly and economic use and development of land containing mineral, petroleum and extractive material resources; and
- to establish appropriate planning controls to encourage ecologically sustainable development through the environmental assessment, and sustainable management, of development of mineral, petroleum and extractive material resources.

Part 2 Clause 6 of the SEPP allows that certain development is “permissible” and may also be carried out without development consent, including development for the purposes of “petroleum exploration”. This means that the original approvals for the WTP had to undergo environmental assessment and approval requirements under Part 5 of the EP&A Act and DPI were the approval body.

Under clause 10 of the SEPP, development for the purpose of "the construction, maintenance and use of equipment for the monitoring of weather, noise, air, groundwater or subsidence" is exempt provided it is of minimal environmental impact and if it is within a state conservation area, it is not land to which the following applies:

(a) coastal waters of the State, or

(b) land to which State Environmental Planning Policy No 14—Coastal Wetlands or State Environmental Planning Policy No 26—Littoral Rainforests applies, or

(c) land reserved as an aquatic reserve under the Fisheries Management Act 1994 or as a marine park under the Marine Parks Act 1997, or

(d) land within a wetland of international significance declared under the Ramsar Convention on Wetlands or within a World heritage area declared under the World Heritage Convention, or

(e) land identified in an environmental planning instrument as being of high Aboriginal cultural significance or high biodiversity significance, or

(f) land reserved as a state conservation area under the *National Parks and Wildlife Act* 1974 , or

(g) land, places, buildings or structures listed on the State Heritage Register, or

(h) land reserved or dedicated under the Crown Lands Act 1989 for the preservation of flora, fauna, geological formations or for other environmental protection purposes, or

(i) land identified as being critical habitat under the *Threatened Species Conservation Act* 1995 or Part 7A of the *Fisheries Management Act* 1994.

The investigation work component of the remediation could be defined as "exempt development" under this SEPP, provided it is considered to be of minimal environmental impact and it is not located within land reserved or dedicated under the *Crown Lands Act 1989* for environmental protection purposes. Further consultation with State Forests is required to determine this.

8.4 State Environmental Planning Policy (State and Regional Development) 2011

SEPP (State and Regional Development) classifies certain development as either State Significant Development or State Significant Infrastructure. Such developments generally require approval by the NSW Department of Planning and Infrastructure (DP&I) and the preparation and submission of an Environmental Impact Statement.

Clause 24 of Schedule 1 defines development for the Remediation of Land to be State Significant development when the following clauses are met:

- Development for the purpose of remediation of land that is category 1 remediation work on significantly contaminated land if the work is required to be carried out under the *Contaminated Land Management Act* 1997 by a management order that requires:

(a) the taking of action of the kind referred to in section 16 (d) or (g) of that Act, or

(b) the preparation of a plan of management that provides for the taking of any such action.

- In this clause, Category 1 remediation work and remediation have the same meanings as in State Environmental Planning Policy No 55—Remediation of Land.

As it is likely that the proposed Remedial Works are Category 2 remediation then Clause 24 of Schedule 1 is not applicable. If it is determined that the Remedial Works is Category 1 remediation this schedule will still not be applicable as the remediation works is not under a Management Order under the *Contaminated Land Management Act 1997*.

As such, the proposed Remedial Works does not come under this clause and therefore are not considered to be State Significant Development; hence approval by NSW DP&I is unlikely to be required.

8.5 Local Council

Whilst the application of SEPP Mining and SEPP 55 overrides the need to consider zoning controls under LEPs (as activities covered by SEPP Mining are permissible without consent or are exempt and under Section 36 of the EP&A Act if there are any inconsistencies between environmental planning instruments the SEPPs prevail over LEPs) for completeness, the objectives of the Narrabri LEPs have been considered.

Narrabri Local Environment Plan 1992

Narrabri Shire Council has three LEPs in force. The applicable LEP for the proposed works is Narrabri Local Environmental Plan 1992. The general aims of this LEP include:

- to encourage the proper management, development and conservation of natural and man-made resources within the Shire of Narrabri by protecting, enhancing or conserving:
  - timber, mineral, soil, water and other natural resources,
  - areas of ecological significance,
  - areas of high scenic or recreational value, and
  - the environmental heritage of the Shire of Narrabri.

8.6 NSW Office of Water (NOW)

Both the Water Act 1912 (WA) and the Water Management Act 2000 (WMA) set out requirements for installation of groundwater wells, drainage construction and extraction of water. The requirements of both Acts will be considered prior to commencing works.

Water Act 1912

The *Water Act 1912* (WA) sets out provisions for the management of; water rights, water and drainage, drainage promotion and artesian wells, in NSW.

Part 5 of the WA requires a licence to be sought from the NOW for the construction and operation of a bore. 'Bore' under the WA, includes any bore, well or any excavation or other work connected or proposed to be connected with sources of sub-surface water and used or proposed to be used to obtain supplies of such water whether the water flows naturally at all times or has to be raised either wholly or at times by pumping or other artificial means.

The CLA will involve installation of monitoring bores and the proposed groundwater interception trench will therefore require an application for a bore licence under Part 5 of the WA will be required. Further consultation with NOW is required to determine this.

Water Management Act 2000

The Water Management Act 2000 (WMA) provides for the integrated and sustainable management of NSW waters. Sections 91A, 91B and 91C of the WMA makes it unlawful for a person to use water, construct or use a water supply work or construct or use a drainage work without an approval from NOW. Further consultation with NOW is required on finalisation of the remedial design prior to commencement of the remedial work to determine the appropriate approvals required for both the interception trench and the diversion of stormwater.

Section 91E of the WMA makes it unlawful for a person to carry out a controlled activity within waterfront land, which is defined as land within 40 metres of a water body (such as Bohena Creek), without a controlled activity approval. However, Section 39 of the Water Management (General) Regulation 2004 grants an exemption from the requirement for a controlled activity approval for activities conducted under the *Petroleum (onshore) Act 1991* (clause 16, Schedule 5 Part 2).

8.7 Office of Environment and Heritage (OEH)

Environment Protection Licence

An assessment of the necessity to obtain an Environment Protection Licence (EPL) for the Remedial Works under the *Protection of the Environment Operations Act* 1997 (POEO Act) was conducted. This involved a review of the Scheduled Activities detailed in Schedule 1 of this Act.

The *Protection of the Environment Operations Act* 1997 (PoEO Act) prohibits the undertaking of development works without a licence for scheduled development work for scheduled activities (as identified in Schedule 1 of the PoEO Act). The PoEO Act also prohibits the undertaking of polluting activities without a licence (both scheduled and unscheduled).

The Remedial Works would be considered to be a scheduled activity in accordance with Schedule 1 of the POEO Act if thresholds of treatment of soil and groundwater are met.

If the Remedial Works meet two criteria for scheduled activities; Contaminated Soil Treatment and Contaminated Groundwater Treatment an EPL will be required. Details of the criteria are as follows:

Contaminated soil treatment

(1) This clause applies to "contaminated soil treatment ", meaning the onsite or off site treatment of contaminated soil (including, in either case, incineration or storage of contaminated soil but excluding excavation for treatment at another site).

(2) The activity to which this clause applies is declared to be a scheduled activity if:

   (a) in any case, it has the capacity to treat more than 1,000 cubic metres per year of contaminated soil received from off site, or

(b) where it treats contaminated soil originating exclusively on site, it has a capacity:

(i) to incinerate more than 1,000 cubic metres per year of contaminated soil, or

(ii to treat (otherwise than by incineration) and store more than 30,000 cubic metres of contaminated soil, or

(iii) to disturb more than an aggregate area of 3 hectares of contaminated soil.

Contaminated groundwater treatment

(1) This clause applies to "contaminated groundwater treatment" meaning the treatment of contaminated water.

(2) The activity to which this clause applies is declared to be a scheduled activity if it has the capacity to treat more than 100 megalitres (ML) per year of contaminated water.

At this point in time it is unlikely that the above scheduled activities will be triggered as a result of the planned rehabilitation works and as such an EPL may not be required. However, this will need to be confirmed once exact quantities and areas to be remediated are ascertained.

Duty to Notify

There is a requirement under the PoEO Act (Part 5.7, cl.147-149) and Petroleum Exploration Licence No. 238 to report any pollution incidents where material harm to the environment is caused or threatened. It is also an offence under the Act (Part 5.2, cl.116) to:

"wilfully, or negligently cause any substance to leak, spill or otherwise escape (whether or not from a container) in a manner that harms or is likely to harm the environment."

Should any pollution incidents such as oil leaks, sediment discharge, or any other contamination occur during the implementation of the Remedial Works, the contractor is responsible for reporting these incidents to the Project Manager immediately and they will then determine the most appropriate course of action.

Further consultation with OEH is required to determine the applicability of the PoEO Act.

8.8 Department of Sustainability, Environment, Water, Population and Communities (SEWPAC)

The Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) commenced on 16 July 2000. The EPBC Act requires approval from the Commonwealth Minister for the Environment for actions which, have, may have, or are likely to have a significant impact on a Matter of National Environmental Significance (MNES).

The impact on items of MNES was determined by RPS (2012) for the Bibblewindi Spill Incident. This assessment considered the actual impact zone as well as a one kilometre buffer zone around the Site. This means that this assessment would be appropriate for use in determining whether the remedial works will likely have a significant impact on MNES (providing the remedial works impact zone is within this area). The report concluded that no impacts to MNES will or have occurred withstanding the Pilliga Mouse, from the spill incident.

It was determined that the spill incident has the potential to have a temporary or permanent impact on the Pilliga Mouse. This conclusion was drawn with the available data and field surveys undertaken by RPS and therefore using a precautionary principle. Given the remedial works will impact this area again (in the process of remediation) there is potential to further impact on the habitat of this species. It is therefore recommended that a further assessment (including a targeted field survey) be undertaken to confirm the presence of this species and recommend appropriate management measures to be implemented during the remedial works.

8.9 Summary of Development Approvals Required

It is understood that ORE will direct Santos to undertake rehabilitation work through the placement of conditions on Santos' existing petroleum title, in accordance with s76 of the *Petroleum (Onshore) Act 1991*. Santos will be required to comply with these new conditions and undertake the rehabilitation works as prescribed by ORE.

Further consultation with Narrabri Council and Forests NSW will help determine the zoning of the site. Once the zoning has been ascertained and the specialist flora and fauna assessment has confirmed the likely impact of the works on MNES and habitat areas associated with planned remedial works, the works can be classed as being either Category 1 or Category 2 and the need for development consent will be established.

A bore licence will be required from NOW for the construction of the monitoring wells and possibly the interception trench. Further consultation with NOW is also recommended to ascertain the other approvals required under the WMA, once further details of the remedial activities have been developed.

It is recommended that a staged approach to the approval process for this project be adapted. Stage 1 would involve finalising the remedial works design so that consultation can commence to ascertain relevant approvals. The completion of the flora and fauna assessment in this stage would also assist with the confirmation of the relevant approval pathway. The notification for Category 2 remediation works would commence for Stage 2. However, if the works are deemed to be Category 1 then any necessary environmental assessment would be undertaken in this stage, along with the preparation of the development application.

8.10 Regulator Consultation Undertaken to Date

NSW Office of Environment and Heritage

Santos received a notice to provide information and / or records (the Notice) issued pursuant to Section 193 of the POEO Act on 22 December 2011 and a request for information on 5 January 2012 from OEH. Santos responded to the Notice and request for information on 23 January 2012 stating that Santos had commenced a review of information and that an update on the outcomes of the review would be provided to OEH by 16 March 2012.

NSW Department of Trade and Investment, Regional Infrastructure and Services

ORE indicated on 2 February 2012 that an investigation would be conducted in relation to the 25 June 2011 incident at the BWTP (then under the control of ESG). On 6 February 2012, Santos replied to ORE stating that Santos has provided ORE with a copy of the ESG internal report relating to the incident and that an investigation had commenced. This investigation (the same as that referred to above) was expected to be completed by 16 March 2012.

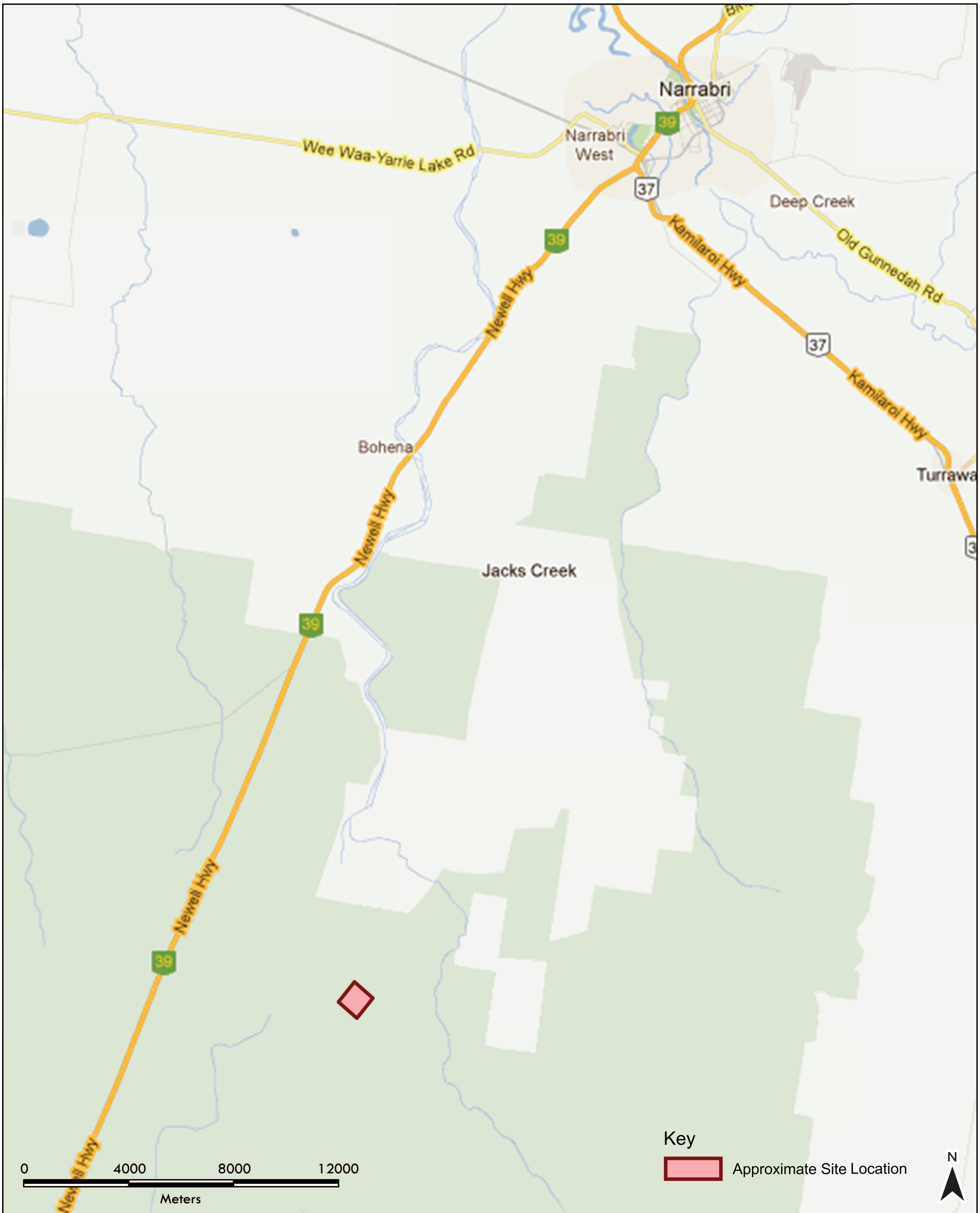
Forests NSW, part of the Department of Primary Industries (DPI; a component of TIRIS) may conduct an independent assessment of the remedial works being undertaken.

DPI is considered to be the land owner of the impacted and affected areas. Therefore, consultation will need to occur with DPI prior to any works being conducted on their land.

9 References

- RPS, *Bibblewindi Spill Incident, Matters of National Environmental Significance Assessment*, 2012
- Santos, *Report into Eastern Star Gas Limited*, 2012
- NEPC, *National Environment Protection (Assessment of Site Contamination) Measure*, 1999;
- NSW EPA, *Contaminated Sites: Guidelines for the Assessment of Service Station Sites*, 1994;
- Golder, *Bibblewindi Water Treatment Facility*, Soil Investigation, 2012
- Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)
- Protection of the Environment Operations Act 1997 (NSW)
- Petroleum (onshore) Act 1991
- Water Act 1912 (WA)
- Water Management Act 2000 (WMA)
- Narrabri Local Environment Plan 1992
- SEPP (Mining, Petroleum Production and Extractive Industries) 2007
- State Environmental Planning Policy No 55 - Remediation of Land (SEPP 55)
- Society for Ecological Restoration (SER 2004
- NSW Department of Environment and Climate Change (DECC), *Contaminated Sites: Guidelines to the Site Auditor Scheme (2nd edition)*, 2006

Figures



CH2MHILL.

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Revision:

Last Modified: February 2012

Coordinate System: MGA Zone 56(GDA94)

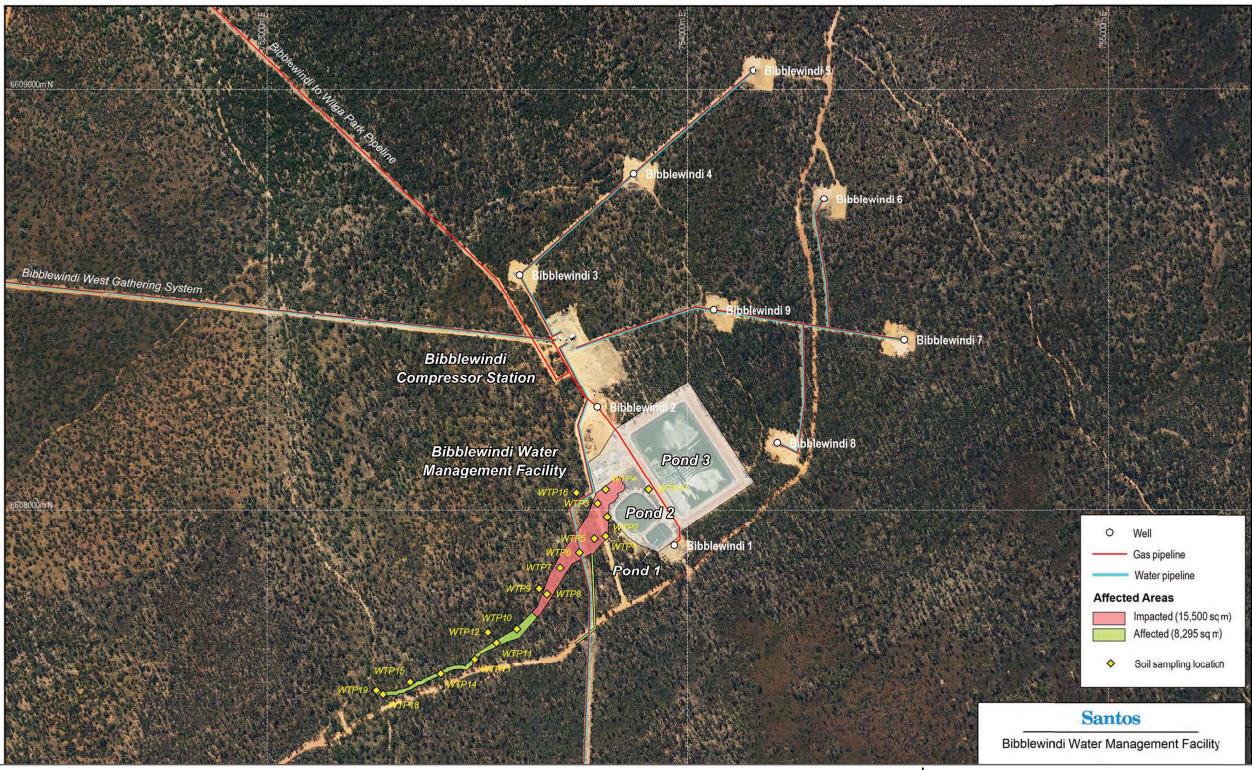
Scale (A4): 1:200,000
Image Source: Googlemaps

Figure 1

Site Location

Bibblewindi Water Treatment Plant

Preliminary Remediation Plan



CH2MHILL

CH2M HILL Australia Pty Ltd
Level 7, 9 Help Street
Chatswood, NSW 2067

Project No. 920534

Author: MG

Revision: 1

Last Modified: February 2012

100 0 100 200 300m

Figure 2

Bibblewindi Site Layout

Bibblewindi Water Treatment Plant

Preliminary Remediation Plan

Tables

Analyte	Units	LOR	Human Health NSW (2006) HIL A	Background Criteria NEPM 1999	Calculated Background Averages: Site Background Average Depth (A)	Site Background Average Depth (B)	Site Background Average Depth (C)	Background Data: NAR_WTP(9A) 14-Jan-12 SOIL	NAR_WTP(9B) 14-Jan-12 SOIL	NAR_WTP(9C) 14-Jan-12 SOIL	NAR_WTP(12A) 14-Jan-12 SOIL	NAR_WTP(12B) 14-Jan-12 SOIL	NAR_WTP(16A) 15-Jan-12 SOIL	NAR_WTP(16B) 15-Jan-12 SOIL	NAR_WTP(19A) 15-Jan-12 SOIL	NAR_WTP(19B) 15-Jan-12 SOIL	Impacted & Affected Area Max	Impacted & Affected Area Avg
EA002 : pH (Soils)																		
pH Value	pH Unit	0.1	--	--	5.60	5.73	5.80	5.6	5.6	5.8	5.7	6.4	5.1	6.1	6	4.8	10.5	8.1
EA010: Conductivity																		
Electrical Conductivity @ 25°C	µS/cm	1	--	--	13.25	48.25	209.00	16	88	209	13	23	10	68	14	14	3220.0	492.7
EA029-C: Sulfur Trail																		
KCl Extractable Sulfur (23Ce)	% S	0.02	--	--	<0.02	<0.02	<0.02										<0.02	<0.02
EA055: Moisture Content																		
Moisture Content (dried @ 103°C)	%	1	--	--	12.90	16.08	9.50	10.7	14.8	9.5	7.4	18	19.7	18.3	13.8	13.2	34.9	18.6
EA150: Particle Sizing																		
+1180µm	%	1	--	--	2.75	5.25	2.00	2	6	2	4	6	3	4	2	5	--	--
+150µm	%	1	--	--	64.75	58.50	50.00	60	51	50	65	63	56	44	78	76	--	--
+19.0mm	%	1	--	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	--	--
+2.36mm	%	1	--	--	<1	2.50	1.00	<1	4	1	<1	2	<1	2	<1	2	--	--
+300µm	%	1	--	--	35.50	33.50	29.00	34	30	29	38	36	34	26	36	42	--	--
+37.5mm	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	--	--
+4.75mm	%	1	--	--	<1	2.50	<1	<1	4	<1	<1	<1	<1	1	<1	<1	--	--
+425µm	%	1	--	--	21.00	21.50	18.00	20	20	18	24	23	21	17	19	26	--	--
+600µm	%	1	--	--	11.50	13.50	10.00	11	13	10	14	15	11	10	10	16	--	--
+75.0mm	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	--	--
+75µm	%	1	--	--	75.75	69.50	59.00	71	61	59	76	77	66	51	90	89	--	--
+9.5mm	%	1	--	--	<1	3.00	<1	<1	3	<1	<1	<1	<1	<1	<1	<1	--	--
EA150: Soil Classification based on Particle Size																		
Cobbles (>6cm)	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	--	--
Fines (	%	1	--	--	24.25	30.50	41.00	29	39	41	24	23	34	49	10	11	--	--
Gravel (>2mm)	%	1	--	--	1.00	2.50	1.00	<1	4	1	1	2	<1	2	<1	2	--	--
Sand (>75 µm)	%	1	--	--	75.00	67.00	58.00	71	57	58	75	75	65	49	89	87	--	--
ED008: Exchangeable Cations																		
Cation Exchange Capacity	meq/100g	0.1	--	--	11.15	21.35	33.00	15.8	32.4	33	13.6	7.2	8.8	44.8	6.4	1	95.6	36.3
Exchangeable Aluminium	meq/100g	0.1	--	--	2.67	0.70	0.70	0.8	0.5	0.7	1.1	0.2	6.1	0.4	<0.2	1.7	4.5	1.0
Exchangeable Calcium	meq/100g	0.1	--	--	5.75	0.90	1.40	9.6	1.4	1.4	8.3	0.4	1.5	<0.2	3.6	<0.2	23.6	6.3
Exchangeable Magnesium	meq/100g	0.1	--	--	4.13	18.48	27.60	4.8	27.1	27.6	3.6	5.7	6.2	40.8	1.9	0.3	47.4	14.0
Exchangeable Potassium	meq/100g	0.1	--	--	1.18	0.78	1.40	1.4	1.4	1.4	1.6	0.9	0.8	0.4	0.9	0.4	5.9	1.9
Exchangeable Sodium	meq/100g	0.1	--	--	<0.2	2.03	2.60	<0.2	2.5	2.6	<0.2	0.2	<0.2	3.4	<0.2	<0.2	57.5	15.3
Exchangeable Sodium Percent	%	0.1	--	--	1.50	6.00	7.70	0.5	7.8	7.7	<0.2	3.5	2.5	7.6	<0.2	5.1	72.5	37.9
ED021: Bicarbonate Extractable Potassium (Colwell)																		
Bicarbonate Extractable K (Colwell)	mg/kg	10	--	--	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	840.0	433.6
ED092: DTPA Extractable Metals																		
Copper	mg/kg	1	--	--	<1	<1	<1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	6.2	2.2
Iron	mg/kg	1	--	--	33.93	67.18	34.50	31.2	89.4	34.5	25	25.2	45.3	54.3	34.2	99.8	687.0	167.8
Manganese	mg/kg	1	--	--	14.71	1.64	<1	32	<1.00	<1.00	11	1.64	13.5	<1.00	2.32	<1.00	239.0	47.5
Zinc	mg/kg	1	--	--	<1	<1	<1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	28.4	10.4
EG005T: Total Metals by ICP-AES																		
Arsenic	mg/kg	5	100	1-50	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Barium	mg/kg	10	--	100-3000	37.50	20.00	30.00	40	10	30	30	10	60	40	20	<10	510.0	101.8
Beryllium	mg/kg	1	20	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.0	1.0
Boron	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Cadmium	mg/kg	1	20	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	mg/kg	2	120000	5-1000	6.00	8.50	12.00	7	15	12	6	5	9	12	2	2	25.0	11.1
Cobalt	mg/kg	2	100	1-40	<2	2.00	3.00	<2	2	3	<2	<2	<2	2	<2	<2	14.0	4.6
Copper	mg/kg	5	1000	2-100	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	8.0	6.4
Lead	mg/kg	5	300	2-200	5.00	6.00	6.00	<5	5	6	<5	<5	5	7	<5	<5	11.0	6.7
Manganese	mg/kg	5	1500	850	93.50	9.00	<5	162	9	<5	160	9	29	<5	23	<5	344.0	110.4
Nickel	mg/kg	2	600	5-500	2.00	2.50	3.00	2	3	3	2	<2	2	2	<2	<2	10.0	4.0
Strontium	mg/kg	2	--	--	6.25	3.50	4.00	8	5	4	9	2	4	<2	4	2	55.0	12.8
Vanadium	mg/kg	5	--	20-500	17.50	24.00	35.00	19	40	35	16	15	24	30	11	11	68.0	28.9
Zinc	mg/kg	5	7000	10-300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	22.0	10.4
EG035T: Total Recoverable Mercury by FIMS																		
Mercury	mg/kg	0.1	15	0.03	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
EK040: Fluoride																		
Fluoride	mg/kg	1	--	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	5.0	2.6
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser																		
Nitrite + Nitrate as N (Sol.)	mg/kg	0.1	--	--	1.40	0.38	0.30	1.8	0.2	0.3	2	0.5	0.5	0.2	1.3	0.6	8.0	1.3
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser																		
Total Kjeldahl Nitrogen as N	mg/kg	20	--	--	492.50	187.50	130.00	620	160	130	580	210	600	270	170	110	1720.0	539.5
EK062: Total Nitrogen as N (TKN + NOx)																		
Total Nitrogen as N	mg/kg	20	--	--	492.50	187.50	130.00	620	160	130	580	210	600	270	170	110	1720.0	539.8
EK067G: Total Phosphorus as P by Discrete Analyser																		
Total Phosphorus as P	mg/kg	2	--	2000	84.50	51.25	32.00	99	45	32	107	92	96	42	36	26	233.0	95.3
EK080: Bicarbonate Extractable Phosphorus (Colwell)																		
Bicarbonate Ext. P (Colwell)	mg/kg	2	--	--	10.00	2.00	<2	<2	<2	<2	10	<2	<2	<2	<2	2	16.0	7.0
EP003: Total Organic Carbon (TOC) in Soil																		
Total Organic Carbon	[illegible]		--	--	1.04	0.28	0.18	1.13	0.27	0.18	1.18	0.25	1.27	0.39	0.56	0.2	3.0	1.1
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons																		
Acenaphthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benz(a)anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene	mg/kg	0.5	1	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g.h.i)perylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(k)fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenz(a.h)anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of polycyclic aromatic hydrocarbons	mg/kg	0.5	20	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
EP080/071: Total Petroleum Hydrocarbons																		
C10 - C14 Fraction	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	110.0	95.0
C15 - C28 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	490.0	223.3
C29 - C36 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	290.0	162.0
C6 - C9 Fraction	mg/kg	10	65	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
C10 - C36 Fraction (sum)	mg/kg	50	1000	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	890.0	355.6
EP071 SG-S: Total Petroleum Hydrocarbons in Soil - Silica gel cleanup																		
C10 - C14 Fraction	mg/kg	50	--	--	--	--	--										<50	<50
C15 - C28 Fraction	mg/kg	100	--	--	--	--	--										<100	<100
C29 - C36 Fraction	mg/kg	100	--	--	--	--	--										<100	<100
C10 - C36 Fraction (sum)	mg/kg	50	1000	--	--	--	--										<50	<50
EP080/071: Total Recoverable Hydrocarbons - NEPM 2010 Draft																		
>C10 - C16 Fraction	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	130.0	112.5
>C16 - C34 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	700.0	296.7
>C34 - C40 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	100.0	100.0
C6 - C10 Fraction	mg/kg	10	--	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	17.0	17.0
C6 - C10 Fraction minus BTEX (F1)	mg/kg	10	--	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	17.0	17.0
>C10 - C40 Fraction (sum)	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	930.0	357.8
EP071 SG: Total Recoverable Hydrocarbons (NEPM 2010 draft) - Silica gel cleanup																		
>C10 - C16 Fraction	mg/kg	50	--	--	--	--	--										<50	<50
>C16 - C34 Fraction	mg/kg	100	--	--	--	--	--										<100	<100
>C34 - C40 Fraction	mg/kg	100	--	--	--	--	--										<100	<100
>C10 - C40 Fraction (sum)	mg/kg	50	--	--	--	--	--										<50	<50
EP080: BTEXN																		
Benzene	mg/kg	0.2	1	--	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	mg/kg	0.5	3.1	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	mg/kg	1	--	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sum of BTEX	mg/kg	0.2	--	--	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	mg/kg	0.5	1.4	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Xylenes	mg/kg	0.5	14	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
meta- & para-Xylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ortho-Xylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
SAMP02: Observations (performed by external sampler)																		
Colour			--	--				Brown	Brown	Orange	Brown	Brown	Brown	Brown	Orange	Orange		
Depth/Depth Range	mm		--	--				0-50	100-200	400-500	0-50	200-300	0-100	300-400	0-100	300-400		
Dominant Horizon			--	--				O	A	B	O	A	O	A	O	A		
Moisture			--	--				DRY	MOIST	MOIST	DRY	MOIST	MOIST	DRY	MOIST	MOIST		
Odour			--	--				NONE	NONE	NONE	NONE	NONE	SULF	SULF	NONE	NONE		
Sampling Method			--	--				H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger		
Santos Suite			--	--				Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W		

Impacted Area Data

Analyte	NAR_WTP(1A) 13-Jan-12 SOIL	NAR_WTP(1B) 13-Jan-12 SOIL	NAR_WTP(1C) 13-Jan-12 SOIL	NAR_WTP(2A) 13-Jan-12 SOIL	NAR_WTP(2B) 13-Jan-12 SOIL	NAR_WTP(2C) 13-Jan-12 SOIL	NAR_WTP(3A) 13-Jan-12 SOIL	NAR_WTP(3B) 13-Jan-12 SOIL	NAR_WTP(3C) 13-Jan-12 SOIL	NAR_WTP(4A) 13-Jan-12 SOIL	NAR_WTP(4B) 13-Jan-12 SOIL	NAR_WTP(4C) 13-Jan-12 SOIL	NAR_WTP(5A) 14-Jan-12 SOIL	NAR_WTP(5B) 14-Jan-12 SOIL	NAR_WTP(5C) 14-Jan-12 SOIL	NAR_WTP(6A) 14-Jan-12 SOIL	NAR_WTP(6B) 14-Jan-12 SOIL	NAR_WTP(6C) 14-Jan-12 SOIL	NAR_WTP(7A) 14-Jan-12 SOIL	NAR_WTP(7B) 14-Jan-12 SOIL	NAR_WTP(7C) 14-Jan-12 SOIL	NAR_WTP(8A) 14-Jan-12 SOIL	NAR_WTP(8B) 14-Jan-12 SOIL
EA002 : pH (Soils)																							
pH Value	9.5	9.1	7.8	9.5	9.1	8.8	9.7	9.8	9.2	9.5	9.5	5.7	8.9	8.3	5.6	10.5	9	6.4	9.2	8.7	6.1	10	8.5
EA010: Conductivity																							
Electrical Conductivity @ 25°C	824	292	265	433	360	424	1450	837	352	1270	715	179	421	275	148	3220	562	212	690	303	198	2070	346
EA029-C: Sulfur Trail																							
KCl Extractable Sulfur (23Ce)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02								
EA055: Moisture Content																							
Moisture Content (dried @ 103°C)	27.3	16.4	9.6	9.5	11.8	26.2	29.3	34.9	12.8	25.1	33.6	16.9	20.4	21.3	16	1.5	15.9	19.4	22.1	16.8	26.4	6.6	18.5
EA150: Particle Sizing																							
+1180µm	4	7	7	2	3	1	3	3	7	2	2	3	5	2	2	4	2	2	4	6	6	2	4
+150µm	50	58	43	60	60	43	16	40	49	22	42	46	46	59	42	60	64	44	59	62	40	59	62
+19.0mm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+2.36mm	2	4	4	<1	<1	<1	1	1	4	<1	<1	<1	2	<1	<1	1	<1	<1	<1	2	3	<1	2
+300µm	32	37	29	38	36	26	11	25	31	15	25	28	32	39	25	38	37	28	38	40	26	34	37
+37.5mm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+4.75mm	<1	2	1	<1	<1	<1	1	<1	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1
+425µm	21	26	21	24	23	16	8	17	21	10	16	18	22	26	16	24	23	18	26	27	18	21	24
+600µm	13	17	14	12	13	8	5	10	14	6	9	10	14	14	9	15	13	10	15	18	13	11	15
+75.0mm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+75µm	56	67	50	67	70	50	17	45	55	26	49	53	50	66	47	70	75	50	66	70	46	69	71
+9.5mm	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
EA150: Soil Classification based on Particle Size																							
Cobbles (>6cm)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Fines (	44	33	50	33	30	50	83	55	45	74	51	47	50	34	53	30	25	50	34	30	54	31	29
Gravel (>2mm)	2	4	3	1	<1	<1	1	1	4	1	<1	1	2	1	1	1	<1	<1	1	2	3	<1	2
Sand (>75 µm)	55	63	46	66	69	50	16	44	51	25	49	53	48	65	47	68	74	50	65	69	43	69	69
ED008: Exchangeable Cations																							
Cation Exchange Capacity	59.9	19.4	46.4	33.6	18.6	26.9	95.6	62.1	30.2	65.3	49.6	47.1	64.8	40.3	32.4	37.3	22.3	54.5	60.9	31.2	50.2	43.8	21.3
Exchangeable Aluminium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	1.3	<0.2	<0.2	4.5	<0.2	<0.2	0.3	<0.2	<0.2	0.4	<0.2	<0.2
Exchangeable Calcium	15.7	1.9	<0.2	7	1.2	<0.2	23.6	13.4	0.8	8.7	5.9	<0.2	11.2	2.5	<0.2	7.4	3.7	<0.2	21.2	5.6	4	5.5	1.6
Exchangeable Magnesium	10.6	6	38.2	7	4.6	17	8.9	7.3	11.2	6.5	5.6	37.9	13.8	10.2	25.7	4.3	3.9	47.4	10.9	6.7	39.6	5.8	5.5
Exchangeable Potassium	5.9	1.6	0.4	1.7	0.9	0.5	5.7	3.9	0.5	2.8	2.3	0.3	2.9	1.4	0.5	2.3	1.6	0.7	4	2.6	1.3	2.9	1.8
Exchangeable Sodium	27.7	9.9	7.7	17.9	11.9	9.2	57.5	37.5	17.8	47.4	35.8	8.8	36.8	26.2	6.1	23.3	13.1	6.2	24.7	16.3	5.4	29.5	12.4
Exchangeable Sodium Percent	46.2	51.1	16.5	53.3	63.8	34.1	60.1	60.4	58.8	72.5	72.2	18.7	56.9	65	18.9	62.6	58.6	11.4	40.6	52.1	10.7	67.4	58.3
ED021: Bicarbonate Extractable Potassium (Colwell)																							
Bicarbonate Extractable K (Colwell)	700	<200	<200	<200	<200	<200	840	800	<200	310	230	<200	270	<200	<200	<200	<200	<200	380	270	<200	300	<200
ED092: DTPA Extractable Metals																							
Copper	1.87	<1.00	<1.00	<1.00	<1.00	<1.00	2.21	1.4	<1.00	2.34	1.89	<1.00	1.23	<1.00	<1.00	2.13	6.24	<1.00	1.04	<1.00	<1.00	1.47	<1.00
Iron	231	90.4	47.2	200	208	68.6	322	186	77.3	439	687	206	371	409	197	180	<1.00	77.9	154	180	89.6	633	93.7
Manganese	100	9.97	<1.00	105	5.68	<1.00	48.3	32.7	<1.00	38.8	33.4	<1.00	104	15.5	<1.00	56.7	1.09	<1.00	239	114	<1.00	79.8	4.52
Zinc	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.09	<1.00	<1.00	1.67	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	28.4	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EG005T: Total Metals by ICP-AES																							
Arsenic	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Barium	290	40	50	220	40	30	510	360	30	210	150	30	220	90	70	110	30	40	110	50	280	70	20
Beryllium	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Boron	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	18	8	14	10	11	13	25	23	13	14	12	12	11	8	13	8	8	20	9	8	16	9	10
Cobalt	8	<2	<2	5	<2	3	13	6	2	6	3	2	4	2	3	2	<2	6	3	<2	3	2	<2
Copper	7	<5	<5	<5	<5	<5	6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6	<5	<5	5	<5	<5
Lead	8	<5	<5	<5	<5	6	10	9	5	6	5	6	6	5	5	<5	<5	10	6	5	7	<5	<5
Manganese	314	27	12	299	19	<5	204	114	<5	101	72	<5	168	31	<5	168	68	6	344	170	6	217	24
Nickel	8	2	3	4	<2	3	10	5	4	5	3	2	4	3	3	3	2	6	4	3	3	4	3
Strontium	22	3	<2	20	2	<2	55	40	<2	19	15	<2	19	5	<2	13	5	2	21	9	12	15	5
Vanadium	33	21	31	20	31	42	44	68	31	30	29	31	24	22	32	18	20	55	24	23	37	22	27
Zinc	14	<5	<5	7	<5	<5	22	8	<5	13	5	<5	8	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS																							
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
EK040: Fluoride																							
Fluoride	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	3	4	<1	2	5	4	2	3
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser																							
Nitrite + Nitrate as N (Sol.)	<0.5	<0.5	0.6	0.9	<0.5	<0.1	<0.5	<0.5	0.6	<0.5	<0.5	0.1	3	<0.5	0.1	<2.5	<0.5	0.4	4	<0.5	0.9	8	<0.5
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser																							
Total Kjeldahl Nitrogen as N	1130	420	280	1220	300	330	1340	730	280	890	760	280	1720	760	480	440	310	290	1060	470	300	720	330
EK062: Total Nitrogen as N (TKN + NOx)																							
Total Nitrogen as N	1130	420	280	1220	300	330	1340	730	280	890	760	280	1720	760	480	440	310	290	1060	470	300	730	330
EK067G: Total Phosphorus as P by Discrete Analyser																							
Total Phosphorus as P	169	80	48	130	81	39	226	148	66	119	129	32	140	78	58	80	98	52	170	124	47	154	110
EK080: Bicarbonate Extractable Phosphorus (Colwell)																							
Bicarbonate Ext. P (Colwell)	9	3	<2	9	6	<2	5	12	<2	4	6	<2	8	<2	2	9	9	<2	16	10	<2	10	8
EP003: Total Organic Carbon (TOC) in Soil																							
Total Organic Carbon	1.84	0.5	0.34	1.64	0.38	0.4	2.14	1.7	0.51	2.72	1.59	0.72	2.86	1.82	0.52	1.63	0.7	0.34	3.01	1.16	0.35	1.65	0.6
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons																							
Acenaphthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benz(a)anthracene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g.h.i)perylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(k)fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenz(a.h)anthracene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of polycyclic aromatic hydrocarbons	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
EP080/071: Total Petroleum Hydrocarbons																							
C10 - C14 Fraction	<50	<50	<50	90	<50	<50	<50	<50	<50	<50	<50	<50	110	70	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction	160	<100	<100	280	<100	<100	140	<100	<100	150	120	<100	490	380	<100	<50	<50	<50	<100	<100	<100	<100	<100
C29 - C36 Fraction	100	<100	<100	160	<100	<100	130	<100	<100	<100	<100	<100	290	130	<100	<100	<100	<100	<100	<100	<100	<100	<100
C6 - C9 Fraction	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<100	<100	<100	<100	<10	<10	<10	<10
C10 - C36 Fraction (sum)	260	<50	<50	530	<50	<50	270	<50	<50	150	120	<50	890	580	<50	<10	<10	<10	<10	<50	<50	<50	<50
EP071 SG-S: Total Petroleum Hydrocarbons in Soil - Silica gel cleanup																							
C10 - C14 Fraction	<50			<50			<50			<50	<50		<50	<50									
C15 - C28 Fraction	<100			<100			<100			<100	<100		<100	<100									
C29 - C36 Fraction	<100			<100			<100			<100	<100		<100	<100									
C10 - C36 Fraction (sum)	<50			<50			<50			<50	<50		<50	<50									
EP080/071: Total Recoverable Hydrocarbons - NEPM 2010 Draft																							
>C10 - C16 Fraction	<50	<50	<50	110	<50	<50	<50	<50	<50	<50	<50	<50	130	100	<50	<50	<50	<50	<50	<50	<50	<50	<50
>C16 - C34 Fraction	220	<100	<100	380	<100	<100	240	<100	<100	210	170	<100	700	430	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C6 - C10 Fraction	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
C6 - C10 Fraction minus BTEX (F1)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
>C10 - C40 Fraction (sum)	220	<50	<50	490	<50	<50	240	<50	<50	210	170	<50	930	530	<50	<50	<50	<50	<50	<50	<50	<50	<50
EP071 SG: Total Recoverable Hydrocarbons (NEPM 2010 draft) - Silica gel cleanup																							
>C10 - C16 Fraction	<50			<50			<50			<50	<50		<50	<50									
>C16 - C34 Fraction	<100			<100			<100			<100	<100		<100	<100									
>C34 - C40 Fraction	<100			<100			<100			<100	<100		<100	<100									
>C10 - C40 Fraction (sum)	<50			<50			<50			<50	<50		<50	<50									
EP080: BTEXN																							
Benzene	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sum of BTEX	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Xylenes	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
meta- & para-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ortho-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
SAMP02: Observations (performed by external sampler)																							
Colour	Black	Grey	Brown	Black	Grey	Brown	Black	Grey	Brown	Black	Grey	Brown	Black	Black	Orange	Black	Orange	Orange	Black	Brown	Orange	Black	Orange
Depth/Depth Range	0-50	50-100	300-400	0-50	50-100	400-500	0-50	50-100	300-400	0-50	50-100	400-500	0-50	100-200	400-500	0-50	100-200	400-500	0-50	50-100	300-400	0-50	50-150
Dominant Horizon	O	A	B	O	A	B	O	A	B	O	A	B	O	A	B	0	A	B	O	A	B	O	A
Moisture	DRY	MOIST	MOIST	DRY	MOIST	MOIST	DRY	MOIST	MOIST	DRY	MOIST	MOIST	DRY	MOIST	MOIST	DRY	MOIST	DRY	DRY	MOIST	DRY	DRY	MOIST
Odour	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF	NONE	SULF	SULF
Sampling Method	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger
Santos Suite	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W

Analyte	Units	LOR	Human Health NSW (2006) HIL A	Background Criteria NEPM 1999	Calculated Background Averages: Site Background Average Depth (A)	Site Background Average Depth (B)	Site Background Average Depth (C)	NAR_WTP(8C)	NAR_WTP(10A)	NAR_WTP(10B)	NAR_WTP(10C)	NAR_WTP(11A)	NAR_WTP(11B)	NAR_WTP(11C)	NAR_WTP(13A)	NAR_WTP(13B)	NAR_WTP(14A)	NAR_WTP(14B)	NAR_WTP(15A)	NAR_WTP(15B)	NAR_WTP(17A)	NAR_WTP(17B)	NAR_WTP(17C)	NAR_WTP(18A)	NAR_WTP(18B)
								14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	14-Jan-12	15-Jan-12	15-Jan-12	15-Jan-12	15-Jan-12	15-Jan-12
								EB1201577009	EB1201577013	EB1201577014	EB1201577015	EB1201577016	EB1201577017	EB1201577018	EB1201577021	EB1201577022	EB1201577023	EB1201577024	EB1201577025	EB1201577026	EB1201577029	EB1201577030	EB1201577031	EB1201577032	EB1201577033
								SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL	SOIL
EA002 : pH (Soils)																									
pH Value	pH Unit	0.1	--	--	5.80	5.73	5.80	6.2	8	7.8	6.3	7.9	7.5	6.7	7.6	7.2	8.6	6.8	9.1	6.6	9	9.2	5.6	6.9	6.7
EA010: Conductivity																									
Electrical Conductivity @ 25°C	µS/cm	1	--	--	13.25	48.25	206.00	238	391	88	174	628	61	221	298	61	158	37	416	69	742	353	335	93	14
EA026-C: Sulfur Trail																									
KCl Extractable Sulfur (CRS)	% S	0.02	--	--	<0.02	<0.02	<0.02																		
EA055: Moisture Content																									
Moisture Content (dried @ 103°C)	%	1	--	--	12.95	16.98	8.50	24.6	19.4	16.5	12.8	15.4	11	18.7	14.4	15.4	12.8	17.7	23.5	17.4	29.7	14.8	22.8	21	17.4
EA150: Particle Sizing																									
+1180µm	%	1	--	--	2.75	5.25	2.00	6	2	5	7	7	5	2	2	4	2	6	2	4	<1	4	2	1	5
+150µm	%	1	--	--	64.75	58.50	50.00	48	60	72	60	64	72	55	68	73	65	55	56	68	2	54	40	69	74
+19.0mm	%	1	--	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+2.36mm	%	1	--	--	<1	2.50	1.00	<1	<1	<1	3	2	1	<1	<1	1	<1	3	<1	<1	<1	1	<1	<1	<1
+300µm	%	1	--	--	38.50	33.50	29.00	28	36	47	38	44	44	31	39	41	19	25	14	44	2	33	23	38	45
+37.5mm	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+4.75mm	%	1	--	--	<1	3.50	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
+425µm	%	1	--	--	21.00	21.50	18.00	19	20	32	26	31	30	19	23	26	10	17	6	30	1	21	14	22	29
+600µm	%	1	--	--	11.50	13.50	10.00	12	14	19	17	20	18	10	12	15	5	11	3	18	1	12	7	10	18
+75.0mm	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
+75µm	%	1	--	--	75.75	69.50	59.00	53	67	81	70	70	85	64	78	85	89	75	88	78	2	61	46	86	86
+9.5mm	%	1	--	--	<1	3.00	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
EA150: Soil Classification based on Particle Size																									
Cobbles (>6cm)	%	1	--	--	<1	<2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Fines (<75µm)	%	1	--	--	24.25	30.50	41.00	47	33	19	30	30	15	36	22	15	11	25	12	22	98	39	54	14	14
Gravel (>2mm)	%	1	--	--	1.00	2.50	1.00	4	1	<1	3	2	1	<1	<1	1	1	3	1	<1	1	1	<1	<1	1
Sand (>75 µm)	%	1	--	--	75.00	67.00	58.00	50	66	81	67	68	84	64	78	84	89	72	87	77	1	60	46	86	86
ED008: Exchangeable Cations																									
Cation Exchange Capacity	meq/100g	0.1	--	--	11.10	21.55	33.00	31.9	45.2	9.3	30.1	30.4	7.4	29.8	25.7	7.1	4.7	13.3	10.2	13.2	60.2	32.4	47.4	5.2	2.2
Exchangeable Aluminium	meq/100g	0.1	--	--	2.67	0.70	0.70	<0.2	<0.2	0.8	0.3	<0.2	0.9	<0.2	<0.2	0.8	<0.2	0.6	<0.2	0.9	<0.2	<0.2	0.3	<0.2	<0.2
Exchangeable Calcium	meq/100g	0.1	--	--	6.75	9.80	1.60	1.1	19.5	2	23.5	8.2	2.6	10.2	7.6	0.2	1.1	1.7	1.7	5.6	15.2	14.8	5.8	1.5	0.8
Exchangeable Magnesium	meq/100g	0.1	--	--	4.15	18.48	27.60	41.1	9	5.2	23.3	7	2.6	23.5	7.9	4.8	1.8	8.6	1.8	5.9	34.5	21.2	41.2	2.1	1
Exchangeable Potassium	meq/100g	0.1	--	--	1.18	0.78	1.60	2.1	2.8	1	3	2.2	0.7	2	2.4	1	0.7	1.4	0.7	1.5	4	1.7	0.8	0.5	0.5
Exchangeable Sodium	meq/100g	0.1	--	--	<0.2	2.03	2.80	7.6	14	0.3	3.4	13	3.5	4.3	8.1	1.2	0.9	1.5	2.6	4.9	35.8	14.8	4.6	0.3	<0.2
Exchangeable Sodium Percent	%	0.1	--	--	1.50	9.43	7.70	14.8	30.8	30.1	11.3	42.5	47.8	14.3	31.4	16.8	19.7	11.6	45.4	37.3	59.7	21.8	9.7	6.1	4.6
ED021: Bicarbonate Extractable Potassium (Colwell)																									
Bicarbonate Extractable K (Colwell)	mg/kg	10	--	--	<200	<200	<200	<200	<200	<200	200	<200	<200	<200	<200	<200	<200	<200	<200	<200	460	<200	<200	<200	<200
ED060: DTPA Extractable Metals																									
Copper	mg/kg	1	--	--	<1	<1	<1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.01	<1.00	<1.00	<1.00	<1.00
Iron	mg/kg	1	--	--	33.93	87.18	34.50	18	116	66.2	31.2	226	33.6	56.8	116	83.7	10.5	82.3	95.2	346	176	36.5	32.2	22.2	9.09
Manganese	mg/kg	1	--	--	18.71	1.64	<1	7.4	133	5.7	<1.00	64.5	3.36	<1.00	59.3	<1.00	2.57	1.14	10.4	<1.00	51.5	17.7	<1.00	11.3	<1.00
Zinc	mg/kg	1	--	--	<1	<1	<1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
EG005T: Total Metals by ICP-AES																									
Arsenic	mg/kg	5	100	1-50	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Barium	mg/kg	10	--	100-3000	37.50	20.00	30.00	50	70	20	10	80	20	30	40	10	10	40	20	20	440	30	60	10	<10
Beryllium	mg/kg	1	20	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1
Boron	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Cadmium	mg/kg	1	20	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	mg/kg	2	120000	5-1000	6.00	8.50	12.00	14	13	7	6	7	6	14	6	5	4	14	4	6	22	11	17	2	2
Cobalt	mg/kg	2	100	1-40	<2	2.00	3.00	3	2	<2	<2	2	<2	3	<2	<2	<2	2	<2	<2	14	6	6	<2	<2
Copper	mg/kg	5	1000	2-100	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	8	<5	<5	<5	<5
Lead	mg/kg	5	300	2-200	5.00	6.00	8.00	7	5	<5	<5	<5	<5	<5	<5	<5	<5	6	<5	<5	11	6	7	<5	<5
Manganese	mg/kg	5	1500	850	93.50	9.50	<5	13	228	30	<5	277	21	<5	191	<5	10	12	18	<5	128	218	7	13	<5
Nickel	mg/kg	2	600	5-500	2.00	2.50	3.00	4	3	<2	2	3	<2	3	2	<2	<2	3	<2	<2	16	5	6	<2	<2
Strontium	mg/kg	2	--	--	5.25	3.50	4.00	4	18	4	<2	12	2	<2	8	<2	<2	4	2	<2	16	13	4	<2	<2
Vanadium	mg/kg	5	--	20-500	17.50	24.00	35.00	29	49	26	14	21	24	32	20	17	12	37	12	16	52	27	42	11	10
Zinc	mg/kg	5	7000	10-300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	12	<5	<5	<5	<5
EG035T: Total Recoverable Mercury by FIMS																									
Mercury	mg/kg	0.1	15	0.03	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
EK040: Fluoride																									
Fluoride	mg/kg	1	--	--	<1	<1	<1	5	2	2	<1	<1	1	<1	1	<1	<1	<1	1	<1	<1	<1	2	<1	<1
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser																									
Nitrite + Nitrate as N (Sol.)	mg/kg	0.1	--	--	1.40	0.38	0.30	0.3	<0.5	<0.1	1.6	2.3	0.2	0.4	0.2	<0.1	0.2	0.3	<0.5	<0.1	<0.1	3.3	0.5	0.1	0.4
EK061G: Total Kjeldahl Nitrogen By Discrete Analyser																									
Total Kjeldahl Nitrogen as N	mg/kg	20	--	--	492.50	187.50	130.00	310	600	280	190	690	160	270	600	220	90	260	900	300	1260	820	310	150	70
EK062: Total Nitrogen as N (TKN + NOx)																									
Total Nitrogen as N	mg/kg	20	--	--	492.50	187.50	130.00	310	600	280	190	690	160	270	600	220	90	260	900	300	1260	820	310	150	70
EK067G: Total Phosphorus as P by Discrete Analyser																									
Total Phosphorus as P	mg/kg	2	--	2000	84.50	51.25	32.00	50	99	74	53	113	55	88	140	65	40	131	81	92	233	178	87	29	36
EK080: Bicarbonate Extractable Phosphorus (Colwell)																									
Bicarbonate Ext. P (Colwell)	mg/kg	2	--	--	10.00	2.00	<2	<2	12	<2	<2	7	2	<2	2	3	<2	8	<2	2	11	7	<2	<2	<2
EP003: Total Organic Carbon (TOC) in Soil																									
Total Organic Carbon			--	--	1.04	0.28	0.18	0.3	2.04	0.44	0.22	1.82	0.37	0.33	1.14	0.42	0.18	1	0.37	0.76	3.03	1.52	1.68	1.56	0.18
EP075(SIM)B: Polynuclear Aromatic Hydrocarbons																									
Acenaphthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benz(a)anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene	mg/kg	0.5	1	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g.h.i)perylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(k)fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenz(a.h)anthracene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of polycyclic aromatic hydrocarbons	mg/kg	0.5	20	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
EP080/071: Total Petroleum Hydrocarbons																									
C10 - C14 Fraction	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	110	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	130	<100	<100	<100	<100	160	<100	<100	<100	<100	<100
C29 - C36 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C6 - C9 Fraction	mg/kg	10	65	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
C10 - C36 Fraction (sum)	mg/kg	50	1000	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	240	<50	<50	<50	<50	160	<50	<50	<50	<50	<50
EP071 SG-S: Total Petroleum Hydrocarbons in Soil - Silica gel cleanup																									
C10 - C14 Fraction	mg/kg	50	--	--	--	--	--																		
C15 - C28 Fraction	mg/kg	100	--	--	--	--	--																		
C29 - C36 Fraction	mg/kg	100	--	--	--	--	--																		
C10 - C36 Fraction (sum)	mg/kg	50	1000	--	--	--	--																		
EP080/071: Total Recoverable Hydrocarbons - NEPM 2010 Draft																									
>C10 - C16 Fraction	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	110	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
>C16 - C34 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	140	<100	<100	<100	<100	180	<100	<100	<100	<100	<100
>C34 - C40 Fraction	mg/kg	100	--	--	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C6 - C10 Fraction	mg/kg	10	--	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	17	<10	<10
C6 - C10 Fraction minus BTEX (F1)	mg/kg	10	--	--	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	17	<10	<10
>C10 - C40 Fraction (sum)	mg/kg	50	--	--	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	250	<50	<50	<50	<50	180	<50	<50	<50	<50	<50
EP071 SG: Total Recoverable Hydrocarbons (NEPM 2010 draft) - Silica gel cleanup																									
>C10 - C16 Fraction	mg/kg	50	--	--	--	--	--																		
>C16 - C34 Fraction	mg/kg	100	--	--	--	--	--																		
>C34 - C40 Fraction	mg/kg	100	--	--	--	--	--																		
>C10 - C40 Fraction (sum)	mg/kg	50	--	--	--	--	--																		
EP080: BTEXN																									
Benzene	mg/kg	0.2	1	--	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethylbenzene	mg/kg	0.5	3.1	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	mg/kg	1	--	--	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sum of BTEX	mg/kg	0.2	--	--	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Toluene	mg/kg	0.5	1.4	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Xylenes	mg/kg	0.5	14	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
meta- & para-Xylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ortho-Xylene	mg/kg	0.5	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
SAMP02: Observations (performed by external sampler)																									
Colour			--	--				Orange	Black	Brown	Brown	Black	Brown	Brown	Black	Brown	Black	Brown	Black	Brown	Black	Grey	Brown	Black	Orange
Depth/Depth Range	mm		--	--				500-600	0-50	50-150	300-400	0-50	100-200	400-500	0-50	200-300	0-100	100-200	0-50	200-300	0-50	50-100	300-400	0-50	100-200
Dominant Horizon			--	--				B	O	A	B	O	A	B	O	A	O	A	O	A	O	A	B	O	A
Moisture			--	--				DRY	DRY	MOIST	DRY	DRY	MOIST	DRY	DRY	MOIST	DRY	MOIST	DRY	MOIST	DRY	MOIST	DRY	DRY	MOIST
Odour			--	--				NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
Sampling Method			--	--				H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger	H Auger
Santos Suite			--	--				Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W	Suite W

CERTIFICATE OF ANALYSIS

Client: ALS - Smithfield

Address: 277 Woodpark Road
Smithfield, NSW 2164

Attention:

Quote:

Project:

ALS Work Order: ES1219271

Laboratory: ALS Water Resources Group Canberra

Date Sampled: 7/08/2012

Date Received: 9/08/2012

Date Analysed: 13/08/2012

Sample Type: W

No. of Samples: 1

ANALYSIS REPORT: **TOTAL PHYTOPLANKTON ENUMERATION**

Comments:

NOTES

Samples were preserved with Lugols Iodine solution.
Samples were analysed in accordance with ALS Quality Work Instruction CAN-LOP 721

Results apply to sample(s) as submitted.

Martin Radic
Team Leader
(Signatory)

Date Reported: 15/812

ALS Sample ID:	**ES1219271 001AA**
Client Sample ID	**120562-1 BCO**
Sample Date:	**7/08/2012**
Sample Time :	**NA**
Units :	**Cells/mL**
CYANOPHYTES (Blue-green algae)	
Chroococcales	
Chroococcus spp.	667
Total Chroococcales	**667**
Total Nostocales	**<1**
Oscillatoriales	
Phormidium spp	384000
Pseudanabaena spp	78000
Total Oscillatoriales	**462000**
Total Stigonematales	**<1**
CHLOROPHYTES (Green algae)	
Chlorococcales	
Closteriopsis sp.	167
Conjugales (Zygnematales)	167
Cosmarium spp	
Volvocales	
Chlamydomonas spp	667
Total Chlorophytes	**1001**
FLAGELLATES	
Euglenophytes	
Euglena spp	1667
Trachelomonas spp	833
Cryptophytes	
Cryptomonas spp	4500
Total flagellates	**7000**
CHRYSOPHYTES (Golden algae)	
Total Chrysophytes	**<1**
BACILLARIOPHYTES (Diatoms)	
Pennates	
Navicula spp	6
Total Bacillariophytes	**6**
TOTAL ALGAE	**470674**

ND = Not Detected
NA = Not available
PTP = Potential Toxin Producer

3.2.2.5 Drilling fluid composition & properties

The drilling fluid composition will predominately be a potassium sulphate (K_2SO_4) based drilling fluid, however, technical requirements may require the use of potassium chloride (KCl).

Potassium sulphate drilling fluids are currently being used by Santos and other operators in Queensland and extensively in Canada. These fluids are considered to have the lowest environmental impact of any water based system currently available.

A potassium sulphate drilling fluid is made up of water (93-95% by volume), K_2SO_4 (5-7% by volume) and polymers.

A potassium chloride based system is made up of water (95-97% by volume), potassium chloride (3-5% by volume) and polymers. 1he salinity resulting from the potassium chloride means that the drilling waste generated will require disposal at a licensed waste disposal facility.

Typical drilling fluid properties are outlined in the following table.

Table 3-1 Typcial drilling fluid properties

Property	Unit (API)	Typical Range
Fluid Weight	Specific Gravity	1.05 – 1.25
Viscosity	sec's/litre (Marsch Funnel)	30 - 45
Plastic Viscosity	Cps (using a 6-speed Rheometer)	5 - 15
Yield Point	Lbs/ft²	2 - 12
pH		8.0 – 9.5
Potassium Content	By volume	3.0 – 8.0
Salinity	ppm Chlorides	< 2,000
Calcium Content	ppm	200 - 800
Solids Content	ppm	0.5 – 7.0
Fluid Loss	Cc's/30min (API Filter Press)	5.0 – 15.0

3.3 Access and Parking

The current operations centre has no formal line marked car parking spaces however site observations indicate that adequate space is available for parking within an area located between the main office building and Yarrie Lake Road. In addition, parking for company vehicles and equipment is also located along the boundaries of the site.

A spot count of the car park was undertaken by GTA Consultants at 3:00pm on 19 September 2012. It indicates an existing on-site car parking demand of up to 20 vehicles. It is also understood that peak parking demand during a busy period can see up 40 vehicles parked on-site.

The previous proposal (DA546-2013) incorporated additional formal line marked on-site parking, including 10 spaces (including 1 disabled) at the front of the proposed office space. Additional hardstand area will also provide for informal parking, as required.

To improve safety and efficiency, access to the site via Yarrie Lake Road is proposed to be upgraded as part of DA546-2013. A two-lane one-way 12m wide circulation road to allow 25m B-double trucks to circulate within the site, and an additional 12m wide two-way vehicular crossover to provide an exit for the site are proposed. These works will service the proposed development.

Summary of Comments on DA769-2013 Statement of Environmental Effects.pdf

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Number: 1 Author: Tony Subject: Highlight Date: 18/05/2017 4:20:37 PM

TONY PICKARD

From: "Nearhos, Dr Steven" <steven@baseline.com.au>
Date: Thursday, 30 August 2012 2:48 PM
To: "TONY PICKARD" <deere@activ8.net.au>
Subject: Re: Last Sample sent

Tony,

Thanks.

Please send a photo.

The black is probably SRB using organic material possibly the cell walls of Iron precipitating bacteria.
Did John organize TOC on this sample.

Sorry I will get back to you ASAP. I do appreciate your patience.

thanks

Steven

> ----- Original Message -----
> **From:** TONY PICKARD
> **To:** Dr Steven Nearhos
> **Sent:** Thursday, August 30, 2012 13:42
> **Subject:** Last Sample sent
>
> Steven—Just looked at my sample of the last sample sent to you, and all the bright red floc is now BLACK, the little bugs that were black are now RED and surviving very well. This sample has been kept in the shed, and well away from direct light although some light does get in. The temperatures have been on the cool side. What does your sample look like now. Answer in your own time.
> Tony

Colour (True)

(endorsed 1996)

GUIDELINE

Based on aesthetic considerations, true colour in drinking water should not exceed 15 HU.

GENERAL DESCRIPTION

Two terms are used to describe colour. 'True colour' is the colour after particulate matter has been removed (usually by filtration through a 0.45 micrometer pore size filter). 'Apparent colour' is what one actually sees; it is the colour resulting from the combined effect of true colour and any particulate matter, or turbidity. In turbid waters, the true colour is substantially less than the apparent colour.

In natural waters, colour is due mainly to the presence of dissolved organic matter including humic and fulvic acids, which originate from soil and decaying vegetable matter. Surface water can also be coloured by waste discharges, for example from dyeing operations in the textile industry, and paper manufacture.

The dissolution of metals in pipes and fittings can also discolour drinking water. Badly corroded iron pipes can produce a brownish colour whereas corrosion of copper pipes can produce a blue-green colouration on sanitary ware and a faint blue colour in water in extreme cases. The condition of household pipes can significantly influence water colour.

In bore water, 'red water' is a frequent problem, caused by the oxidation of iron. In addition, a black discolouration in reservoirs and distribution systems can result from the action of bacteria on dissolved manganese to produce insoluble oxides. Some of these compounds form fine suspensions, or are only partially dissolved, and so contribute to apparent rather than true colour. (See Section 5.6 *Nuisance organisms.*)

As a guide, tea has a colour of about 2500 Hazen units (HU, see below). A true colour of 15 HU can be detected in a glass of water, and a true colour of 5 HU can be seen in larger volumes of water, for instance in a white bath. Few people can detect a true colour level of 3 HU, and a true colour of up to 25 HU would probably be accepted by most people provided the turbidity was low. Some examples of drinking water with differing turbidity and colour are shown in Plate 1.

True colour is preferred analytically, as the measurement is more precise than for apparent colour, and not as dependent on site or time. If both true colour and turbidity are at the guideline values (i.e. true colour of 15 HU and turbidity of 5 NTU[Nephelometric Turbidity Units]), the apparent colour could be 20 HU. This is considered to be acceptable.

Variations in colour are likely to lead to more complaints than a high but consistent colour.

TYPICAL VALUES IN AUSTRALIAN DRINKING WATER

In major Australian reticulated supplies true colour ranges from 1 HU to 25 HU for filtered or fully treated supplies, and from 1 HU to 85 HU for unfiltered supplies.

MEASUREMENT

Colour can be measured spectrophotometrically or using a visual comparator. In both cases, the standard unit of measurement is the Hazen unit (HU). (True colour is often quoted as True Colour Units, or TCU; however, the numerical values are identical.) Hazen units are defined in terms of a platinum–cobalt standard (APHA Method 2120B 1992). This standard was developed for the analysis of colour in natural waters with a yellow-brown appearance, and is not applicable to waters with different colours.

It is advisable to record the pH with the colour measurement, as the colour of natural surface waters increases with pH.

Colour values obtained using a spectrophotometer are dependent on the wavelength used for the measurement. There is no standard wavelength used in Australia, but values ranging from 395 nm to 465 nm are generally used. In the absence of a suitable Australian Standard, the British Standard, which uses 436 nm (BSI Method BS6068 1986), is suitable.

TREATMENT OF DRINKING WATER

Constituents of natural colour derived from humic and fulvic acids can be reduced by coagulation followed by filtration (AWWA 1990). Oxidation by chlorine or ozone will also reduce colour but may produce undesirable by-products.

HEALTH CONSIDERATIONS

Colour is generally related to organic content, and while colour derived from natural sources such as humic and fulvic acids is not a health consideration, chlorination of such water can produce a variety of chlorinated organic compounds as by-products (see Section 6.3.2 on disinfection by-products). If the colour is high at the time of disinfection, then the water should be checked for disinfection by-products. It should be noted, however, that low colour at the time of disinfection does not necessarily mean that the concentration of disinfection by-products will be low.

Reactions between naturally occurring humic and fulvic material and water disinfectants (such as chlorine, ozone, chloramines and chlorine dioxide) can also cause difficulties in maintaining an adequate level of disinfectant, thus creating the opportunity for bacterial reinfection or regrowth.

The solubility of some organic pollutants can also be increased through complex formation with humic material.

Coloured water may prompt people to seek other, perhaps less safe, sources of drinking water.

DERIVATION OF GUIDELINE

The guideline value is based on the colour that is just noticeable in a glass of water. This is generally accepted as being 15 HU.

GUIDELINES IN OTHER COUNTRIES

The Canadian Guidelines and the 1984 World Health Organization (WHO) Guidelines both recommend a value of 15 HU. The 1993 WHO Guidelines indicate that a colour above 15 TCU may give rise to consumer complaints.

The United States EPA Secondary Drinking water Regulations have a maximum concentration for colour of 15 HU.

The European Economic Community Standards for colour are a maximum admissible value of 20 HU and a guideline value of 1 HU.

REFERENCES

APHA Method 2120B (1992). Colour: Visual comparison method. Standard Methods for the Examination of Water and Wastewater, 18th edition. American Public Health Association, Washington.

AWWA (American Water Works Association) (1990). *Water Quality and Treatment: A handbook of community water supplies*. AWWA, 4th edition, McGraw-Hill Inc.

BSI Method BS6068 (1986). Examination and determination of colour. British Standards Institution, British Standard for Water Quality, Section 2.22.

WHO (World Health Organization) (2006). *Guidelines for Drinking-water Quality*. 3rd Edition, WHO, Geneva, Switzerland.

NOTE: Important general information is contained in PART II, Chapter 6

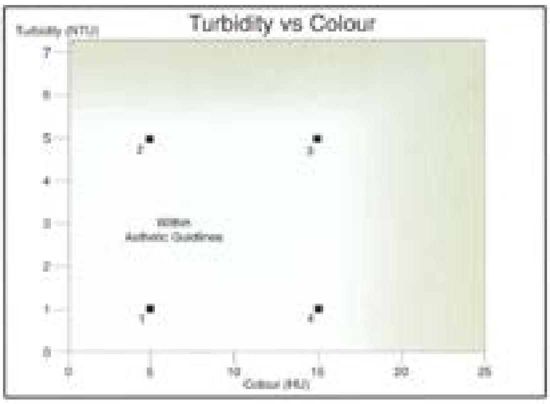
Colour and Turbidity

1. Colour = 5 HU
   Turbidity = 1 NTU

2. Colour = 5 HU
   Turbidity = 5 NTU

3. Colour = 15 HU
   Turbidity = 5 NTU

4. Colour = 15 HU
   Turbidity = 1 NTU



NOTE: Important general information is contained in PART II, Chapter 6

Turbidity

(endorsed 2011)

GUIDELINE

Chlorine-resistant pathogen reduction: Where filtration alone is used as the water treatment process to address identified risks from Cryptosporidium and Giardia, it is essential that filtration is optimised and consequently the target for the turbidity of water leaving individual filters should be less than 0.2 NTU, and should not exceed 0.5 NTU at any time

Disinfection: A turbidity of less than 1 NTU is desirable at the time of disinfection with chlorine unless a higher value can be validated in a specific context.

Aesthetic: Based on aesthetic considerations, the turbidity should not exceed 5 NTU at the consumer's tap.

GENERAL DESCRIPTION

Turbidity is a measure of the light-scattering property of water caused by the presence of fine suspended matter such as clay, silt, plankton and other microscopic organisms. The degree of scattering depends on the amount, size and composition of the suspended matter. At low levels, turbidity can only be detected by instruments, but at higher levels the water has a "muddy" or "milky" appearance clearly visible to the naked eye. As a guide, water with a turbidity of 5 Nephelometric Turbidity Units (NTU) appears slightly muddy or milky in a glass, while at >60 NTU, it is not possible to see through the water. "Crystal-clear" water usually has a turbidity of less than 1 NTU.

There are three distinct aspects to turbidity to be considered within the catchment-to-consumer risk management framework:

- the use of turbidity as a measure to provide assurance of the optimal operation of filter performance, where filtration is used to address identified risks associated with chlorine-resistant pathogens in the source water;
- the impact of turbidity on the efficiency of disinfection processes;
- the effect that turbidity has on the aesthetics of the treated water.

MEASUREMENT

For laboratory-based analyses, the ration-recording nephelometroc turbidity meter is the preferred method for turbidity meanreument, as it can compensate for the effect of dissolved colour. Results are expressed in NTU and are calibrated against a prepared formazin standard (APHA 2130B, 2005). The detection limit is about 0.1 NTU.

When using turbidity for accurate monitoring of filter performance (i.e. where filtration is the only water treatment process to remove chlorine-resistant pathogens), it is recommended that on-line, continuously reading turbidity meters be installed on the outlet of each individual filter in addition to any on-line turbidity meter that is installed on the combined filter outlet. It is prudent to have the turbidity meter outputs linked into plant SCADA and/or alarm systems, to ensure that immediate action is taken in response to the detection of filtered water turbidity above the set target. This intensity or operational monitoring is strongly recommended to ensure that any performance issues related to individual filters are detected and addressed proactively (USEPA 2004, Mosse 2009). Particle counting facilities are used for the same purpose of filter optimisation but the results are too dependent on the actual equipment used and their mode of operation to provide general guidance in the same context as for tubidity.

While real-time monitoring of the turbidity trends generated from the on-line instruments is crucial in determining the instantaneous performance of the plant, and therefore the safety of the water, longer-term monitoring is beneficial to demonstrate the need for continuous improvement and maintenance activities such as filter inspections, optimised backwash and other process procedures.

TREATMENT OF DRINKING WATER

Pathogen reduction

Chlorine-based disinfection is only effective against bacterial and most viral, pathogens. At the doses typically applied in water treatment, chlorine is not effective against the protozoan pathogen *Cryptosporidium* and only has a limited effect on *Giardia* in the absence of large filtered water storages to provide adequate contact time for effective disinfection. *Cryptosporidium* oocysts are quite small (4-6 µm) and will pass readily through a conventional media filter in the absence of effective coagulation and flocculation. Filtration combined with effective coagulation, flocculation and clarification can be used as a barrier for *Cryptosporidium* and other protozoan pathogens. In many cases, coagulation-assisted clarification and filtration may be the only existing treatment barrier to protozoan pathogens.

In the absence of reliable real-time pathogen detection methodologies, continuous turbidity monitoring is considered the best available surrogate for assessing filter performance.

Many studies have investigated the relationship between pre-treatment turbidity, turbidity reduction (or particle removal) via filtration, and pathogen reduction. It has been demonstrated in pilot scale trials that a change in filter effluent turbidity from 1.0 through 0.5 to 0.3 NTU would not significantly improve the reliability of pathogen control. However, by setting filter effluent turbidity goals below 0.2 NTU, significant improvements in microbial quality could be obtained (Xagoraraki *et al* 2004). The USEPA identified that turbidity limits of 0.15 NTU from individual filters with an upper limit of 0.3 NTU provided a substantial improvement in removal of *Cryptosporidium* compared to its previous limits of 0.3 NTU, with an upper limit of 1 NTU (USEPA 2006).

Targets for filtered water turbidity should be based on the pathogen risks in the raw water; for example, surface run-off from a catchment with significant sewage inputs or dairy farms would have tighter turbidity targets than a catchment without such impacts. Therefore, when setting turbidity targets for filtered water, raw water quality and treatment capabilities need to be aligned to manage any potential health risks. The United States Environmental Protection *Agency Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2006) and the *Drinking-water Standards for New Zealand* (NZ-MOH 2008) directly relate raw water quality to the setting of filtered water turbidity targets.

Where a given water supply system risk assessment identifies a significant risk associated with protozoan pathogens, and a high level of operational monitoring of turbidity and any associated adjustment or maintenance of coagulation, flocculation, clarification and filtration processes or facilities are not considered practical, then alternative processes (e.g. ultraviolet radiation disinfection) may need to be applied to ensure the identified risk is adequately addressed.

Catchment management and source protection can be good enough to obviate the need for water treatment to remove and/or inactive protozoan pathogens. Exclusion of contamination from humans and domesticated animals in run-off from catchments and source areas generally leads to only minimal risk from protozoan pathogens in the Australian context, and specific treatment to remove protozoa is not required. In many cases, however, catchments and sources are not sufficiently managed and protected to ensure safe drinking water without additional treatment.

Where water is harvested from partly protected catchments and sources with a relatively low level of contamination, protozoan pathogens can be removed adequately by conventional treatment alone. Conventional treatment involves the addition of coagulants, removal of solids using clarifiers such as sedimentation, solids contact or dissolved air floatation, and removal of the remaining solids in clarified water in media filters, followed by chlorine-based disinfection. Such treatment is widely used and technically capable of reducing turbidity to below 0.2 NTU but requires close operator attention and continuous monitoring as discussed above.

Where water is harvested from sources with significant risks of contamination with protozoan pathogens, filtration to 0.2 NTU alone may not reduce the risk from protozoan pathogens to acceptable levels. Other treatment, such as membrane filtration, or disinfection by ultraviolet radiation or ozonation, may be needed.

In most cases, the turbidity of the filtered water during ripening periods after filter backwash, may exceed 0.3 NTU. It is considered best practice to limit these short spikes in turbidity to no longer than 15 minutes. Spikes above 0.3 NTU represent periods of increased risk, and appropriate risk management practices should be employed, such as rejecting ripening water to waste or optimising filter backwash processes.

Turbidity added after treatment can arise from the use of lime to raise the final pH of the water. This turbidity is unlikely to have an associated pathogen risk.

Disinfection

High turbidity has been shown to shield microorganisms from the action of disinfectants (Katz 1986). Low turbidity, however, is no guarantee that water is free from pathogenic microorganisms.

If the turbidity in a water supply exceeds 1 NTU, adequate disinfection may be more difficult to maintain, but may nevertheless be achievable.

Where water that is to be disinfected has not been previously filtered, it is desirable that the turbidity be less than 1 NTU at the time of disinfection, subject to the type of disinfectant being used. For example, disinfection using ultraviolet light is likely to remain effective at turbidities above 1 NTU, providing transmission is maintained, whereas the effectiveness of chlorine-based disinfectant can be affected above 1 NTU.

If water of a higher turbidity is to be disinfected, then validation work should be undertaken to demonstrate that disinfection of water under such conditions is effective.

Disinfection is discussed in more detail in Information Sheet 1 Disinfection of drinking water.

Aesthetics

Turbidity has an impact on the aesthetic acceptability of water. Many consumers relate the appearance of water to its safety, and turbid or coloured water is interpreted as being unsafe to drink. Turbidity must therefore be maintained as low as possible to the point of supply to customers.

Passage of water through a distribution system can also lead to an increase in turbidity, generally as a result of the resuspension of fine sediments settled over a long period of time, or from the breakdown of pipe materials or biofilms lining the walls of the pipes. While the associated health risk is generally minimal, it may be significant in poorly maintained systems, as some biofilms are known to harbour living microorganisms. Therefore turbidity in the distribution system can be also used as an indicator of good distribution management practices.

HEALTH CONSIDERATIONS

Consumption of highly turbid waters is not necessarily a health hazard, but may constitute a health risk if the suspended particles harbour pathogenic microorganisms capable of causing disease in humans, or if the particles have adsorbed toxic organic or inorganic compounds.

For a treatment system designed for chlorine-resistant pathogen reduction via filtration only, detection of increases in the turbidity of filtered water above 0.5 NTU should trigger investigative action. Major filtration failures should referred to the relevant health authority or regulator to assess the potential health risk.

Turbidity can have a significant impact on the microbiological quality of drinking water. High turbidity interferes with both the detection and the disinfection of pathogens, by adsorbing them into the particulate matter and thus shielding them. Some turbidity may also promote bacterial growth if they provide a source of nutrients.

It is important to recognise the sources of suspended or particulate matter in water, and the potential associated risks to human health. Particulate matter from multi-use surface catchments often contains human pathogens. The poor management of turbid water events is a significant factor in many waterborne disease outbreaks (Hrudey and Hrudey 2004).

REFERENCES

APHA Method 2130B (2005). Turbidity: nephelometric method. *Standard Methods for the Examination of Water and Wastewater*, 21st edition. American Public Health Association, Washington.

Hrudey SE, Hrudey EJ (2004). *Safe Drinking Water – Lessons from recent outbreaks in affluent countries*. IWA Publishing, London.

Katz EL (1986). The stability of turbidity in raw water and its relationship to chlorine demand. *Journal of theAmerican Water Works Association*, 78:72–75.

Mosse P (2009). Longterm filter monitoring and safe drinking water – data from two Australian water utilities. *Water Works – Officical Journal of the Water Industry Operators Association*, June 2009, Water Industry Operators Association, Shepparton, p8-11.

NZ-MOH (New Zealand Ministry of Health) (2008). *Drinking-water Standards for New Zealand* 92005, revised 2008)

USEPA (2004). *Long Term 1 Enhanced Surface Water Treatment Rule – Turbidity Provisions – Technical Guidance Manual*.

USEPA. 2006. *National Primary Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule: Final Rule*.

Drinking-water Standards for New Zealand 2005 (revised 2008) (2008). Ministry of Health.

Xagoraraki I, Harrington GW, Assavasilavasukul P, Standridge JH (2004). Removal of emerging pathogens and pathogen indicators. *AWWA Journ*al, 96(5):102-113

NOTE: Important general information is contained in PART II, Chapter 6

From 1 July 2016 a number of functions related to the delivery of water services in NSW will be transferred from DPI Water to WaterNSW. Over time, content on this website will be updated to reflect these changes.

Turbidity

Turbidity is a common water quality problem in NSW, particularly in the inland areas. Turbidity refers to how clear the water is – the greater the amount of total suspended solids in the water, the murkier or muddier it appears and the higher the measured turbidity. In most rivers turbidity increases after rainfall and flooding because of soil erosion. This can cause sedimentation of rivers and dams which can smother water plants. The suspended sediments can also absorb and transport nutrients, heavy metals, pesticides and other chemicals. Turbid water is a problem for country town water supplies – it is difficult and costly to remedy and may create heath problems.

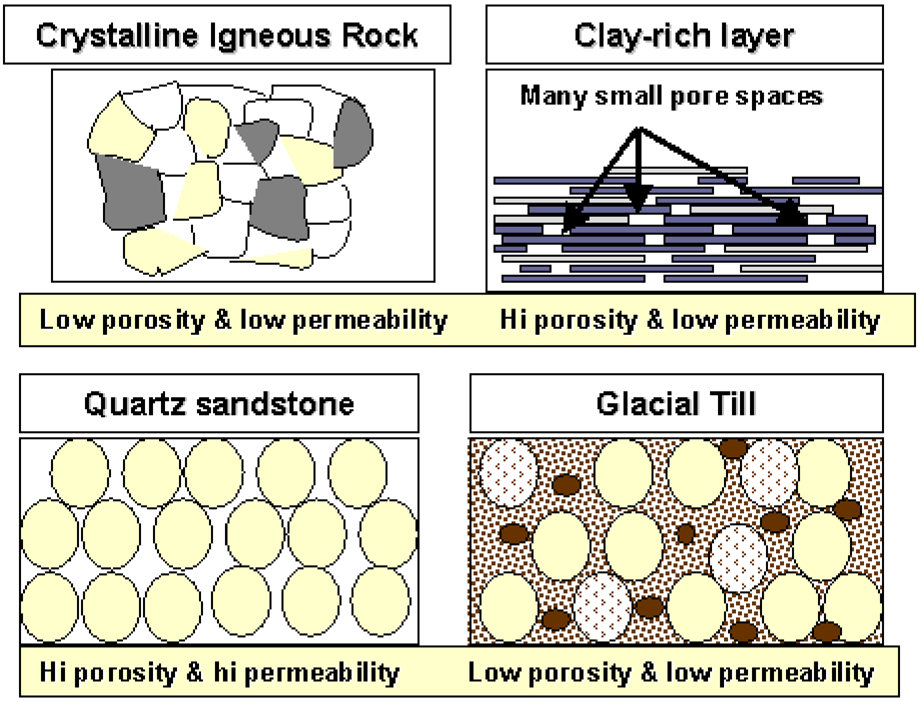
What is Groundwater?

Groundwater is water, in it's liquid form, that is found underground. Water seeps into the ground after a rainfall event or snowmelt, and is stored in an aquifer.

An aquifer is the means of storing and transmitting groundwater. There are three types of aquifers:

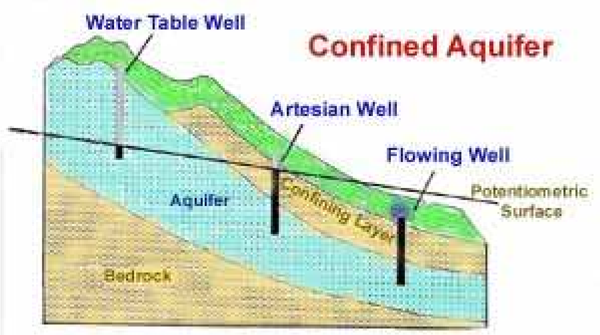
1. **Unconfined aquifer**
2. **Confined aquifer**
3. **Perched aquifer**

The porosity and permeability of an aquifer determines it's ability to hold and transmit water. Porosity is the small amount of air that is left between sediment and rocks. Permeability is the ability of water to move through the material.



UNCONFINED AQUIFERS are aquifers that have no confining layers between the water level and ground level.

CONFINED AQUIFERS are aquifers that have a confining layer between the water level and ground level. A confining layer is a layer of material that has little or no porosity.



PERCHED AQUIFERS are aquifers that have a confining layer below the groundwater, and sits above the main water table.

[What about Pepin County's Groundwater?]

How does Groundwater Move?

Groundwater, just like any other water, flows downhill. Groundwater movement can be predicted by examining the topography of the land. Pepin County's groundwater flow can be seen on this map.

Back Home Next

HYDROLOGICAL PROCESSES
Hydrol. Process. (in press)
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The role of perched aquifers in hydrological connectivity and biogeochemical processes in vernal pool landscapes, Central Valley, California

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Abstract:

Relatively little is known about the role of perched aquifers in hydrological, biogeochemical, and biological processes of vernal pool landscapes. The objectives of this study are to introduce a perched aquifer concept for vernal pool formation and maintenance and to examine the resulting hydrological and biogeochemical phenomena in a representative catchment with three vernal pools connected to one another and to a seasonal stream by swales. A combined hydrometric and geochemical approach was used. Annual rainfall infiltrated but perched on a claypan/duripan, and this perched groundwater flowed downgradient toward the seasonal stream. The upper layer of soil above the claypan/duripan is ~0·6 m in thickness in the uplands and ~0·1 m in thickness in the vernal pools. Some groundwater flowed through the vernal pools when heads in the perched aquifer exceeded ~0·1 m above the claypan/duripan. Perched groundwater discharge accounted for 30–60% of the inflow to the vernal pools during and immediately following storm events. However, most perched groundwater flowed under or around the vernal pools or was recharged by annual rainfall downgradient of the vernal pools. Most of the perched groundwater was discharged to the outlet swale immediately upgradient of the seasonal stream, and most water discharging from the outlet swale to the seasonal stream was perched groundwater that had not flowed through the vernal pools. Therefore, nitrate-nitrogen concentrations were lower (e.g. 0·17 to 0·39 mg l^{-1}) and dissolved organic carbon concentrations were higher (e.g. 5·97 to 3·24 mg l^{-1}) in vernal pool water than in outlet swale water discharging to the seasonal stream. Though the uplands, vernal pools, and seasonal stream are part of a single surface-water and perched groundwater system, the vernal pools apparently play a limited role in controlling landscape-scale water quality. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS wetlands; vernal pools; perched aquifers; claypans; duripans; connectivity

INTRODUCTION

Perched aquifers have long been recognized, but have infrequently been studied (Fetter, 2001). Perching layers reduce rates of recharge to underlying regional aquifers (Bagtzoglou *et al*., 2000) and redirect subsurface water flow along horizontal flowpaths (Driese *et al*., 2001). Where perching layers outcrop or intersect the ground surface, perched aquifers can discharge water to springs (Rabbo, 2000; Amit *et al*., 2002), streams (von der Heyden and New, 2003), and wetlands (O'Driscoll and Parizek, 2003; von der Heyden and New, 2003). Where perching layers completely underlie wetlands and lakes, surface-water levels can remain relatively stable even as regional water tables decline (Pirkle and Brooks, 1959; Auler, 1995). Still, relatively little is known about how perched aquifers regulate hydrological, biogeochemical, and biological processes in wetland ecosystems in general and vernal pool landscapes in particular.

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Vernal pools are small depressional wetlands that pond for portions of the wet season, then drain and dry in the late wet and early dry seasons (Stebbins, 1976). Vernal pools occur in southern Oregon, California, northern Baja California, and in other seasonal climates of the world (Riefner and Pryor, 1996). Vernal pools typically range from 50 to 5000 m^2 in area (Mitsch and Gosselink, 2000) and from 0·1 to 1 m in depth (Hanes and Stromberg, 1998; Brooks and Hayashi, 2002).

Vernal pools occur on many geological surfaces. However, in all cases vernal pools are underlain by low-permeability layers such as claypans or hardpans (e.g. silica-cemented duripans; Nikiforoff, 1941; Hobson and Dahlgren, 1998; Smith and Verrill, 1998), clay-rich soils (Smith and Verrill, 1998), mudflows or lahars (Jokerst, 1990; Smith and Verrill, 1998), or bedrock (Weitkamp *et al*., 1996). In all cases, vernal pool surface water and/or groundwater are perched above regional water tables.

Vernal pools are associated with specific types of geological formations, landforms, and soils (Smith and Verrill, 1998). Therefore, vernal pools tend to be clustered at the landscape scale. Currently, these vernal pool landscapes cover more than 4100 km^2, or $\sim$5% of the total land surface of the Central Valley, California (Holland, 1998). In these vernal pool landscapes, vernal pools that are potentially jurisdictional wetlands typically comprise less than 10% of the total land surface. In many of these vernal pool landscapes, surface water flows through ephemeral or seasonal swales to other vernal pools and ultimately to seasonal streams. Therefore, vernal pool landscapes comprise the upper watershed position of many stream systems that originate in the Central Valley, California.

Vernal pools are best known for the biological functions that they perform. Vernal pools are among the last remaining California ecosystems still typically dominated by native flora (Barbour *et al*., 1993). Many vernal pool floral and macroinvertebrate species are endemic, and some vernal pool floral and macroinvertebrate species are rare (Holland and Jain, 1988; Keeley and Zedler, 1998). Therefore, vernal pools are critical components of regional biological conservation efforts. Vernal pool flora are sensitive to variations in inundation duration (Holland and Jain, 1984; Bauder, 2000), and vernal pool macroinvertebrates are sensitive to variations in inundation duration (Gallagher, 1996), salinity (Gonzales *et al*., 1996), and possibly several other water chemistry constituents (e.g. pH, dissolved oxygen, and nutrients). It is therefore surprising that few studies of vernal pool hydrogeology and biogeochemistry have been conducted (Hanes and Stromberg, 1998; Brooks and Hayashi, 2002).

This project is part of a larger interdisciplinary project, the overall objective of which is to provide public and private sector land managers with information to be used in making informed land-use decisions in vernal pool landscapes. Vernal pools typically are treated as isolated depressions that pond largely due to direct precipitation and drain and dry largely due to evapotranspiration. The specific objective of this study is to show that this conceptual model may be largely incorrect for vernal pools underlain by a claypan or duripan, perhaps the most common type of vernal pool in the Central Valley, California (Smith and Verrill, 1998). Rather, many or most of these vernal pools appear to be supported by perched aquifers, wherein seasonal surface water and perched groundwater hydrologically and biogeochemically connect uplands, vernal pools, and streams at the catchment scale. To our knowledge, this is the first study to document the importance of perched aquifers as hydrological and biogeochemical pathways in vernal pool landscapes.

SITE DESCRIPTION

Location and setting

This study was conducted at Mather Regional Park in the southern Sacramento Valley near Sacramento, California (Figure 1). The study site is a 0·1 km^2 catchment with three vernal pools connected to one another and to a seasonal stream by ephemeral or seasonal swales. The three vernal pools cover $\sim$2% of the catchment area. Elevations of the upper catchment divide, the vernal pools, and the outlet swale just upgradient of the seasonal stream are $\sim$47 m, 43 m, and 39 m above mean sea level respectively. Slope, though locally variable, is $\sim$0·02. The site was grazed during the late 19th and early 20th centuries, but it has been used largely as

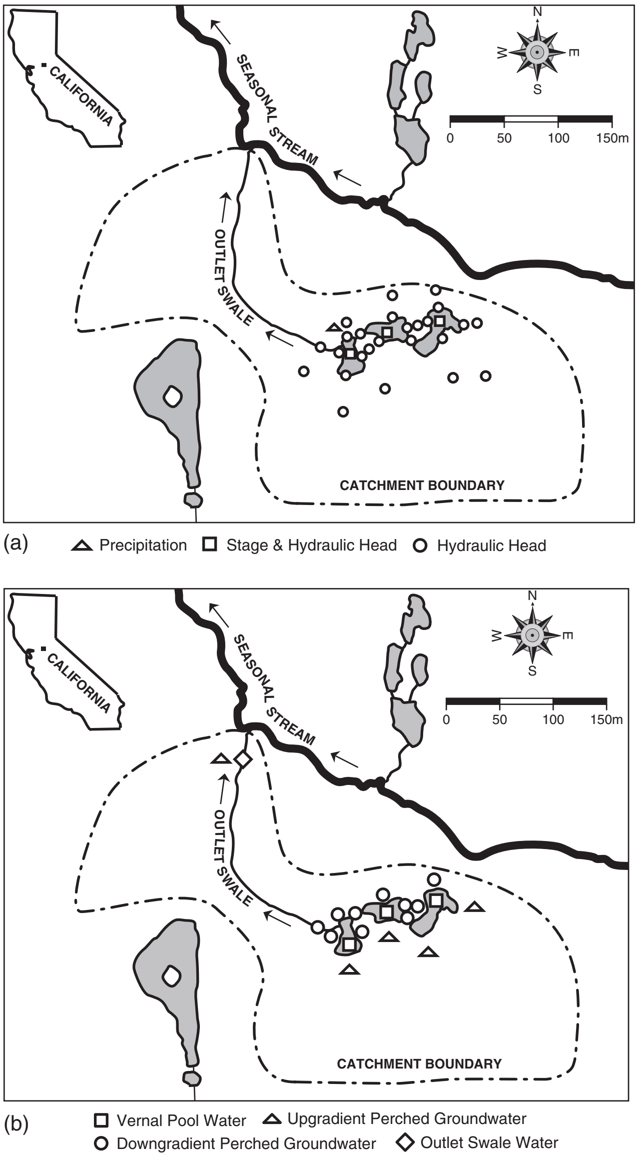

Figure 1. Local setting showing (a) the hydrometric instrumentation locations and (b) the surface water and perched groundwater sample collection locations. The study site is the delineated catchment with the three vernal pools connected to one another and to the seasonal stream by swales. Elevations of the upper catchment divide, the vernal pools, and the confluence of the outlet swale and the seasonal stream are ~47 m, 43 m, and 39 m respectively above mean sea level

open space since being annexed for military use in 1918 and becoming part of Mather Regional Park in 1995. The study site is generally representative of regional vernal pool landscapes.

Climate

The climate is Mediterranean, with mild, wet winters and hot, dry summers (Western Regional Climate Center data for Sacramento Executive Airport for the years 1971–2000). Mean maximum, minimum, and daily temperatures are 23·0 °C, 9·0 °C, and 16·0 °C respectively. Mean annual precipitation is 455 mm, with

~96% falling during the months of October–May. However, annual precipitation is variable, with the standard deviation around the mean annual precipitation being 174 mm. Annual precipitation during the 2003 water year (October 2002–September 2003), in which the study took place, was 388 mm, with 100% falling during the months of October–May. These are within normal ranges, so the 2003 water year in which the study took place was a typical water year.

Geology and soils

The study site is located on the Fair Oaks Formation, an alluvial deposit composed primarily of quartzite and amphibole cobbles and boulders in a granitic sand matrix (Shlemon, 1972). The absolute age of the Fair Oaks Formation is unknown, though younger deposits occur in the same stratigraphic interval as sediments in the San Joaquin Valley that have been radiometrically dated at about 600 000 years old (Shlemon, 1972).

The Fair Oaks Formation is capped with well-developed soils of the Red Bluff and Redding series (Shlemon, 1972; Tugel, 1993). Red Bluff soils (Ultic Palexeralfs) occur on summit positions, and Redding soils (Abruptic Durixeralfs) occur on shoulder, backslope, footslope, and toeslope positions (Tugel, 1993). Field investigations indicate that soils at the study site are predominantly of the Redding series. The upper layer of the soil has a gravelly loam texture. The upper layer is underlain by a claypan composed of ~50% clay and is immediately underlain by a duripan composed of gravel and cobbles in a granitic sand matrix cemented by silica and iron (Tugel, 1993). Redding soils typically have hydraulic conductivities of $10^{-1} - 10^{0}$ m day^{-1} in the upper layer of the soil and $<10^{-2}$ m day^{-1} in the claypan/duripan (Tugel, 1993). Values for the upper layer of soil on the study site were not confirmed, though slug tests indicated that hydraulic conductivities of the claypan/duripan on the study site are $\leq 10^{-2}$ m day^{-1}. The claypan/duripan is laterally extensive throughout the catchment. The vernal pools appear to be deflation basins, ~0·5 m in depth. Multiple hand-augered holes and tile probe penetrations indicate that the upper layer of soil above the claypan/duripan is ~0·6 m in thickness in the uplands and ~0·1m in thickness in the vernal pools (Figure 2).

Vegetation

Vegetation is typical of vernal pools in the Central Valley, California, with primarily native annual grasses and forbs and a ~1 cm layer of pool-bed algae. Species composition is typical of Northern Hardpan Vernal

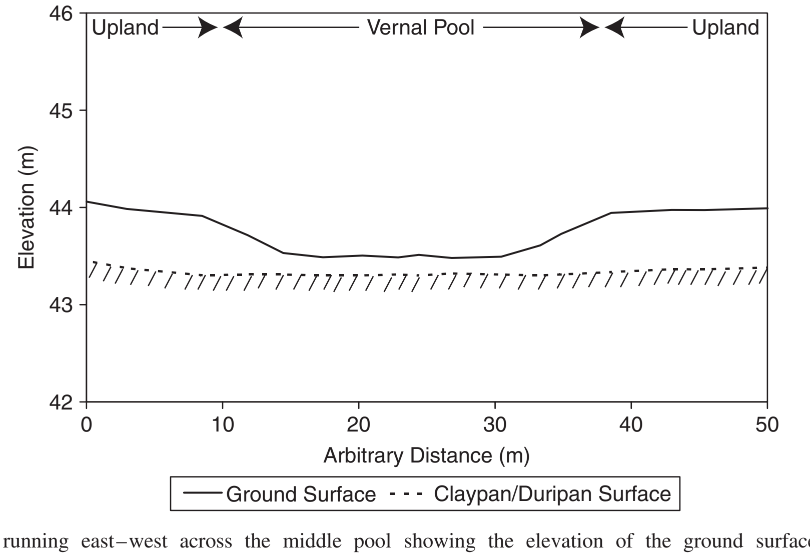

Figure 2. Cross-section running east–west across the middle pool showing the elevation of the ground surface and the underlying claypan/duripan in metres above mean sea level. Vertical exaggeration is ~7×

Pool series (Sawyer and Keeler-Wolf, 1995). Typical species include the native species pale spikerush (*Eleocharis macrostachya*), wooly marbles (*Psilocarphus brevissimus* var. *brevissimus*), and Vasey's coyote-thistle (*Eryngium vaseyi*). The surrounding uplands are characterized by moderate coverage with primarily non-native annual grasses. Species composition is typical of California Annual Grassland series (Sawyer and Keeler-Wolf, 1995). Species commonly include the non-native species soft chess (*Bromus hordeaceous*), ripgut brome (*Bromus diandrus*), and wild oat (*Avena fatua*).

METHODS

A combined hydrometric and geochemical approach was used in this study. Hydrometric data included precipitation depths, vernal pool stages, and groundwater hydraulic heads, and geochemical data included dissolved constituent concentrations and stable isotope ratios.

Field measurements

Precipitation was measured in the catchment, stages were measured in the three vernal pools, and hydraulic heads were measured at 28 piezometer nests (Figure 1). Precipitation was measured continuously with a tipping-bucket rain gauge, and stages in the three vernal pools were measured hourly with pressure transducers and dataloggers. Each piezometer nest had three piezometers with 2·5 cm inside diameters and with open ends ~0·6, 1·2, and 1·8 m below the ground surface. The shallow piezometers (0·6 m) were either above or in the upper part of the claypan/duripan. The middle piezometers (1·2 m) and deep piezometers (1·8 m) were either below or in the lower part of the claypan/duripan. Piezometers were installed using a Geoprobe hydraulic-powered direct push system by removing cores and pushing the piezometers into the open boreholes. The inside diameters of the boreholes were slightly smaller than the outside diameters of the piezometers, which ensured a tight fit. Bentonite surface seals were emplaced around the outside of the piezometers. Hydraulic heads at the 28 piezometer nests were measured at least weekly with a manually operated water-level meter. Time-lag errors can arise in piezometers screened in low-conductivity formations (Hanschke and Baird, 2001). The potential for time-lag errors was minimized during data collection by using small-diameter standpipes so that the volumes of water required to flow between the formations and the standpipes were minimal. The potential for time-lag errors was further minimized during data interpretation by interpreting time-series data over the course of days and weeks, which eliminated time-lag errors that occurred over the course of hours.

Water sample collection

Surface water samples were collected at four locations, while perched groundwater samples were collected at 15 locations (Figure 1). Vernal pool water samples were collected from each of the vernal pools, while outlet swale water samples were collected just upgradient of the seasonal stream. Perched groundwater samples were collected from above the claypan/duripan throughout the catchment. Perched groundwater samples collected upgradient of the vernal pools and upgradient of the outlet swale are hereafter referred to as upgradient perched groundwater, while perched groundwater samples collected downgradient of at least one vernal pool are hereafter referred to as downgradient perched groundwater (Figure 1).

Surface water samples were collected during and immediately following storms in December 2002 and March 2003, and surface water and perched groundwater samples were collected once between storms in early March 2003. Each surface water sample was a composite of two surface water subsamples. Piezometers were not available at every groundwater sampling location, and the small-diameter piezometers did not always contain enough water to comprise meaningful samples, so perched groundwater samples were collected from uncased boreholes. Boreholes were hand-augered, perched groundwater was purged until electrical conductivity stabilized, perched groundwater samples were collected, and boreholes were refilled with native materials. A total of 50 surface water and 15 perched groundwater samples were collected.

Analytical procedures

Electrical conductivity on each surface water and perched groundwater sample was measured in the field at least weekly while conducting regular hydrometric monitoring (Thermo Orion Model 116). All samples, except samples used for deuterium (D) and oxygen-18 (^{18}O) analyses, were filtered through 0·2 μm polycarbonate membranes prior to analysis. Samples were stored at 4 °C through completion of analyses. Total alkalinity, as an estimate of carbonate alkalinity, was measured in the laboratory by titration of samples with 0·25 M H_2SO_4 (Rhoades, 1982). Major cations (i.e. sodium, potassium, calcium, magnesium, and ammonium) and anions (i.e. chloride, sulphate, nitrate, and phosphate) were measured on a Dionex 500x ion chromatograph. Silica was measured by the molybdosilicate method on a Lachat Quik-Chem 8000 autoanalyser (Clesceri *et al*., 1998). Dissolved organic carbon (DOC) was measured by the UV–persulphate oxidation/IR detection using a Tekmar-Dohrmann Phoenix 8000 TOC analyser (Clesceri *et al*., 1998). Analytical precisions were typically better than ±5% for all analyses.

Surface water and perched groundwater samples that were collected between storms in early March 2003 were also analysed for D and ^{18}O, which were measured on a Finnigan 251 isotope ratio mass spectrometer using a constant-temperature water bath for equilibration of aqueous samples. For D analyses, 5 ml samples were equilibrated with H_2 in the presence of a platinum catalyst (Coplen *et al*., 1991). For ^{18}O analyses, 5 ml samples were equilibrated with CO_2 (Epstein and Mayeda, 1953). Equilibration temperature was 18·1 °C, and equilibration times were 120 min and 600 min for D and ^{18}O respectively. Analytical precisions were ±1·0‰ and ±0·05‰ for D and ^{18}O analyses respectively.

D and ^{18}O are reported in the conventional δ notation:

$$\delta = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 10^3$$

where R is the D/H ratio or $^{18}O/^{16}O$ for D or ^{18}O respectively (Craig, 1961). The resulting sample values of δD and $\delta^{18}O$ are reported in per mil deviation relative to Vienna Standard Mean Ocean Water (VSMOW) and, by convention, the δD and $\delta^{18}O$ of VSMOW are set at 0‰ VSMOW (Gonfiantini, 1978).

Mass-balance mixing modelling

The relative contributions of direct precipitation and upgradient perched groundwater to vernal pool water during and immediately following storms in December 2002 and March 2003 were estimated using three-end, mass-balance mixing models with silica as a conservative natural tracer. Silica in natural water originates primarily from contact between natural water and silicate and clay minerals or decomposed plant materials (Iler, 1979). Therefore, silica was used as a conservative, natural tracer to distinguish between direct precipitation and upgradient perched groundwater. The mass balance mixing model was

$$[SiO_2]_s = f_{vp}[SiO_2]_{vp} + f_p[SiO_2]_p + f_{gw}[SiO_2]_{gw}$$

$$f_{pvp} + f_p + f_{gw} = 1$$

where $[SiO_2]$ and f are the silica concentrations and proportions that sum to one respectively, and where the subscripts 's', 'vp', 'p', and 'gw' refer to a given sample of vernal pool water during or immediately following a storm event, vernal pool water immediately prior to a storm event, direct precipitation, and upgradient perched groundwater respectively. This is a mathematically indeterminate system of two equations in three unknowns for which there is no unique solution. However, mass-balance conservation can still be used to find multiple combinations of end-member proportions that are feasible solutions to the system of equations (Phillips and Gregg, 2003). The primary assumptions of the three-end, mass-balance mixing model were that a given sample was an instantaneous mix of the three end members and that silica was conservative in the vernal pool water column over short time periods.

Results of the three-end, mass-balance mixing models were corroborated by water budgets for one vernal pool during and immediately following the storms in December 2002 and March 2003. In both cases, surface water flux was negligible and the simplified water budget was

$$P - ET + \Delta GW = \Delta S$$

where P is direct precipitation, ET is evapotranspiration, ΔGW is the net groundwater flux into the vernal pool (i.e. groundwater inflow minus groundwater outflow), and ΔS is the change in storage (i.e. change in vernal pool stage). Evapotranspiration estimates were computed by a modified Penman equation (Pruitt and Doorenbos, 1977) using data from a station located ~10 km from the study site in an environment with similar characteristics, e.g. same landform, soils, vegetation, and fetch (California Irrigation Management System Station No. 131). The simplified water budget was solved for groundwater flux, and groundwater flux was expressed as the proportion of the change in storage during and immediately following the December 2002 and March 2003 storms.

The relative contributions of vernal pool water and upgradient perched groundwater to downgradient perched groundwater and outlet swale water between storms in early March 2003 were estimated using a two-end, mass-balance mixing model with $\delta^{18}O$ as a conservative natural tracer. The mass-balance mixing model was run for a typical day in early March 2003 when vernal pool stages were moderately high and surface water was flowing out of the middle and lower vernal pools and discharging to the seasonal stream. $\delta^{18}O$ in natural water varies as a function of conservative mixing, evaporation, or high-temperature and/or long-term water–rock interaction and does not vary as a function of uptake by vegetation (Gat, 1996; Clark and Fritz, 1997). Therefore, $\delta^{18}O$ was used as a conservative, natural tracer to distinguish between vernal pool water and upgradient perched groundwater. The mass-balance mixing model was

$$\delta^{18}O_s = f_{vp}\delta^{18}O_{vp} + f_{gw}\delta^{18}O_{gw}$$
$$f_{vp} + f_{gw} = 1$$

where $\delta^{18}O$ and f are the ^{18}O signatures and proportions that sum to one respectively, and where the subscripts 's', 'vp', and 'gw' refer to a given sample of downgradient perched groundwater or outlet swale water, vernal pool water, and upgradient perched groundwater respectively. The primary assumptions of the two-end, mass-balance mixing model were that a given sample was an instantaneous mix of the two end members and that fractionation during mixing was negligible.

RESULTS

Physical hydrology

Approximately 15 cm of rain fell between November 5 and December 16 prior to the initiation of ponding in the vernal pools, indicating that early wet-season rainfall largely infiltrated and augmented soil moisture (Figure 3). Approximately 75% of the shallow (0·6 m) piezometers had free (i.e. standing) groundwater during or immediately following the early wet-season storm events. Approximately 70% of the middle (1·2 m) piezometers and 95% of the deep (1·8 m) piezometers remained dry for many weeks following the early wet-season storm events, and ~30% of the middle and deep piezometers remained dry for the entire period of record. The regional water table was ~30 m below the ground surface throughout the period of study (California Department of Water Resources data for California State Well Nos. 08N06E17H001 and 08N06E09Q004M). Therefore, shallow groundwater was perched on the claypan/duripan. Throughout the observation period, hydraulic heads measured in the shallow piezometers generally followed the overall gradient of the land surface, with heads being highest in the upper parts of the catchment and lowest in the

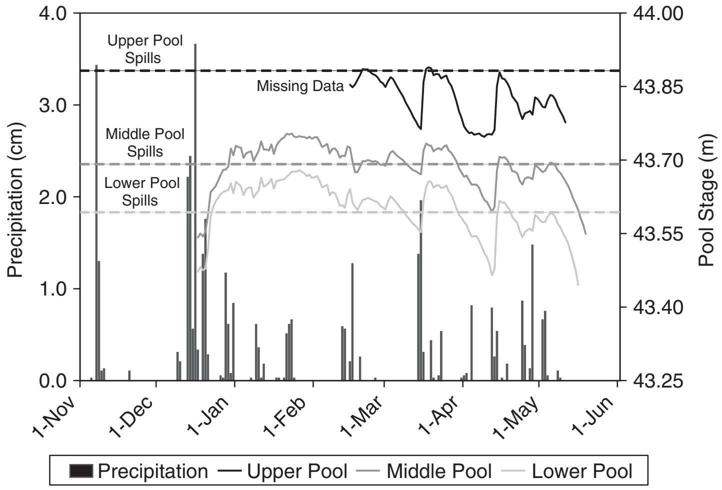

Figure 3. Daily precipitation and vernal pool stages in metres above mean sea level. Horizontal dashed lines indicate the stages at which surface water flows out of each vernal pool via an outlet swale

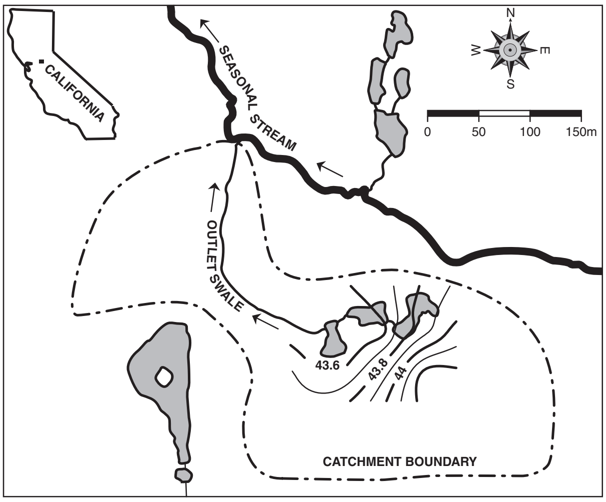

Figure 4. Hydraulic head above the claypan/duripan in the seasonal, perched groundwater system in metres above mean sea level. Stages in the vernal pools were neglected in generating these contours. Data are from late February 2003, and are similar to data from earlier and later in the wet season

lowest parts of the catchment and perched groundwater flowing through, under, or around the vernal pools (Figure 4).

Once the soils above the claypan/duripan were saturated, subsequent rainfall caused the vernal pools to fill, beginning December 17 (Figure 3). A datalogger failure on the upper vernal pool resulted in missing data during the early wet season, but field observations indicated that the upper vernal pool had standing water for slightly less than 150 days. The middle and lower vernal pools had standing water for 154 and 151 days respectively. Surface water outflows from the upper vernal pool were ephemeral, and the surface water connection between the upper and middle vernal pools was maintained for ∼10% of the days during which vernal pool water was present. Surface water outflows from the middle and lower vernal pools were seasonal, and the surface water connections between the middle and lower vernal pools and the lower vernal pool and the seasonal stream were maintained for ~60% of the days during which vernal pool water was present.

During storm events, vernal pool stages began to rise on the same day as the initiation of rainfall and continued to rise until 1 to 2 days after the cessation of rainfall. At no time was overland flow observed delivering water from the uplands to the vernal pools. Therefore, surface water inflows to the upper vernal pool were negligible. The connecting swales are similar in roughness, geometry, and slope, so connecting swale discharge is proportional to vernal pool stage above the outlet. Vernal pool stage above the outlet in the middle vernal pool always equalled or exceeded vernal pool stage above the outlet in the upper vernal pool, with the difference ranging from 0 to 4 cm (Figure 3). Vernal pool stage above the outlet in the lower vernal pool always equalled or exceeded vernal pool stage above the outlet in the middle vernal pool, with the difference ranging from 0 to 2 cm (Figure 3). Therefore, surface water outflows typically equalled or exceeded surface water inflows in each of the vernal pools, indicating that perched groundwater discharge from the uplands to the vernal pools was largely responsible for the observed continued rise in vernal pool stages in the days following the cessation of rainfall.

Chemical hydrology and mass-balance mixing models

Silica concentrations in rainfall are typically <0·2 mg l^{-1} (McCutcheon *et al.*, 1993), and are typically <0·3 mg l^{-1} in nearby watersheds (Holloway and Dahlgren, 2001). Therefore, silica concentrations of rainfall were assumed to be negligible, whereas silica concentrations of the perched groundwater upgradient of the vernal pools and upgradient of the outlet swale were ~22 mg l^{-1} (Table I). The silica data can, therefore, be used to elucidate the roles of direct precipitation and perched groundwater discharge during the early- and late-season storm events. Silica concentrations in the vernal pool water began to rise on the same day as the initiation of rainfall and remained level or continued to rise until 1 to 2 days after the cessation of rainfall (Figure 5). Therefore, these data again indicate that perched groundwater was discharging from the uplands to the vernal pools during and immediately following the storm events.

The three-end, mass-balance mixing models indicate that discharge of upgradient perched groundwater to the vernal pools accounted for 35–60% of the inflow to the vernal pools during and immediately following the first rainfall of the early-season storm event and 40–50% of the inflow to the vernal pools during and immediately following the late-season storm event (Table II). Water budget calculations generally corroborate these results. During and immediately following the first rainfall of the early-season rainfall event, direct precipitation was 8·65 cm, evapotranspiration was 0·54 cm, and the change in vernal pool stage was 11·41 cm. Therefore, groundwater flux was 3·30 cm, or approximately 29% of the change in storage. During and immediately following the late-season storm event, direct precipitation was 9·22 cm, evapotranspiration was 1·41 cm, and the change in vernal pool stage was 12·19 cm. Therefore, groundwater flux was 4·38 cm, or approximately 36% of the change in storage.

When plotted in a Piper diagram (Piper, 1944), all surface water and perched groundwater samples plot as $Ca-Mg-Na-HCO_3$ water types (Figure 6). This is typical of regional rainfall of recent origin that has undergone slight alteration due to short-term contact with soils or sediments (Criss and Davisson, 1996). When plotted on a δD versus $\delta^{18}O$ scatterplot, surface water and perched groundwater samples collected between storms in early March 2003 plot on a line with a slope of 3·8 that intersects the global meteoric water line at −7·5‰ (Figure 7). This is typical of the weighted average of regional rainfall that has undergone varying degrees of fractionation due to evaporation (Criss and Davisson, 1996).

Only surface water and perched groundwater samples collected between storms in early March 2003 were used in the two-end, mass-balance mixing model analysis. These data were collected on a typical day: it was not raining, though there had been moderate amounts of rain in the previous weeks; there was no surface water outflow from the upper vernal pool; and there were moderate surface water outflows from the middle and lower vernal pools. Vernal pool water had mean δD and $\delta^{18}O$ of −32·1‰ and −2·6‰ VSMOW respectively, whereas upgradient perched groundwater had mean δD and $\delta^{18}O$ of −43·3‰ and

Table I. Geochemical and isotopic characteristics of all surface water and perched groundwater samples. Surface water samples were collected prior to, during, and following storms in December 2002 and March 2003, and surface water and perched groundwater samples were collected once between storms in early March 2003. Upgradient perched groundwater samples were collected upgradient of the vernal pools and upgradient of the outlet swale, and downgradient perched groundwater samples were collected downgradient of at least one vernal pool

	Surface water				Perched groundwater			
	Vernal pools ($n = 42$)		Outlet swale ($n = 8$)		Upgradient ($n = 5$)		Downgradient ($n = 10$)	
	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2
EC (μS cm^{-1})	52	16	41	11	56	11	71	11
Na (mg l^{-1})	3·4	0·5	3·1	0·4	4·4	0·6	5·5	1·4
K (mg l^{-1})	0·9	0·4	0·4	0·2	0·4	0·1	0·6	0·7
Mg (mg l^{-1})	2·2	0·2	2·3	0·3	2·7	0·7	3·3	0·7
Ca (mg l^{-1})	4·8	0·6	4·3	0·6	4·9	1·2	6·1	1·1
Cl (mg l^{-1})	3·0	1·0	2·1	1·2	4·4	1·6	3·9	1·9
SO_4 (mg l^{-1})	2·7	1·3	2·5	0·4	3·4	1·0	4·5	2·1
$HCO_3 + CO_3$(mg l^{-1})	21·5	2·4	19·7	2·5	22·5	6·6	30·6	5·2
SiO_2 (mg l^{-1})	9·8	3·4	14·5	1·3	22·2	5·3	22·9	6·0
NO_3-N (mg l^{-1})[a]	0·17	0·24	0·39	0·54	0·21	0·44	0·01	0·02
NH_4-N (mg l^{-1})[b]	0·03	0·05	0·01	0·01	0·01	0·02	0·02	0·06
PO_4-P (mg l^{-1})	<0·010	<0·010	<0·010	<0·010	<0·010	<0·010	<0·010	<0·010
DOC (mg l^{-1})	5·97	1·57	3·24	1·09	1·24	0·36	2·24	0·66
δD (‰ VSMOW)[c]	−32·1	1·7	−46·9	—[d]	−43·2	2·6	−38·8	2·3
δ^{18}O (‰ VSMOW)[c]	−2·6	0·6	−6·0	—[d]	−5·7	0·3	−4·7	0·5

[a] Below NO_3-N detection limit of 0.006 mg l^{-1} in 20 of 42 vernal pool samples, one of eight outlet swale samples, three of five upgradient perched groundwater samples, and seven of ten downgradient perched groundwater samples.
[b] Below NH_4-N detection limit of 0.010 mg l^{-1} in 28 of 42 vernal pool samples, seven of eight outlet swale samples, four of five upgradient perched groundwater samples, and nine of ten downgradient perched groundwater samples.
[c] δD and δ^{18}O analysed on only 3 of 42 vernal pool and one of eight outlet swale water samples.
[d] Insufficient sample numbers to calculate standard deviation.

−5·7‰ VSMOW respectively (Figure 7). These were the two end members from which downgradient perched groundwater and outlet swale water were assumed to have originated. Downgradient perched groundwater had mean δD and δ^{18}O of −38·8‰ and −4·7‰ VSMOW respectively, which was intermediate between the two end members (Figure 7). On average, downgradient perched groundwater was composed of ~30% of the vernal pool water end member and ~70% of the upgradient perched groundwater end member (Table III). Outlet swale water had a δD and δ^{18}O of −46·9‰ and −6·0‰ VSMOW respectively, similar to the upgradient perched groundwater end member (Figure 7). Therefore, contributions from the vernal pool water end member to the outlet swale water were negligible (Table III).

Electrical conductivity of the vernal pool water was relatively low, averaging 44 μS cm^{-1} and ranging from 25 to 66 μS cm^{-1} (Figure 8). Electrical conductivity tended to decline throughout most of the period during which vernal pool water was present, suggesting a progressive flushing of solutes. Electrical conductivity increased sharply only when small volumes of vernal pool water remained, e.g. when the upper vernal pool temporarily dried during a prolonged dry period in late March and when the upper, middle, and lower vernal pools permanently dried at the end of the wet season in late May.

Biogeochemistry

During the early-season storm event, nitrate-nitrogen concentrations in vernal pool water tended to increase immediately in response to the initiation of rainfall and the subsequent increase in perched groundwater

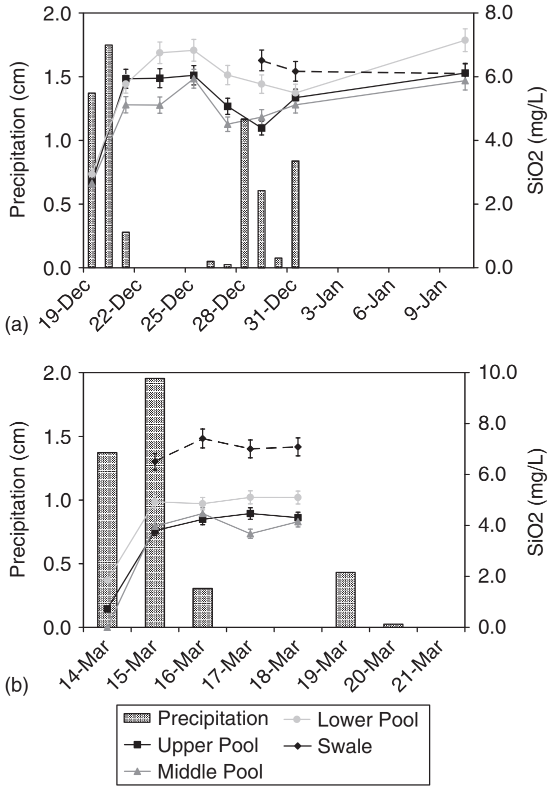

Figure 5. Daily precipitation and silica concentrations in vernal pool water during the (a) early- and (b) late-season storm events

Table II. Three-end, mass-balance mixing model results showing the relative contribution of upgradient perched groundwater to inflow to the vernal pools during and immediately following the December 2002 and March 2003 storms. Three-end, mass-balance mixing models were computed daily. This is a mathematically indeterminate system of two equations in three unknowns for which there is no unique solution, so there were multiple combinations of end member proportions that were feasible solutions to the system of equations. Proportions are presented as the minimum and maximum values computed over the course of the storms

Storm	Upper vernal pool	Middle vernal pool	Lower vernal pool
December 2002	0·35–0·60	0·35–0·50	0·50–0·60
March 2003	0·40	0·40	0·40–0·50

discharge, then decline steadily in response to the cessation of rainfall and the subsequent decrease in perched groundwater discharge (Figure 9). During the late-season storm event, nitrate-nitrogen concentrations in vernal pool water were below detection limits (i.e. [NO_3-N] $<0{\cdot}006$ mg l^{-1}). At all times during the early- and late-season storm events, nitrate-nitrogen concentrations in the outlet swale water were higher than nitrate-nitrogen concentrations in the vernal pools (Figure 9). Overall, nitrate-nitrogen concentrations in the vernal pool water and outlet swale water were 0·17 mg l^{-1} and 0·39 mg l^{-1} respectively (Table I) and were significantly different from one another ($p = 0{\cdot}04$). Ammonium-nitrogen concentrations were always low and typically below detection limits ([NH_4-N] $<0{\cdot}010$ mg l^{-1}) and phosphate-phosphorus concentrations were always below detection limits ([PO_4-P] $<0{\cdot}010$ mg l^{-1}).

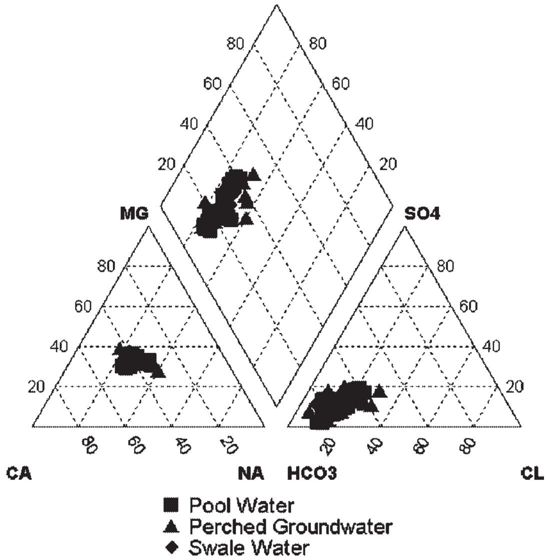

Figure 6. Piper diagrams summarizing the relative concentrations of the major cations and anions in vernal pool water (squares), perched groundwater (triangles), and outlet swale water just upgradient of the seasonal stream (diamonds). All surface water and perched groundwater samples are included. All surface water and perched groundwater samples plot as Ca–Mg–Na–HCO_3, which is typical of regional rainfall that has undergone slight alteration due to short-term contact with sediments

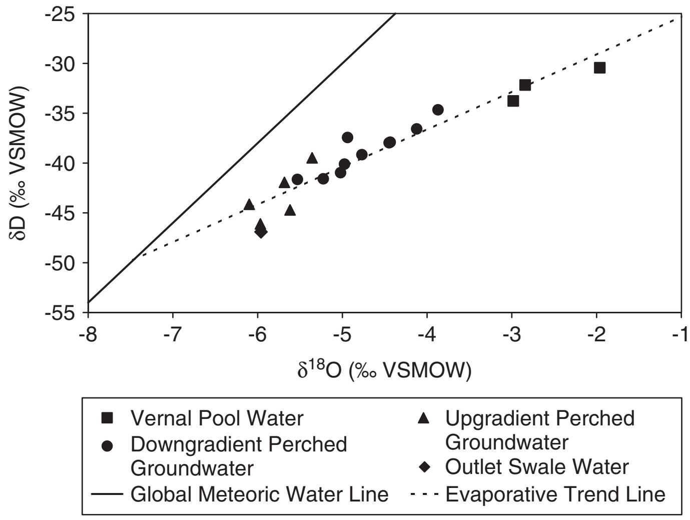

Figure 7. Scatterplot of δD and $\delta^{18}O$ in vernal pool water (squares), upgradient perched groundwater (triangles), downgradient perched groundwater (circles), and outlet swale water (diamonds). The global meteoric water line (Craig, 1961) is the solid line and the evaporative trend line calculated via least-squares regression is the dashed line. Only surface water and perched groundwater samples collected between storms in early March 2003 are included

During the early- and late-season storm events, DOC concentrations in vernal pool water tended to decline immediately in response to the initiation of rainfall and the subsequent increase in perched groundwater discharge, then increase steadily in response to the cessation of rainfall and the subsequent decrease in perched groundwater discharge (Figure 9). With the exception of 1 day at the beginning of the late-season storm event, DOC concentrations in the outlet swale water were lower than DOC concentrations in the vernal pools

Table III. Two-end, mass-balance mixing model results showing the relative contributions of vernal pool water and upgradient perched groundwater to downgradient perched groundwater and outlet swale water between storms in early March 2003

Water	Mean $\delta^{18}O$ (‰ VSMOW)	Standard deviation $\delta^{18}O$ (‰ VSMOW)	Pool water : perched groundwater
Vernal pool water ($n = 3$)	−2·6	0·6	1.0 : 0.0
Upgradient perched groundwater ($n = 5$)	−5·7	0·3	0.0 : 1.0
Downgradient perched groundwater ($n = 10$)	−4·7	0·5	0.3 : 0.7
Outlet swale water ($n = 1$)	−6·0	—[a]	0.0 : 1.0

[a] Insufficient sample numbers to calculate standard deviation.

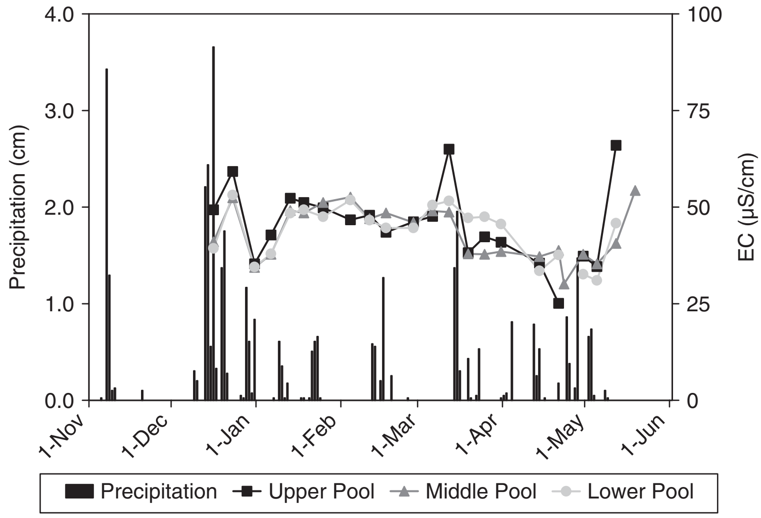

Figure 8. Daily precipitation and weekly vernal pool water electrical conductivities over the study period

(Figure 9). Overall, DOC concentrations in the vernal pool water and outlet swale water were 5·97 mg l^{-1} and 3·24 mg l^{-1} respectively (Table I) and were significantly different from one another ($p < 0{\cdot}01$).

DISCUSSION

Hydrology and hydrological connectivity

The results indicate that vernal pools on soils with relatively coarse-grained surface deposits overlying claypans/duripans are seasonal, surface water components of integrated surface water and perched groundwater systems. Annual rainfall infiltrates but perches on the claypan/duripan, and this perched groundwater flows downgradient toward the seasonal stream. The upper layer of soil above the claypan/duripan is ∼0·6 m in thickness in the uplands and ∼0·1 m in thickness in the vernal pools. When hydraulic heads in the perched aquifer exceed ∼0·1 m above the claypan/duripan, some perched groundwater flows through the vernal pools by discharging primarily at the upgradient end of the vernal pool and recharging primarily at the downgradient end of the vernal pool. The claypan/duripan is laterally extensive throughout the catchment, so all of the perched groundwater must flow through a very small cross-sectional area immediately prior to discharging to the seasonal stream. Accordingly, it appears that perched groundwater discharges to the outlet swale just upgradient of the seasonal stream. However, vernal pools comprise ∼2% of the total catchment area, so most

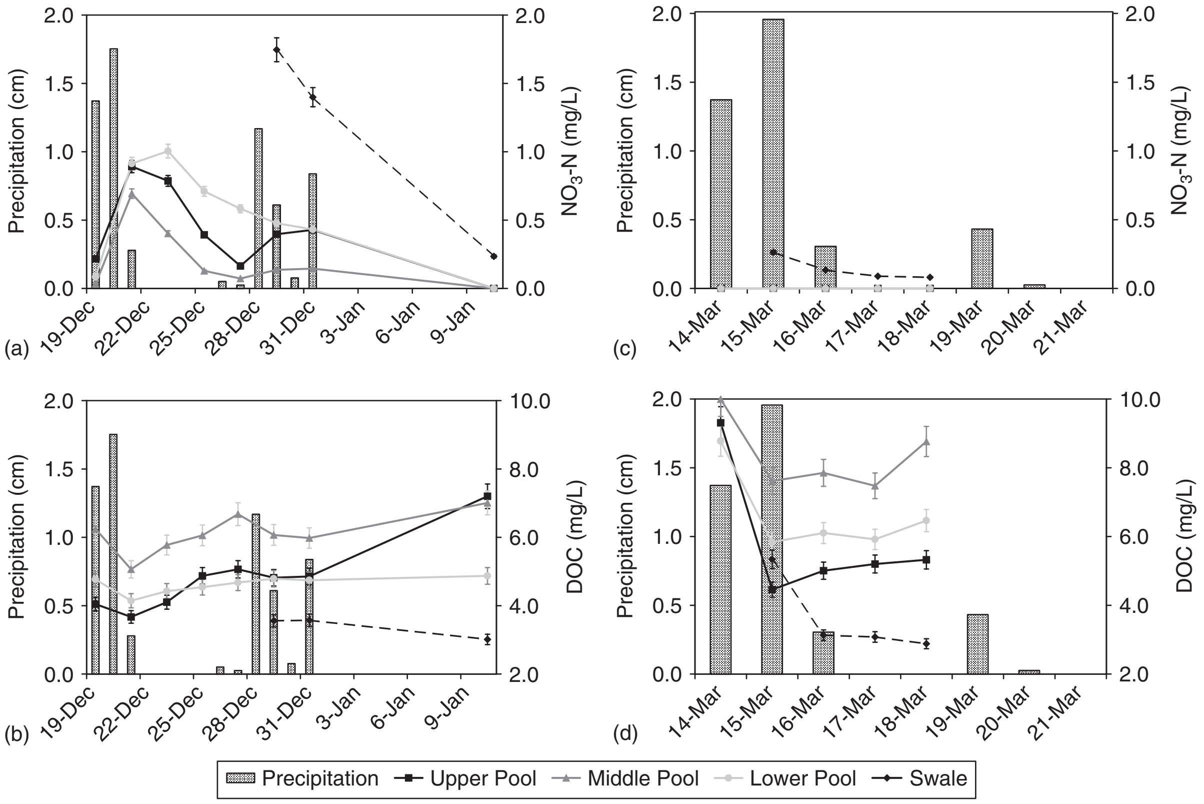

Figure 9. Daily precipitation and (a) NO_3-N and (b) DOC concentrations in vernal pool water during the early-season storm event, and daily precipitation and (c) NO_3-N and (d) DOC concentrations in vernal pool water during the late-season storm event

perched groundwater in the catchment flows under or around the vernal pools or is recharged by annual rainfall downgradient of the vernal pools. Therefore, most outlet swale water discharging to the seasonal stream is perched groundwater that has not flowed through the vernal pools.

Rates of silica dissolution are low (Iler, 1979), so silica is likely reasonably conservative over short periods of time in direct precipitation and upgradient perched groundwater. However, silica fluxes from the beds of shallow freshwater systems are typically negative due to the low rates of silica dissolution and the high rates of diatom frustule synthesis (Thorbergsdóttir, 2004), so silica is likely not as conservative over short periods of time in vernal pool water. Therefore, the three-end, mass-balance mixing model results may underestimate the contribution of upgradient perched groundwater to vernal pool water during and immediately following storm events. Similarly, the upgradient perched groundwater end members had δD and δ^{18}O compositions typical of the weighted average of regional rainfall, whereas the vernal pool water end members had δD and δ^{18}O compositions typical of the weighted average of regional rainfall that had undergone fractionation due to evaporation (Criss and Davisson, 1996). The upgradient perched groundwater end members had much more time to mix and were, therefore, assumed to be reasonably stable. However, the vernal pool end members were likely becoming heavier as the vernal pool water evaporated throughout the wet season. Therefore, the two-end, mass-balance mixing model results may underestimate the contribution of vernal pool water to downgradient perched groundwater. Accordingly, the mass-balance mixing model results should be considered indicative of trends in and not absolute quantities of perched groundwater flux through the vernal pools.

The trends indicate that these vernal pools are surface water and perched groundwater flow-through depressional wetlands. Flow-through lakes and depressional wetlands have long been recognized. Born *et al.*

(1979) found that 23 of 63 study lakes in the Midwestern USA were flow-through lakes. Flow-through prairie pothole wetlands were first described by Sloan (1972) and were further described by Richardson *et al*. (1992). However, vernal pools at this site represent a special case, because the flow-through phenomenon is supported by a seasonal perched aquifer that is unconnected to the underlying regional aquifers.

Vernal pools are not simply isolated depressions that pond largely due to direct precipitation and drain and dry largely due to evapotranspiration. If evapotranspiration were the primary water loss from the vernal pools, then electrical conductivity of the vernal pool water would increase over time due to evapoconcentration. This was not the case. Rather, electrical conductivity tended to decline or remain relatively stable, indicating that continued surface water and perched groundwater flow through the vernal pools provided a continuous source of fresh water that limited the local effects of evapoconcentration. Evapoconcentration only occurred when small volumes of water remained, such as when the upper vernal pool temporarily dried during a prolonged dry period in late March and when the upper, middle, and lower vernal pools permanently dried at the end of the wet season in late May.

Biogeochemistry

The first and second rainfalls of the early-season storm event and the late-season storm event were similar in magnitude and duration. NO_3-N concentrations in the vernal pools, however, were relatively high following the first rainfall of the early-season storm event, noticeably lower following the second rainfall of the early-season storm event, and below detection limits ($[NO_3\text{-N}] < 0{\cdot}006$ mg l^{-1}) following the late-season storm event. This trend is unlikely due to variations in nitrate-nitrogen concentrations in direct precipitation because nitrate-nitrogen concentrations averaged 0·07 mg l^{-1} in December 2002 when the early-season storm event occurred and 0·05 mg l^{-1} in March 2003 when the late-season storm event occurred (National Atmospheric Deposition Program Site CA88). It is more likely that the amount of nitrate-nitrogen transported from the upland soils to the vernal pools declined with each successive rainfall. This trend has been previously observed and explained as an asynchrony between hydrological and biological processes in annual grasslands in Mediterranean-type climates (Tate *et al*., 1999; Holloway and Dahlgren, 2001). Upland annual grasses senesce in the dry season. However, microbial activity continues, nitrogen is mineralized, and nitrate accumulates in the upland soils. Annual grasses germinate early in the wet season, but do not develop substantial biomass until the middle- to late-growing season (i.e. March–April). Thus, during the early-season storm events, there is little biological demand for nitrate and it is readily leached from the upland soils into the perched groundwater that ultimately discharges to the vernal pools. Later in the wet season, much of the nitrate in the upland soils has been flushed and the upland annual grasses are flourishing, which produces a large biological demand for the remaining nitrate. Therefore, the amount of nitrate leaching into the perched groundwater and subsequently discharging to the vernal pools decreases. Concurrently, the vernal pool rim and basin plant communities apparently remove the remaining nitrate from the perched groundwater, because the perched water table intersects the root zone both in the immediate vicinity of and within the vernal pool.

The vernal pools are characterized by dense coverage with primarily native annual grasses, forbs, and pool-bed algae and are inundated for ~150 days per year, whereas the surrounding uplands are characterized by moderate coverage with primarily non-native annual grasses and are not inundated at any point during the year. The vernal pools are relatively high productivity islands in a relatively low productivity landscape and support anaerobic soils when inundated. Nitrate concentrations in vernal pool water decline immediately following the cessation of rainfall, indicating that nitrate is rapidly assimilated by biota or denitrified by anaerobic bacteria (Ponnamperuma, 1972). Therefore, nitrate concentrations in vernal pool water are lower than in groundwater. DOC accumulates in vernal pool water through leaching of particulate organic matter (Orem *et al*., 1986) and desorption from mineral surfaces (Jardin *et al*., 1989). The high iron oxide content of upland and vernal pool soils strongly sorb and, therefore, immobilize DOC in perched groundwater (Hobson and Dahlgren, 1998). Furthermore, though temperatures are relatively low, residence times are relatively short, and DOC is a relatively recalcitrant form of organic matter; nevertheless, microbial decomposition in the shallow subsurface may consume some DOC in perched groundwater. Therefore, DOC concentrations in vernal pool water are higher than in perched groundwater.

Wetlands have long been known for the biogeochemical functions they perform, such as denitrification (Ponnamperuma, 1972) and DOC production (Fogg, 1977), and the water quality benefits of these biogeochemical functions are often assumed to be translated to downgradient aquatic ecosystems (Brinson *et al*., 1995). However, the water quality benefits of wetlands will be translated to downgradient aquatic ecosystems only if the wetlands provide substantial amounts of water to the downgradient aquatic ecosystems. This is often the case in river systems, where nitrogen loss (Hill *et al*., 1998; Alexander *et al*., 2000) and DOC production (Moore, 2003) are readily translated to downgradient locations in the same river system. In this case, however, the primary source of water to the seasonal stream is perched groundwater that has not flowed through the vernal pools. Therefore, the water quality benefits of these vernal pools can be observed at the pool scale, but not at the catchment scale.

Potential implications for vernal pool biota

Perched groundwater discharges from uplands to vernal pools stabilize vernal pool water levels, causing them to be inundated over larger areas for longer periods of time than would be the case if they were recharged only by precipitation. Hydrological conditions can be expressed through soil chemical reactions that influence plant productivity, such as redox reactions limiting root oxygen and nutrient availability (Hobson and Dahlgren, 2001). Holland and Jain (1984) and Bauder (2000) noted that competitive niche partitioning along hydrological gradients determines floral distributions in and around vernal pools, and that annual variations in hydrological conditions cause annual shifts in floral distributions in and around vernal pools. Hydrological conditions can also be expressed through habitat availability for faunal support. Gallagher (1996) noted that branchiopod species differ in life history duration and, consequently, in inundation duration requirements. Therefore, the stabilizing effect of perched groundwater discharge from the uplands to the vernal pools may increase the likelihood that certain vernal pool flora and fauna will flourish.

Perched groundwater discharge from uplands to vernal pools also buffers the electrical conductivity of vernal pool water by limiting the local effects of evapoconcentration. Gonzales *et al*. (1996) found that the ability to regulate the ionic composition of haemolymph (i.e. the blood analogue used by those animals, such as all arthropods and most molluscs, that have an open circulatory system) plays an important role in restricting some fairy shrimp species to low electrical conductivity vernal pools, restricting other fairy shrimp species to high electrical conductivity vernal pools, and allowing yet other fairy shrimp species to persist in both low and high electrical conductivity vernal pools. Therefore, the buffering effect of perched groundwater discharge from the uplands to the vernal pools may increase the likelihood that certain vernal pool flora and fauna will flourish.

Regulatory context and management implications

In 2001, the US Supreme Court ruled that the US Army Corps of Engineers exceeded its statutory authority by asserting Clean Water Act (CWA) jurisdiction over non-navigable, isolated, intrastate waters based solely on their use by migratory birds (Solid Waste Agency of Northern Cook County versus US Army Corps of Engineers, 531 US 159, 2001). The Supreme Court's reasoning was that the CWA implies that non-navigable, isolated, intrastate waters need a 'significant nexus' to navigable waters to be jurisdictional. To date, neither the courts nor the agencies have defined 'significant nexus', though making a significant contribution to the physical, chemical, and biological integrity of navigable waters seems a reasonable definition.

In this case, the uplands, vernal pools, and seasonal stream are connected at the catchment scale by an integrated seasonal surface water and perched groundwater system. However, questions remain regarding the significance of this connectivity to the physical, chemical, and biological integrity of navigable waters. For example, the results of this study are from a single catchment in which vernal pools cover $\sim$2% of the catchment area. In catchments where vernal pools cover a larger fraction of the catchment area, one would expect greater effects of vernal pool biogeochemical processes on the chemistry of the water discharged from the outlet swales. At what fraction would the vernal pools make a significant contribution to the physical, chemical, and biological integrity of navigable waters and do these fractions commonly occur in nature? Additional hydrogeological investigations of other vernal pool landscapes would elucidate this important issue.

Large changes in regional aquifer management, such as substantially increased groundwater pumping from wells, will have no effects on the vernal pools because perched groundwater flows laterally and downward at rates that are unaffected by the position of the regional water table. On the other hand, small changes in local land use, such as the development of irrigated agriculture or parkland, may have considerable impacts on the vernal pools. The degree to which small changes in local land use might affect the vernal pools is poorly understood, because the fundamental hydrogeological characteristics of perched aquifers remain relatively unexplored. The management of perched aquifers should rest on a scientific foundation that provides a general understanding of the conditions necessary to maintain perched aquifers capable of supporting the physical and biological functions of dependent wetland ecosystems. This scientific foundation, though within reach of current technologies and methods, appears to be virtually nonexistent because hydrogeologists have largely pursued analyses of regional aquifers that can be exploited for water supply purposes rather than perched aquifers that typically are too local and/or shallow to be exploited for any appreciable water supply purposes. The recognition that perched aquifers play important roles in maintaining some wetland ecosystem functions provides a renewed impetus to study and understand shallow perched groundwater systems better.

CONCLUSIONS

The results of this study show that some vernal pools are supported by perched aquifers wherein seasonal surface water and perched groundwater hydrologically and biogeochemically connect uplands, vernal pools, and streams at the catchment scale. However, the degree of connectivity between the various stores is apparently governed by issues of spatial and temporal scale. The vernal pools and adjacent uplands are quite obviously hydrologically and biogeochemically connected. Perched groundwater flowed through the vernal pools, largely controlling vernal pool stage, electrical conductivity, and nitrate and DOC dynamics, particularly during and immediately following storm events. The vernal pools and seasonal stream also are quite obviously hydrologically connected. Surface water flowed out of the lower vernal pool, though the outlet swale, and into the seasonal stream for approximately 90 days, and the perched aquifer maintained a saturated connection between the vernal pools and the seasonal stream throughout the wet season. However, the vernal pools and seasonal stream are not as obviously biogeochemically connected. The vernal pools comprise $\sim$2% of the total catchment area, so most outlet swale water discharging to the seasonal stream was perched groundwater that had not flowed through the vernal pools. Therefore, though the uplands, vernal pools, and seasonal stream are part of a single surface water and perched groundwater system, the vernal pools apparently play a limited role in controlling landscape-scale water quality.

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REFERENCES

Alexander RB, Smith RA, Schwarz GE. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. *Nature* **403**: 758–761.

Amit H, Lyakhovsky V, Katz A, Starinsky A, Burg A. 2002. Interpretation of spring recession curves. *Ground Water* **40**: 543–551.

Auler A. 1995. Lakes as a speleogenetic agent in the karst of Lagoa Santa, Brazil. *Cave and Karst Science—Transactions of the British Cave Research Association* **21**: 105–110.

Bagtzoglou AC, Tolley TL, Stothoff SA, Turner DR. 2000. Perched aquifers in arid environments and inferences for recharge rates. In *Tracers and Modelling in Hydrogeology*, Dassargues A (ed.). *IAHS Special Publication* No. 262. IAHS Press: Wallingford; 401–406.

Barbour M, Pavlik B, Drysdale F, Lindstrom S. 1993. *California's Changing Landscapes: Diversity and Conservation of California Vegetation*. California Native Plant Society: Sacramento, CA.

Bauder ET. 2000. Inundation effects on small-scale distributions in San Diego, California vernal pools. *Aquatic Ecology* **34**: 43–61.

Born SM, Smith SA, Stephenson DA. 1979. The hydrologic regime of glacial terrain lakes. *Journal of Hydrology* **43**: 7–44.

Brinson MM, Hauer FR, Lee LC, Nutter WL, Rheinhardt RD, Smith RD, Whigham D. 1995. *A guidebook for application of hydrogeomorphic assessments to riverine wetlands*. Technical Report WRP-DE-11. US Army Corps of Engineers, US Engineer Waterways Experiment Station, Vicksburg, MI.

Brooks RT, Hayashi M. 2002. Depth–area–volume and hydroperiod relationships of ephemeral (vernal) forest pools in southern New England. *Wetlands* **22**: 247–255.

Clark I, Fritz P. 1997. *Environmental Isotopes in Hydrogeology*. Lewis Publishers: Boca Raton, FL.

Clesceri LS, Greenberg AE, Eaton AD (eds). 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association: Washington, DC.

Coplen TB, Wildman JD, Chen J. 1991. Improvements in the gaseous hydrogen–water equilibration technique for hydrogen isotope ratio analysis. *Analytical Chemistry* **63**: 910–912.

Craig H. 1961. Isotopic variation in meteoric waters. *Science* **133**: 1702–1703.

Criss RE, Davisson ML. 1996. Isotopic imaging of surface water/groundwater interactions, Sacramento Valley, California. *Journal of Hydrology* **178**: 205–222.

Driese SG, McKay LD, Penfield CP. 2001. Lithologic and pedogenic influences on porosity distribution and groundwater flow in fractured sedimentary saprolite; a new application of environmental sedimentology. *Journal of Sedimentary Research* **71**: 843–857.

Epstein S, Mayeda T. 1953. Variation of O^{18} content of waters from natural sources. *Geochimica et Cosmochimica Acta* **4**: 213–224.

Fetter CW. 2001. *Applied Hydrogeology*, 4th edn. Prentice Hall: Upper Saddle River, NJ.

Fogg GE. 1977. Excretion of organic matter by phytoplankton. *Limnology and Oceanography* **22**: 576–577.

Gallagher SP. 1996. Seasonal occurrence and habitat characteristics of some vernal pool Branchiopoda in northern California, USA. *Journal of Crustacean Biology* **16**: 323–329.

Gat JR. 1996. Oxygen and hydrogen in the hydrologic cycle. *Annual Review of Earth Planetary Science* **24**: 225–262.

Gonfiantini R. 1978. Standards for stable isotope measurements in natural compounds. *Nature* **271**: 534–536.

Gonzales JG, Drazen J, Hathaway S, Bauer B, Simovich M. 1996. Physiological correlates of water chemistry in fairly shrimp (*Anostraca*) from southern California. *Journal of Crustacean Biology* **16**: 315–322.

Hanes T, Stromberg L. 1998. Hydrology of vernal pools on non-volcanic soils in the Sacramento Valley. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems*, Witham CW, Bauder ET, Belk D, Ferren Jr WR, Ornduf R (eds). California Native Plant Society: Sacramento, CA; 38–49.

Hanschke T, Baird AJ. 2001. Time-lag errors associated with the use of simple standpipe piezometers in wetland soils. *Wetlands* **21**: 412–421.

Hill AR, Labadia CF, Sanmugadas K. 1998. Hyporheic zone hydrology and nitrogen dynamics in relation to the streambed topography of a N-rich stream. *Biogeochemistry* **42**: 285–310.

Hobson WA, Dahlgren RA. 1998. Soil forming processes in vernal pools of northern California, Chico area. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems*, Witham CW, Bauder ET, Belk D, Ferren Jr WR, Ornduf R (eds). California Native Plant Society: Sacramento, CA; 24–37.

Hobson WA, Dahlgren RA. 2001. Wetland soils of basins and depressions: case studies of vernal pools. In *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification*, Richardson JL, Vepraskas MJ (eds). Lewis Publishers: Boca Raton, FL; 267–281.

Holland RF. 1998. Great Valley vernal pool distribution, photorevised 1996. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems*, Witham CW, Bauder ET, Belk D, Ferren Jr WR, Ornduf R (eds). California Native Plant Society: Sacramento, CA; 71–75.

Holland RF, Jain SK. 1984. Spatial and temporal variation in species diversity of vernal pools. In *Vernal Pools and Intermittent Streams*, Jain S, Moyle P (eds). *Institute of Ecology Publication* No. 28. University of California: Davis, CA; 198–209.

Holland RF, Jain S. 1988. Vernal pools. In *Terrestrial Vegetation of California*, 2nd edn, Barbour MG, Major J (eds). California Native Plant Society: Sacramento, CA; 515–533.

Holloway JM, Dahlgren RA. 2001. Seasonal and event-scale variations in solute chemistry for four Sierra Nevada catchments. *Journal of Hydrology* **250**: 106–121.

Iler RK. 1979. *The Chemistry of Silica: Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry*. Wiley: New York.

Jardin PM, Weber NL, McCarthy JF. 1989. Mechanisms of dissolved organic carbon adsorption on soil. *Soil Science Society of America Journal* **53**: 1378–1385.

Jokerst JD. 1990. Floristic analysis of volcanic mudflow vernal pools. In *Vernal Pool Plants: Their Habitat and Biology*, Ikeda DH, Schlising RA (eds). *Studies from the Herbarium Number* 8. California State University: Chico, CA; 1–26.

Keeley JE, Zedler PH. 1998. Characterization and global distribution of vernal pools. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems*, Witham CW, Bauder ET, Belk D, Ferren Jr WR, Ornduf R (eds). California Native Plant Society: Sacramento, CA; 1–14.

McCutcheon SC, Martin JL, Barnwell Jr TO. 1993. Water quality. In *Handbook of Hydrology*, Maidment DR (ed.). McGraw-Hill: New York; 11.1–11.73.
Mitsch WJ, Gosselink JG. 2000. *Wetlands*, 3rd edn. Van Nostrand Reinhold: New York.
Moore TR. 2003. Dissolved organic carbon in a northern boreal landscape. *Global Biogeochemical Cycles* **17**: 1109.
Nikiforoff CC. 1941. *Hardpan and Micro Relief in Certain Soil Complexes of California*. *US Department of Agriculture Technical Bulletin* No. 745. US Government Printing Office: Washington, DC.
O'Driscoll MA, Parizek RR. 2003. The hydrologic catchment area of a chain of karst wetlands in central Pennsylvania. *Wetlands* **23**: 171–179.
Orem WH, Hatcher PG, Spiker EC, Sceverenyi NM, Macial GE. 1986. Dissolved organic matter in anoxic pore waters from Mangrove Lake, Bermuda. *Geochimica et Cosmochimica Acta* **50**: 609–618.
Phillips DL, Gregg JW. 2003. Source partitioning using stable isotopes: coping with too many sources. *Oecologia* **136**: 261–269.
Piper AM. 1944. A graphic procedure in the geochemical interpretation of water analyses. *Transactions, American Geophysical Union* **25**: 914–923.
Pirkle EC, Brooks HK. 1959. Origin and hydrology of Orange Lake, Santa Fe Lake, and Levys Prairie Lakes of north-central peninsular Florida. *Journal of Geology* **67**: 302–317.
Pruitt WO, Doorenbos J. 1977. Background and development of methods to predict reference crop evapotranspiration (ETo). In *Guidelines for Predicting Crop Water Requirements*, Doorenbos J, Pruitt WO (eds). *FAO Irrigation and Drainage Paper* No. 24. Food and Agriculture Organization of the United Nations: Rome; 108–119.
Ponnamperuma FN. 1972. The chemistry of submerged soils. *Advances in Agronomy* **24**: 29–96.
Rabbo AA. 2000. The geohydrology and water quality of the springs and wells of the western catchment to the Dead Sea, West Bank, Palestine. *Water Science and Technology* **42**: 7–12.
Rhoades JD. 1982. Soluble salts. In *Methods of Soil Analysis, Part 2*, 2nd edn, Page AL (ed.). American Society of Agronomy: Madison, WI; 167–179.
Richardson JL, Wilding LP, Daniels RB. 1992. Recharge and discharge of groundwater in aquic conditions illustrated with flownet analysis. *Geoderma* **53**: 65–78.
Riefner RE, Pryor DR. 1996. New locations and interpretations of vernal pools in southern California. *Phytologia* **80**: 296–327.
Sawyer JO, Keeler-Wolf T. 1995. *A Manual of California Vegetation*. California Native Plant Society: Sacramento, CA.
Shlemon RJ. 1972. The lower American River area, California: a model of Pleistocene landscape evolution. *Association of Pacific Coast Geographers Yearbook* **34**: 61–86.
Sloan CE. 1972. *Ground-Water Hydrology of Prairie Potholes in North Dakota*. *US Geological Survey Professional Paper* 585-C. US Government Printing Office: Washington, DC.
Smith DW, Verrill WL. 1998. Vernal pool–soil–landform relationships in the Central Valley, California. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems*, Witham CW, Bauder ET, Belk D, Ferren Jr WR, Ornduf R (eds). California Native Plant Society: Sacramento, CA; 15–23.
Stebbins GL. 1976. Ecological islands and vernal pools of California. In *Vernal Pools: Their Ecology and Conservation*, Jain S (ed.). *Institute of Ecology Publication* 9. University of California: Davis, CA; 1–4.
Tate KW, Dahlgren RA, Singer MJ, Allen-Diaz B, Atwill ER. 1999. Timing, frequency of sampling affect accuracy of water-quality monitoring. *California Agriculture* **53**: 44–48.
Thorbergsdóttir IM. 2004. Internal loading of nutrients and certain metals in the shallow eutrophic Lake Myvatn, Iceland. *Aquatic Ecology* **38**: 191–208.
Tugel AJ. 1993. *Soil Survey of Sacramento County, California*. US Department of Agriculture, Soil Conservation Service: Washington, DC.
Von der Heyden CJ, New MG. 2003. The role of a dambo in the hydrology of a catchment and the river network downstream. *Hydrology and Earth System Sciences* **7**: 339–357.
Weitkamp WA, Graham RC, Anderson MA, Amrhein C. 1996. Pedogenesis of a vernal pool Entisol–Alfisol–Vertisol catena in southern California. *Soil Science Society of America Journal* **60**: 316–323.

#3A

Dewhurst 19 core hole, Pad surface is imported soil/rock, notice spilt drill fluid and Chemicals from and around trailer.

Drill fluid being recycled through lined drill ponds, notice the unlined pond into which Drill fluid/chemicals are being discharged, pond has quantity of “grey” coloured water in it.

Notice the chemicals stored on the ground, and the spilt Chemical in the trailer, this will dislodge during transit on fall onto the forest Roads.

(See #4E for final resting place of removed imported pad surface).

The unlined Drill pond constitutes a Breach of the Exploration Licence Conditions (p 1).

#4E

Dewhurst 19 core hole pad rehabilitation and imported soil removal. Replacement with soil not of the area, hence like Bohena will run a high risk of introducing non indigenous flora to the Forest.

Location of some removed soil as road repair material outside Bibblewindi 22

This is a breach of Exploration Licence as well as REF

Media Statement

Eastern Star Gas

February 25, 2010

Eastern Star Gas is working with authorities and landholders to limit any impact from the release of a limited volume of waste water into Mollee Creek, west of Narrabri, yesterday afternoon.

Spill isolation commenced immediately and rehabilitation efforts are well underway.

Preliminary investigations indicate that without authority and contrary to company policy, the waste water was released into the creek by an operational sub-contractor.

The fluid released contains water, bentonite clays, food industry grade polymers, salt and potassium chloride. Potassium chloride is commonly employed by farmers as a fertiliser in the improvement of pastures, is an inert substance and biodegrades readily.

While field testing of the water body indicates that these additives have been diluted to near background levels, further laboratory testing will be undertaken in accordance with NSW water quality guidelines.

"We regret this incident occurred. In addition to working with the relevant authorities, I have ordered a full internal inquiry to get to the bottom of what happened," Eastern Star Managing Director David Casey said.

"We will take any action required to fix this mistake and ensure it does not happen again."

Narrabri Shire, the NSW Environment Protection Authority and the NSW Department of Industry and Investment were notified yesterday afternoon. Eastern Star is also liaising with affected landholders.

- **For further information please contact Scott McFarlane on 0407 265 053**

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Field_ID	Pond	Sample Date	>C10 - C40 Fraction (sum) mg/L	Dissolved Organic Carbon mg/L	Dissolved Oxygen ppm ppm	Field Dissolved Oxygen mg/L	Langelier Index -	Nitrite + Nitrate as N mg/L	Santos Suite -	Sulphate Reducing Bacteria MPN/100ml	Suspended Solids (SS) mg/L	Total Dissolved Solids (Calc.) mg/L	Total Dissolved Solids @180°C mg/L	S Clarity --	BTEX: Benzene µg/L	BTEX: Ethylbenzene µg/L	BTEX: Toluene µg/L	BTEX: Sum of BTEX µg/L	BTEX: Xylene (m & p) µg/L	BTEX: Xylene (o) µg/L	BTEX: Xylene Total µg/L	Field: Dissolved Oxygen mg/L	Field: EC (field) uS/cm	Field: pH (Field) pH_Uni	Field: Temp oC	Field: Turbidity ntu
EQL			0.1	1		0.1	0.1	0.01		300	5		10		1	2	2	1	2	2	2	0.1		0.01		0.1
NAR_BWDPD3(A)1_DAM_W	BWDFA Pond 3	2/28/2012	0.46	339	-	-	3.12	<0.01	1	-	58	-	24,400	-	<1	<2	<2	<1	<2	<2	<2	1.8	-	9.41	-	404
NAR_BWDPD3(A)2_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	939	-	-	3.04	<0.01	1	-	128	-	27,300	-	<1	<2	<2	<1	<2	<2	<2	0.5	-	9.05	-	11
NAR_BWDPD3(A)3_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	594	-	-	2.97	0.08	1	-	10	-	25,400	-	<1	<2	<2	<1	<2	<2	<2	2.2	-	8.99	-	11
NAR_BWDPD3(B)1_DAM_W	BWDFA Pond 3	2/28/2012	0.7	380	-	-	3.09	0.01	1	-	76	-	27,100	-	<1	<2	<2	<1	<2	<2	<2	1.8	-	9.4	-	342
NAR_BWDPD3(B)2_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	628	-	-	2.97	<0.01	1	-	26	-	31,400	-	<1	<2	<2	<1	<2	<2	<2	3.2	-	9.01	-	9.5
NAR_BWDPD3(B)3_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	439	-	-	3.01	0.01	1	-	15	-	36,300	-	<1	<2	<2	<1	<2	<2	<2	1.9	-	9.01	-	13
NAR_BWDPD3(C)1_DAM_W	BWDFA Pond 3	2/28/2012	0.11	340	-	-	3.11	<0.01	1	-	75	-	27,700	-	<1	<2	<2	<1	<2	<2	<2	2.3	-	9.4	-	433
NAR_BWDPD3(C)2_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	598	-	-	3.05	<0.01	1	-	15	-	36,900	-	<1	<2	<2	<1	<2	<2	<2	1.5	-	9.06	-	15
NAR_BWDPD3(C)3_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	487	-	-	2.96	<0.01	1	-	10	-	33,900	-	<1	<2	<2	<1	<2	<2	<2	2.4	-	8.98	-	12
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/14/2012	-	-	13.3	-	-	-	-	-	-	25,840	-	-	-	-	-	-	-	-	-	-	36,860	9.53	21.2	-
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/15/2012	-	-	-	9.49	-	-	-	15,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/15/2012	-	-	9.49	-	-	-	-	-	-	25,910	-	-	-	-	-	-	-	-	-	-	36,800	9.56	21	-
NAR_BWDPD3N_DAM_W	BWDFA Pond 3	2/28/2012	<0.1	21	-	-	-	<0.01	1	-	-	-	30	-	<1	<2	<2	<1	<2	<2	<2	2.9	-	7.55	-	1.2

Field_ID	Sample Date	Inorganics: Alkalinity (Bicarbonate as CaCO3) mg/L	Alkalinity (Carbonate as CaCO3) mg/L	Alkalinity (Hydroxide) as CaCO3 µg/L	Alkalinity (total) as CaCO3 mg/L	Ammonia mg/L	Ammonia as N µg/L	Anions Total meq/L	Bicarbonate mg/L	BOD mg/L	Carbonate mg/L	Cations Total meq/L	Chloride mg/L	Electrical conductivity *(lab) uS/cm	Fluoride mg/L	Ionic Balance %	Kjeldahl Nitrogen Total mg/L	Nitrate (as N) mg/L	Nitrate (as NO3-) mg/L	Nitrite (as N) mg/L	Nitrogen (Total Oxidised) mg/L	Nitrogen (Total) µg/L	pH (Lab) pH_Units	Reactive Phosphorus as P mg/L	Silica µg/L	Sodium (Filtered) mg/L	Sulphate mg/L	TOC mg/L
EQL		1	1	1000	1	0.01	10	0.01	1	2	1	0.01	1	1	0.1	0.01	0.1	0.01	0.01	0.01	0.01	100	0.01	0.01	100	1	1	1
NAR_BWDPD3(A)1_DAM_W	2/28/2012	-	-	<1000	20,300	0.02	-	492	9820	146	10,500	458	3080	-	10.6	3.65	30.2	-	<0.01	<0.01	-	30,200	-	<0.05	44,100	10,400	<1	473
NAR_BWDPD3(A)2_DAM_W	2/28/2012	-	-	<1000	26,200	0.48	-	644	16,400	36	9850	600	4280	-	15.5	3.64	6.6	-	<0.01	<0.01	-	6600	-	2.73	61,500	13,600	<1	1110
NAR_BWDPD3(A)3_DAM_W	2/28/2012	-	-	<1000	27,800	8.92	-	663	19,000	59	8790	617	3800	-	14.3	3.62	14.8	-	0.08	<0.01	-	14,900	-	3.71	60,400	14,000	<1	912
NAR_BWDPD3(B)1_DAM_W	2/28/2012	-	-	<1000	19,600	0.02	-	480	9070	133	10,500	463	3150	-	10.1	1.95	26	-	0.01	<0.01	-	26,000	-	<0.05	43,900	10,500	<1	594
NAR_BWDPD3(B)2_DAM_W	2/28/2012	-	-	<1000	24,400	0.46	-	607	15,400	34	9000	595	4240	-	13.9	1.05	6.2	-	<0.01	<0.01	-	6200	-	0.34	60,400	13,500	<1	907
NAR_BWDPD3(B)3_DAM_W	2/28/2012	-	-	<1000	28,600	6.5	-	689	19,600	61	8930	643	4180	-	20.9	3.54	14.3	-	0.01	<0.01	-	14,300	-	4.6	60,200	14,600	6	804
NAR_BWDPD3(C)1_DAM_W	2/28/2012	-	-	<1000	20,300	0.06	-	494	9940	150	10,400	454	3120	-	16.3	4.26	28.6	-	<0.01	<0.01	-	28,600	-	0.52	43,700	10,300	<1	516
NAR_BWDPD3(C)2_DAM_W	2/28/2012	-	-	<1000	28,500	0.91	-	688	19,000	37	9570	652	4210	-	21.1	2.79	6.6	-	<0.01	<0.01	-	6600	-	0.32	61,100	14,800	7	642
NAR_BWDPD3(C)3_DAM_W	2/28/2012	-	-	<1000	27,800	8.2	-	672	19,400	61	8430	648	4130	-	14.8	1.91	14.9	-	<0.01	<0.01	-	14,900	-	0.89	61,300	14,700	<1	705
NAR_BWDPD3_DAM_W	10/14/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.56	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3N_DAM_W	2/28/2012	-	-	<1000	10	0.15	-	0.2	10	<2	<1	0.3	<1	-	<0.1	-	0.5	-	<0.01	<0.01	-	500	-	0.02	100	7	<1	35

Field_ID	Sample Date	Lead: Lead mg/L	Lead: Lead (Filtered) mg/L	Metals: Aluminium mg/L	Aluminium (Filtered) mg/L	Arsenic mg/L	Arsenic (Filtered) mg/L	Barium mg/L	Barium (Filtered) mg/L	Beryllium mg/L	Beryllium (Filtered) mg/L	Boron mg/L	Boron (Filtered) mg/L	Cadmium mg/L	Cadmium (Filtered) mg/L	Calcium (Filtered) mg/L	Chromium (III+VI) mg/L	Chromium (III+VI) (Filtered) mg/L	Cobalt mg/L	Cobalt (Filtered) mg/L
EQL		0.001	0.001	0.01	0.01	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.05	0.0001	0.0001	1	0.001	0.001	0.001	0.001
NAR_BWDPD3(A)1_DAM_W	2/28/2012	<0.005	-	<0.05	-	0.007	-	18.5	-	<0.005	-	1.52	-	0.0006	-	8	<0.005	-	<0.005	-
NAR_BWDPD3(A)2_DAM_W	2/28/2012	<0.01	<0.01	<0.5	<0.5	<0.05	<0.05	25.4	26.5	<0.01	<0.01	1.97	1.96	<0.005	<0.005	12	<0.01	0.058	<0.01	<0.01
NAR_BWDPD3(A)3_DAM_W	2/28/2012	<0.01	<0.01	<0.5	<0.5	<0.05	<0.05	27.9	26	<0.01	<0.01	2.04	1.91	<0.005	<0.005	11	<0.01	0.047	<0.01	<0.01
NAR_BWDPD3(B)1_DAM_W	2/28/2012	<0.005	<0.005	<0.05	<0.05	<0.005	0.007	18.2	16.7	<0.005	<0.005	1.4	1.32	0.0005	0.0014	8	<0.005	0.032	<0.005	<0.005
NAR_BWDPD3(B)2_DAM_W	2/28/2012	<0.01	<0.01	<0.5	<0.5	<0.05	<0.05	27.8	26.2	<0.01	<0.01	2.05	1.9	<0.005	<0.005	12	<0.01	0.052	<0.01	<0.01
NAR_BWDPD3(B)3_DAM_W	2/28/2012	<0.005	<0.005	<0.05	<0.05	0.006	0.017	28.8	25.8	<0.005	<0.005	1.98	1.98	<0.0005	0.002	11	<0.025	<0.025	<0.005	<0.005
NAR_BWDPD3(C)1_DAM_W	2/28/2012	<0.005	<0.005	<0.05	<0.05	0.006	0.012	20	16.5	<0.005	<0.005	1.46	1.38	0.0008	0.0014	8	<0.025	<0.025	<0.005	<0.005
NAR_BWDPD3(C)2_DAM_W	2/28/2012	<0.005	<0.005	<0.05	<0.05	<0.005	0.014	28.6	25	<0.005	<0.005	2.02	1.92	0.0008	0.0021	11	<0.025	0.043	<0.005	<0.005
NAR_BWDPD3(C)3_DAM_W	2/28/2012	<0.005	<0.005	<0.05	<0.05	0.007	0.016	30.3	26	<0.005	<0.005	2.08	1.95	0.0007	0.002	11	<0.025	0.049	<0.005	<0.005
NAR_BWDPD3_DAM_W	10/14/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3N_DAM_W	2/28/2012	<0.001	<0.001	0.01	<0.01	<0.001	<0.001	0.008	0.012	<0.001	<0.001	<0.05	<0.05	<0.0001	<0.0001	<1	<0.001	<0.001	<0.001	<0.001

Field_ID	Pond	Sample Date	Metals: Copper mg/L	Copper (Filtered) mg/L	Iron mg/L	Iron (Filtered) mg/L	Lithium mg/L	Lithium (Filtered) mg/L	Magnesium (Filtered) mg/L	Manganese mg/L	Manganese (Filtered) mg/L	Mercury mg/L	Mercury (Filtered) mg/L	Molybdenum mg/L	Molybdenum (Filtered) mg/L	Nickel mg/L	Nickel (Filtered) mg/L	Phosphorus mg/L	Potassium (Filtered) mg/L	Selenium mg/L	Selenium (Filtered) mg/L	Silver mg/L	Silver (Filtered) mg/L	Strontium mg/L	Strontium (Filtered) mg/L	Tin mg/L	Tin (Filtered) mg/L	Uranium µg/L	Uranium (Filtered) µg/L	Vanadium mg/L	Vanadium (Filtered) mg/L	Zinc mg/L	Zinc (Filtered) mg/L
EQL			0.001	0.001	0.05	0.05	0	0	1	0.001	0	0.0001	0.0001	0.001	0	0.001	0.001	0.01	1	0.01	0.01	0.001	0.001	0	0	0.001	0.001	1	1	0.01	0.01	0.005	0.005
NAR_BWDPD3(A)1_DAM_W	BWDFA Pond 3	2/28/2012	0.01	-	0.49	-	5.11	-	7	0.028	-	<0.0001	<0.0001	<0.005	-	<0.005	-	5.05	194	<0.05	-	<0.005	-	3.03	-	<0.005	-	<5	-	<0.05	-	0.026	-
NAR_BWDPD3(A)2_DAM_W	BWDFA Pond 3	2/28/2012	<0.05	<0.05	0.6	0.62	6.28	6.32	11	0.03	0.02	<0.0001	<0.0001	<0.01	0.01	<0.05	<0.05	4.72	259	<0.1	<0.1	<0.01	<0.01	3.85	3.57	<0.01	<0.01	<10	<10	<0.1	0.24	<0.05	<0.05
NAR_BWDPD3(A)3_DAM_W	BWDFA Pond 3	2/28/2012	<0.05	<0.05	0.78	0.68	6.15	6.23	11	0.033	0.02	<0.0001	<0.0001	<0.01	<0.01	<0.05	<0.05	6.3	261	<0.1	<0.1	<0.01	<0.01	4.03	3.53	<0.01	<0.01	<10	<10	<0.1	0.22	<0.05	<0.05
NAR_BWDPD3(B)1_DAM_W	BWDFA Pond 3	2/28/2012	0.02	<0.005	0.4	0.31	4.27	4.53	7	0.024	0.01	<0.0001	<0.0001	<0.005	0.01	<0.005	<0.005	4.88	194	<0.05	<0.05	<0.005	<0.005	2.76	2.46	<0.005	<0.005	<5	<5	<0.05	0.16	0.028	<0.025
NAR_BWDPD3(B)2_DAM_W	BWDFA Pond 3	2/28/2012	<0.05	<0.05	<0.5	0.57	6.2	6.3	11	0.03	0.02	<0.0001	<0.0001	<0.01	<0.01	<0.05	<0.05	4.88	254	<0.1	<0.1	<0.01	<0.01	4.07	3.56	<0.01	<0.01	<10	<10	<0.1	0.24	<0.05	<0.05
NAR_BWDPD3(B)3_DAM_W	BWDFA Pond 3	2/28/2012	0.009	0.008	1.04	0.73	6.47	6.37	11	0.034	0.02	<0.0001	<0.0001	0.006	0.02	<0.005	<0.005	5.18	258	<0.05	<0.05	<0.005	<0.005	4.38	3.89	<0.005	<0.005	<5	<5	<0.05	0.21	<0.026	<0.025
NAR_BWDPD3(C)1_DAM_W	BWDFA Pond 3	2/28/2012	0.011	<0.005	0.58	0.36	4.79	4.6	7	0.027	0.01	<0.0001	<0.0001	<0.005	0.01	<0.005	<0.005	4.95	190	<0.05	<0.05	<0.005	<0.005	3.13	2.64	<0.005	0.007	<5	<5	<0.05	0.14	0.026	<0.025
NAR_BWDPD3(C)2_DAM_W	BWDFA Pond 3	2/28/2012	0.01	0.008	0.85	0.61	6.34	6.18	11	0.03	0.02	<0.0001	<0.0001	0.006	0.01	<0.005	<0.005	4.53	257	<0.05	<0.05	<0.005	<0.005	4.13	3.74	<0.005	<0.005	<5	<5	<0.05	0.21	<0.026	<0.025
NAR_BWDPD3(C)3_DAM_W	BWDFA Pond 3	2/28/2012	0.013	0.008	0.94	0.71	6.51	6.23	11	0.03	0.02	<0.0001	<0.0001	0.006	0.01	<0.005	<0.005	6.05	263	<0.05	<0.05	<0.005	<0.005	4.25	3.83	<0.005	<0.005	<5	<5	<0.05	0.21	<0.026	<0.025
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/14/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	BWDFA Pond 3	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3N_DAM_W	BWDFA Pond 3	2/28/2012	<0.001	0.001	<0.05	<0.05	0	0	<1	<0.001	<0.001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.001	0.06	<1	<0.01	<0.01	<0.001	<0.001	0	0	<0.001	<0.001	<1	<1	<0.01	<0.01	<0.005	0.008

Field_ID	Sample Date	PAH/Phenols: PAH (total, NSW Waste 2008) mg/L	Acenaphthene µg/L	Acenaphthylene µg/L	Anthracene µg/L	Benz(a)anthracene µg/L	Benzo(a) pyrene µg/L	Benzo(b)fluoranthene µg/L	Benzo(g,h,i)perylene µg/L	Benzo(k)fluoranthene µg/L	Chrysene µg/L	Dibenz(a,h)anthracene µg/L	Fluoranthene µg/L	Fluorene µg/L	Indeno(1,2,3-c,d)pyrene µg/L	Naphthalene µg/L	PAHs (Sum of total) µg/L	Phenanthrene µg/L	Pyrene µg/L
EQL			1	1	1	1	0.5	1	1	1	1	1	1	1	1	1	0.5	1	1
NAR_BWDPD3(A)1_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(A)2_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(A)3_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(B)1_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(B)2_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(B)3_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(C)1_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(C)2_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3(C)3_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1
NAR_BWDPD3_DAM_W	10/14/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3N_DAM_W	2/28/2012	<0.0155	<1	<1	<1	<1	<0.5	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	<1	<1

Field_ID	Sample Date	Polychlorinated Biphenyls: Arochlor 1016 µg/L	Arochlor 1221 µg/L	Arochlor 1232 µg/L	Arochlor 1242 µg/L	Arochlor 1248 µg/L	Arochlor 1254 µg/L	Arochlor 1260 µg/L	Aroclor 1262 µg/L	PCBs (Sum of total) µg/L	TPH: C10-C16 mg/L	C16-C34 mg/L	C34-C40 mg/L	C6 - C10 Fraction minus BTEX (F1) µg/L	C10 - C14 µg/L	C6 - C9 µg/L	C15 - C28 µg/L	C29-C36 µg/L	+C10 - C36 (Sum of total) µg/L	C10 - C40 (Sum of total) µg/L	C6-C10 mg/L
EQL		1	1	1	1	1	1	1	1	1	0.1	0.1	0.1	20	50	20	100	50	50	100	0.02
NAR_BWDPD3(A)1_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.21	0.25	<0.1	<20	<50	<20	380	60	440 - 465	-	<0.02
NAR_BWDPD3(A)2_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3(A)3_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3(B)1_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.33	0.37	<0.1	<20	70	<20	580	100	750	-	<0.02
NAR_BWDPD3(B)2_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3(B)3_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3(C)1_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.11	<0.1	<0.1	<20	<50	<20	140	<50	140 - 190	-	<0.02
NAR_BWDPD3(C)2_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3(C)3_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02
NAR_BWDPD3_DAM_W	10/14/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3_DAM_W	10/15/2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAR_BWDPD3N_DAM_W	2/28/2012	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1	<0.1	<20	<50	<20	<100	<50	<50	-	<0.02

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Name of the project:

Santos

Bibblewindi

Electrical Survey Technical Report
HDPE Geomembrane Liner

Project No:

Approved by:

Phillip Bennett

28th JUNE 2012

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Content

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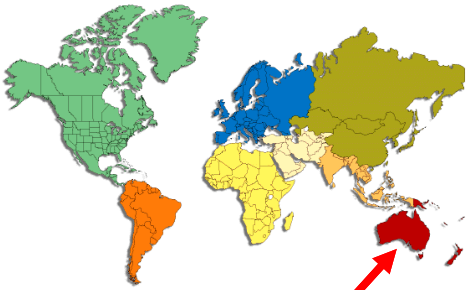
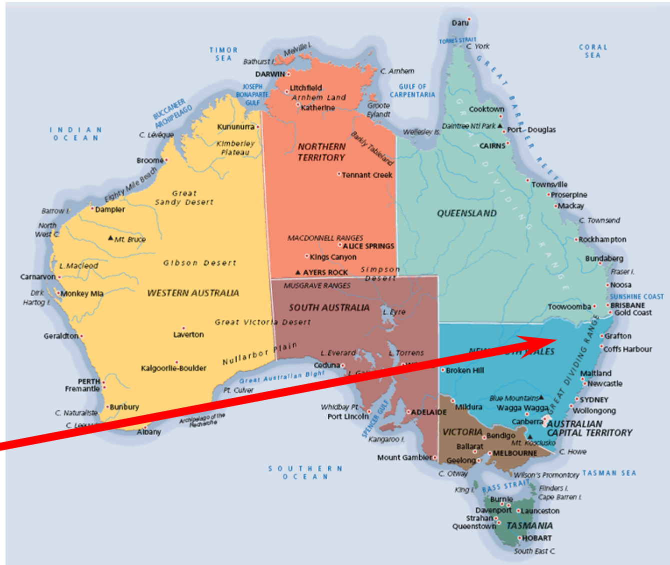


Santos
Bibblewindi Ponds
Narrabri



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DESCRIPTION OF SITE

Santos ponds at Bibblewindi are synthetically lined with a HDPE geomembrane anchored via anchor trench around the top perimeter of the basin.

Pond 1 is 1mm material possibly Damtuff or GSE material no further information was available TDS approx 7000

Pond 2 is 1mm material possibly Damtuff or GSE material no further information was available

TDS approx 7000

Pond3 is 2mm HDPE geomembrane. The material is a 2.0 mm Smooth HDPE manufactured by Sotrafa from the south of Spain.

TDS approx 28000

The general specification of the material is compliant to GM 13 standards.

The geomembrane liners were installed by Barrier Curtis Dec2006. –March 2007

SCOPE

The Principal, Santos, has requested an electrical survey be carried out to identify breaches in the liners. Electrical surveying is carried out utilizing Pontoon and GPS to ASTM D7007 modified.

The system has the ability to record the electrical potential at a GPS grid position allowing a 3d surfacing graph to be produced to show trends in the electrical gradient across the ponds.

The limitations of this system is that it positioning is reduced by the depth of the pond and ability to pinpoint the holes is reduced, this is also compromised by the increase in the conductivity of the ponds

As the conductivity of the ponds increase the electrical gradient across the pond is flatter and harder to differentiate against background noise.

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THE COMPANY

Geotest is a company that has been established and incorporated in the state of South Australia specifically to offer an independent service of geomembrane inspection and testing post installation throughout Australia. Investigating and reporting to geomembrane installation companies, consulting engineers and principals on the integrity of installed geomembranes, auditing of materials, and advice on long term performance of installations.

These installations include landfill liners, industrial storage ponds, wastewater treatment membranes, potable water storage basins, tank installations, methane collection covers, dam drainage systems, tunnels etc.

Geotest system uses both AC and DC testing currents and both manual and automatic recording including computer mapping of the surface to highlight areas of anomalies. Main commercial activities consist of environmental services, including geomembrane damage control system supplying a QA QC service to the industries. The systems and methods used are based on both industry current technology and in-house Research and Development programs to further improve on those systems currently being used worldwide.

COMPANY MANAGEMENT

Mr. Phillip John Bennett

Phillip Bennett has been involved in the design and installation of geomembranes for over 25 years, and has been involved in some of the more complex and challenging geomembrane installation and constructions throughout Australia and overseas.

With a large network of fellow geomembrane designers and installation companies both in Australia and overseas, he has contributed to and experienced the development and changes within the industry.

After 22 years of owning and managing Fabtech SA Pty Ltd, Phillip sold in July 2007 to embark on a new venture testing the integrity of geomembranes post installation.

Phillip has travelled overseas and collected technology from Europe and the United States and has developed a R&D program in-house to refine and improve on theses worldwide techniques to give greater scope and ability to carry out these surveys.

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1. GENERAL DESCRIPTION

GEOMEMBRANE DAMAGE DETECTION METHOD

Leak detection techniques are used to verify the integrity of exposed geomembranes and/or on geomembranes covered with soil and/or water.

Systems are based on an electrical potential being applied between the surface or into the soil or water covering the membrane and the ground outside the containment

Sensing Electrodes are used on the surface of the membrane or into the water layer to measure the intensity of electrical current via specialized measuring equipment.

These electrical potentials are then mapped and plotted in direction and intensity.

With the mapping of these currents and analysing the results, any anomalies in the surface that have an ability to conduct currents correlate with holes in the membrane.

2. PROCEDURE OF THE OPERATION

PREPARATION

- a site visit and completion of work sheets and site inspection check list are undertaken,
- preparation of sensors, cables, instruments, probes, connections
- set-up tests - measure background input voltage - measure input voltage with artificial test hole; measure input voltage with test hole and earth return; measure distance in voltage input readings from artificial test hole.

MEASUREMENT

- measurement of the natural electric field (background levels)
- measurement of the active artificial electric field
- the result represents the assessment of the liner’s integrity

REPORT

- Provision of the final technical report

3. STANDARDS AND EQUIPMENT

Based on the characteristic of the installation and requirements of the customer, the following standard can be used:

Standard

The integrity survey is carried out in accordance with:

ASTM D7007. Standard Practices For Electrical Methods For Locating Leaks In Geomembranes Covered With Water Or Earth Materials. Modified using pontoon and data logger.

Cables

Connection cables consist of metal core (Cu 2.5 mm^2) and PVC insulation.

Measurement and data processing unit

The measurement unit itself consists of:

- **Output unit**
- source of the voltage (connected to 240V network, generator)
- 600 volt DC power supply adjustable
- **Input unit**
- voltage input D C voltage 0 – 2000 milli volts
- measurement units micro amps and milli volts
- **Processing unit**
- Data Logger

4. DAILY REPORT AND TEST SET-UP RESULTS

Site condition 9th May 2012 – The weather during the testing was hot with an ambient temperature of 29 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and calibrated to allow the survey to begin on pond 3.

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Site condition 10th May 2012 – The weather during the testing was hot with an ambient temperature of 29 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying continued on pond 3.

Site condition 11th May 2012 – The weather during the testing was hot with an ambient temperature of 33 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying continued on pond 3.

Site condition 12th May 2012 – The weather during the testing was hot with an ambient temperature of 25 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying continued on pond 3.

Site condition 13th May 2012 – The weather during the testing was hot with an ambient temperature of 26 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying continued on pond 3.

Site condition 14th May 2012 – The weather during the testing was hot with an ambient temperature of 28deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying continued on pond 3.

Site condition 15th May 2012 – The weather during the testing was warm with an ambient temperature of 20 deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying was completed on pond 3. Pontoon and the data logger was then setup on pond 1.

Site condition 16th May 2012 – The weather during the testing was warm with an ambient temperature of 22deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying was completed on pond 1.

Site condition 24th May 2012 Pond 2– The weather during the testing was cool with rain imminent and an ambient temperature of 15deg. Celsius. Water was covering the pond which made it suitable for testing. Geotest pontoon and data logger was setup and surveying of pond 2 began and was completed before rain came.

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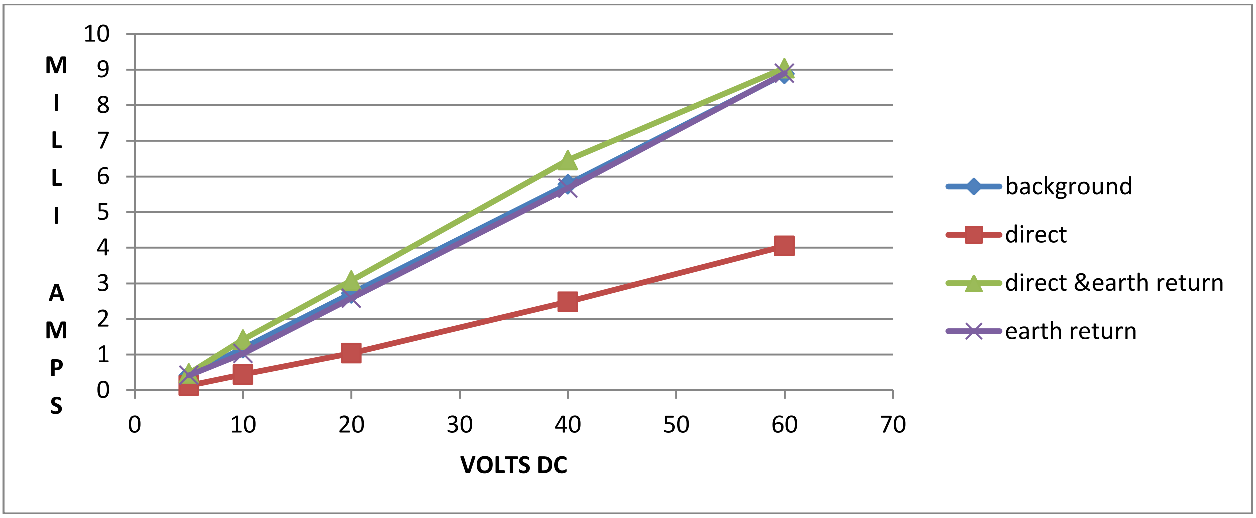
The following Graphs of Pond 1 , Pond 2 and Pond 3 were formed with the setup measurements **(see graphs below)**;

Results - Electric measurements using variable voltages were carried out in the water covered basin are reflected in the following comparison chart

- between background noise
- intensity of current around an artificial hole
- resistance in the sub-grade
- conductivity of the water.

Graph – Comparison results



Bibblewindi pond 1

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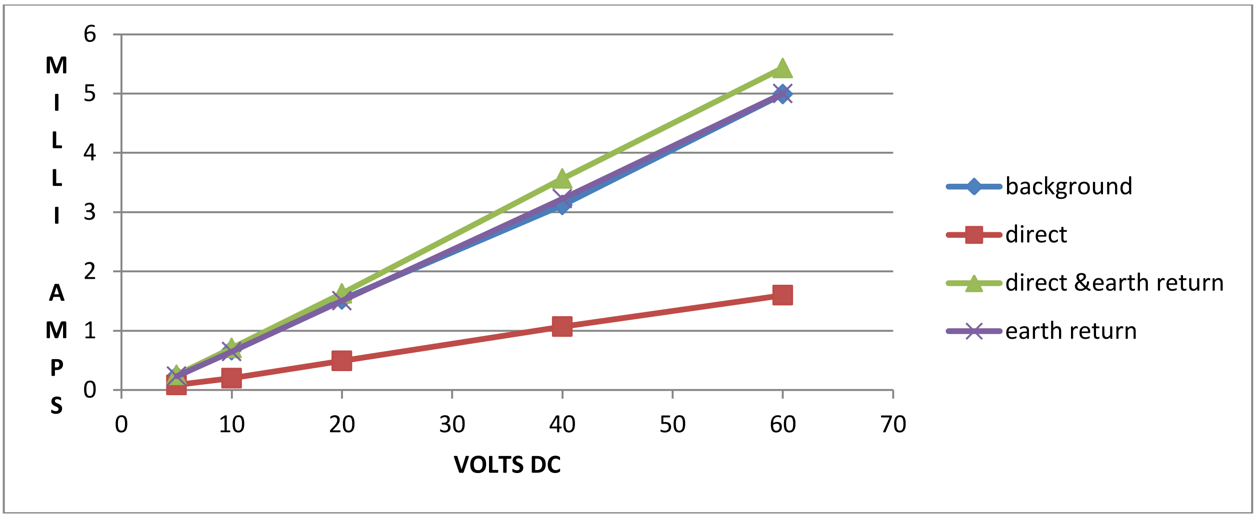
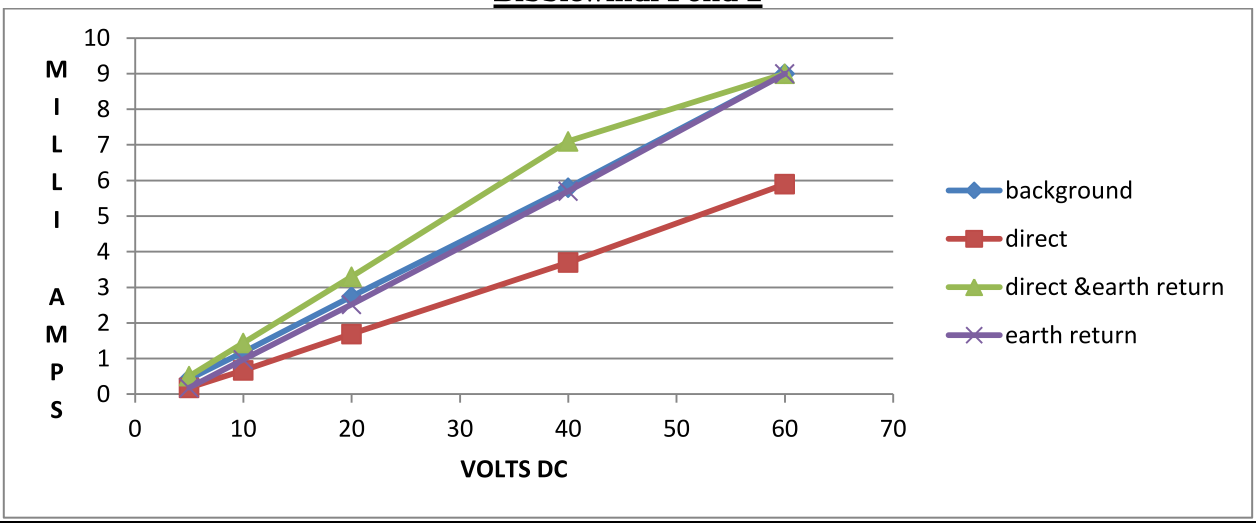


Bibblewindi Pond 2



Bibblewindi Pond 3

The results of these Graphs show

1. conductivity is present and can be measured

2. Conductivity readings in the pond increase as the voltage is increased.

The relationship between each of the setups shows different resistance including confirmation that conductivity can be detected using the soil to carry the return current.

Note there is only a small variation between background and direct & earth return

A survey is possible with this combination to the extent that leakage can be detected but only general locations are possible.

Note an intact liner would show as a flat line, representing no current flow or high resistance.

5. THE CONCLUSION

Pond 1

The inspection of pond 1 and the state of the liner along with the results obtained during the electrical testing indicates the liner installation is of poor quality and shows no evidence of field testing or CQA in accordance with industry standards.

The conductivity between the water in the pond and the subgrade shows very little resistance even with the increase in a calibrated Puck, there was no increase in current flow or decrease in resistance which indicates that the liner has major holes and therefore is not impervious.

The HDPE material installed is below the current industry standard for this type of containment.

There are substantial leaks in the liner and evidence that the subgrade is unstable and we recommend immediate action is required.

The liner is showing signs of degradation and fatigue and is not operating as intended, and the liner requires major rework, the capital value of the installation would be low if non existence, with the cost to restore or repair the liner greater than a new installation. Therefore we recommend a replacement 2mm HDPE liner be installed to Pond 1 in accordance with IAGI and GM19 standards.

Pond 2

The inspection of the pond and the state of the liner along with the results obtained during the electrical testing indicates the liner installation is of poor quality and shows no evidence of field testing or CQA in accordance with industry standards.

In checking background currents we were unable to isolate single hole only general areas of concern. This can be caused by a number of situations or a calumniation of events; the most likely cause is the high salinity of the water combined with numerous holes in the liner.

The conductivity between the water in the pond and the subgrade shows very little resistance even with the increase in a calibrated Puck, there was no increase in current flow or decrease in resistance which indicates that the liner has major holes and therefore is not impervious.

The HDPE material installed is below the current industry standard for this type of containment.

The liner is leaking and there is evidence that the subgrade is unstable and immediate action is required.

As with Pond 1 Pond 2 liner is showing signs of degradation and fatigue and is not operating as intended, it requires major rework, the capital value of the installation would be low if non existence, with the cost to restore or repair the liner greater than a new installation. Therefore we recommend a replacement 2mm HDPE liner be installed to Pond 2 in accordance with IAGI and GM19 standards.

Pond 3

The inspection of pond 3 and the state of the liner along with the results obtained during the electrical testing indicates the liner installation is of poor quality and shows no evidence of field testing or CQA in accordance with industry standards.

In checking background currents we were unable to isolate single hole only general areas of concern. This can be caused by a number of situations or a calumniation of events; the most likely cause is the high salinity of the water combined with numerous holes in the liner.

The fact that we are getting a high current with relative low voltage confirms that there is a direct connection between the saline water in the pond and the subgrade beneath the liner. If the was no connection between the water and the subgrade the current would be almost zero at all voltages.

The installation of the liner requires rework to correct installation techniques and design faults incorporated during installations which are not in accordance with the industry standards

The general appearance of the 2mm HDPE material is good and is therefore commercially valuable if the supporting sub grade is sufficient to support the liner.

Samples of the material should be extracted and tested to ascertain the physical properties along with the residual stabilizers in the material to evaluate the serviceable life left in the material. This requires the removal of approx 12 A3 sized pieces of material and these samples being sent to testing lab EG Excelplas in Melbourne for evaluation.

The tests required for evaluation are as follows:-

1. Elongation
2. Tensile
3. HPOIT
4. OIT
5. MFI
6. Microscopic evaluation

Based on the results of the testing the liner should be able to be reworked and repaired to recoup some of the capital value left in the liner.

Once the liner repairs are completed the pond should be retested to verify the works and are in accordance with procedures out-lined under GRI GM19 and IAGI.

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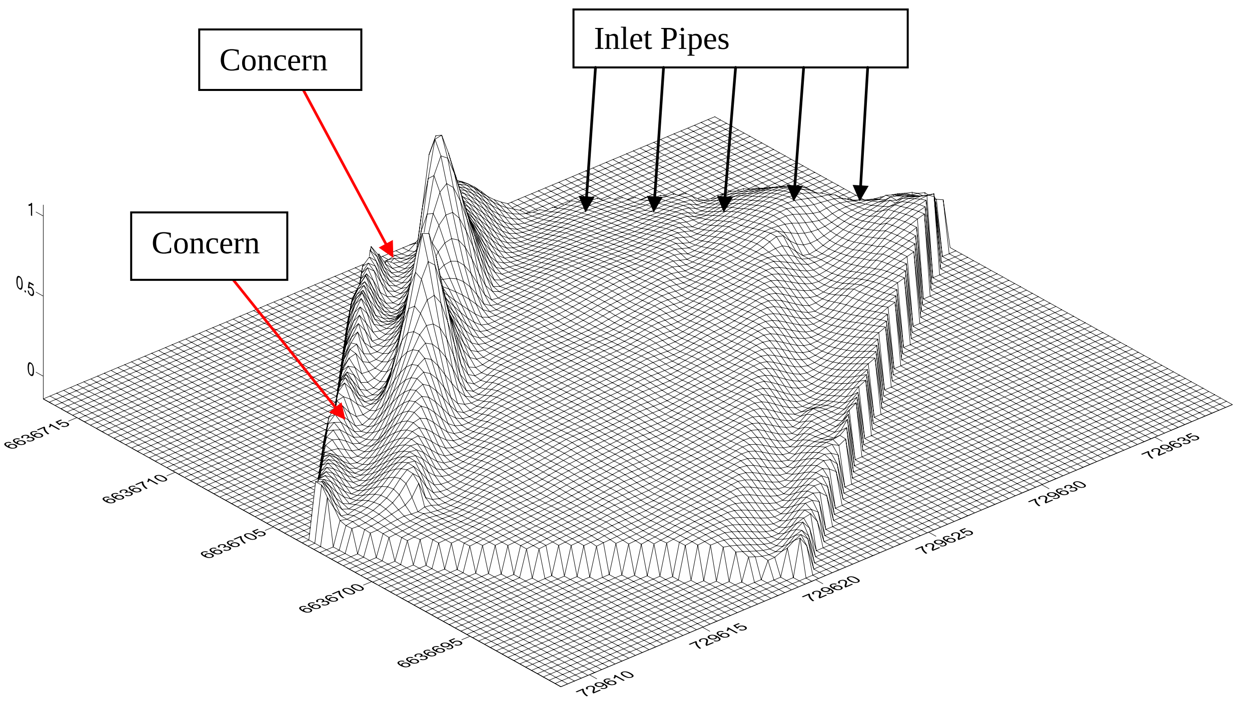
SURVEY PLOT - POND 1

The following shows two surveys of pond 1 with different orientation of the recording probes. Areas highlighted with red arrows are areas that showed higher conductivity and are mostly likely to have breaches in the liner.

The first survey diagram shows areas of high conductivity on the left side of the pond this corresponds with the approximate position of the toe of the slope. This is where the base liner sheets meet the wall liner sheets and are areas of stress in liners because of the tie in weld joining the sheets together. Historically it has been found that 80% of failures are either in the corners or the toe of the slope.

The second survey diagram shows problems on the right side of the grid, which indicates the same prognosis as survey 1. The large depression in the forefront is the energiser position.



Pond 1 Survey 1

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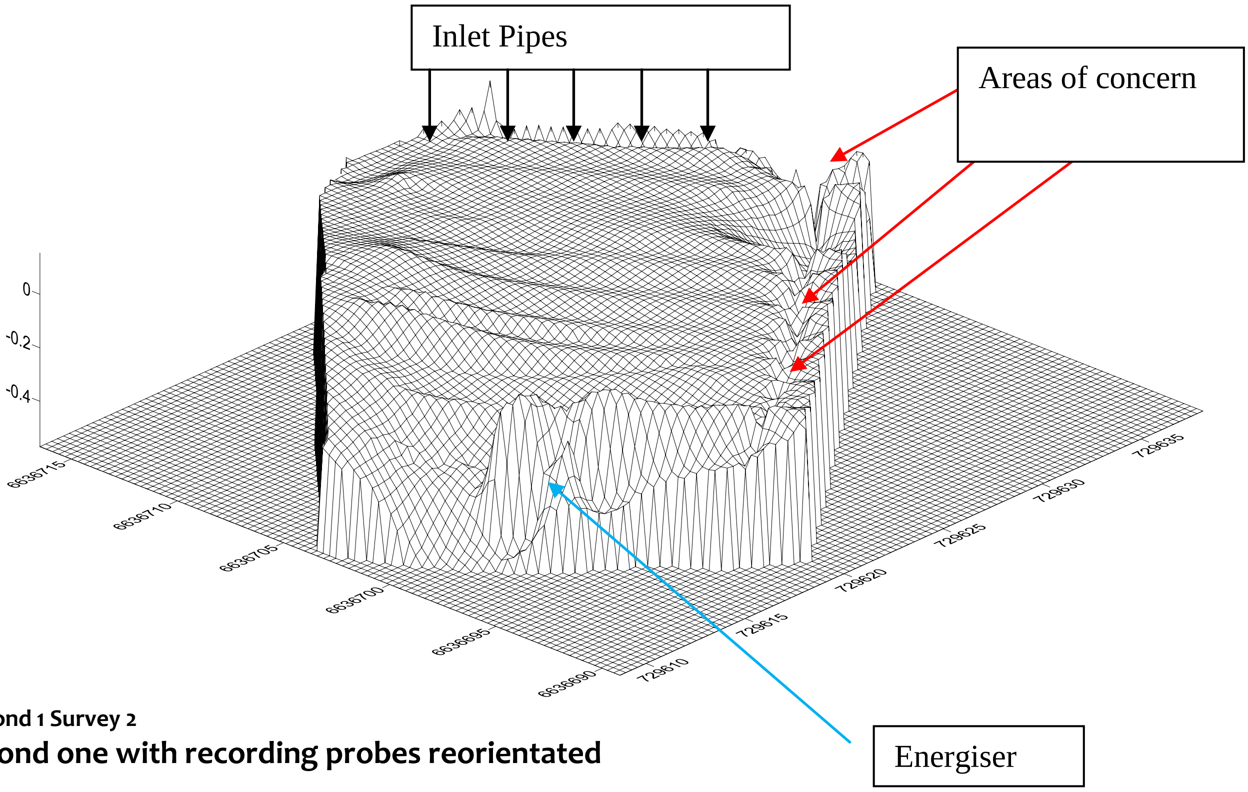

Pond 1 Survey 2

Pond one with recording probes reorientated

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SURVEY PLOT - POND 2

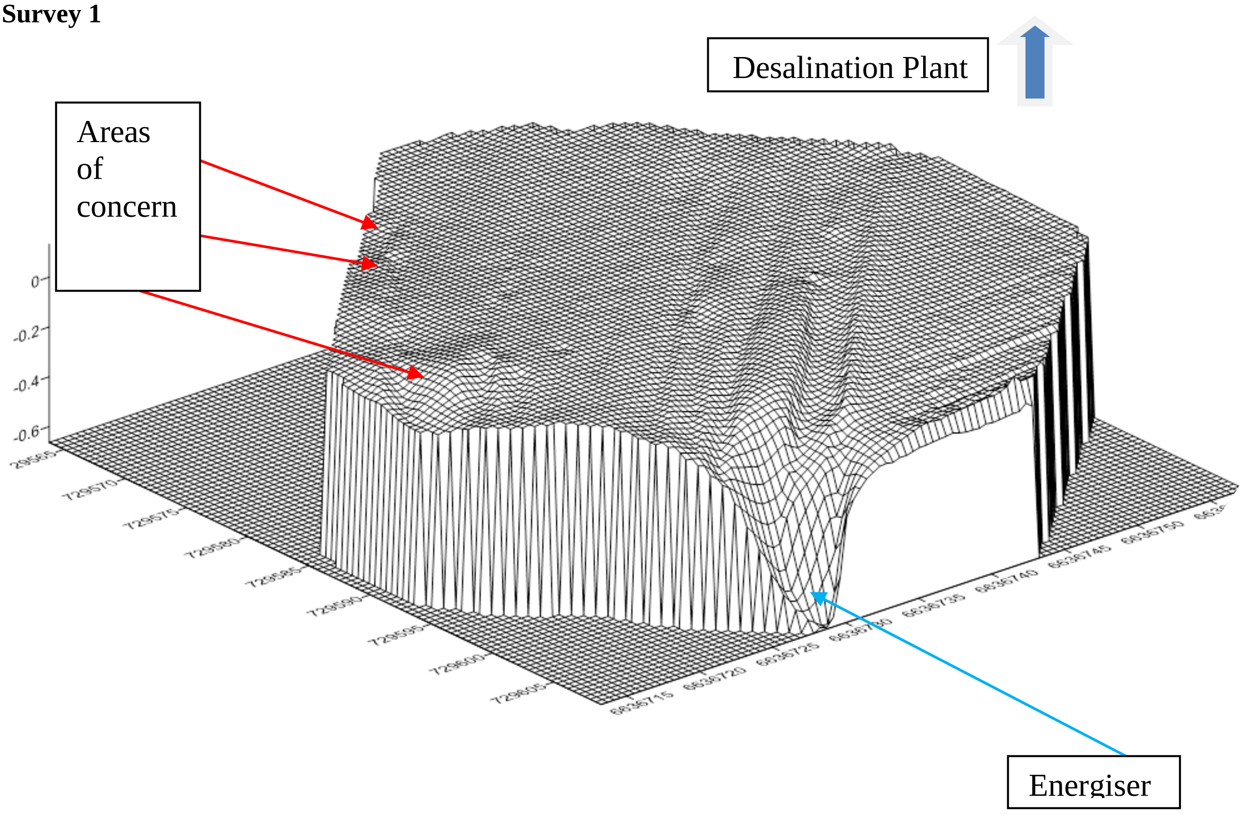
The following shows three diagrams of pond 2, the first two diagrams show the west and eastern sides of the pond separately with some overlay, the third diagram shows the complete pond. Areas highlighted with red arrows are areas that showed higher conductivity and are mostly likely to have breaches in the liner.

First diagram shows on the left hand side (north western side of pond) areas of concern showing increases in conductivity in the localised area and possible holes in the liner. The depression at the end of pond is where energiser plate shows large fields of electrical interference and is not an area of concern.

Second diagram one half of the pond survey shows area of concern in the north eastern corner of the pond highlighted by red arrow.

Third diagram is the two diagrams merged together which remains consistent with the other two diagrams.

Pond 2 - Survey 1



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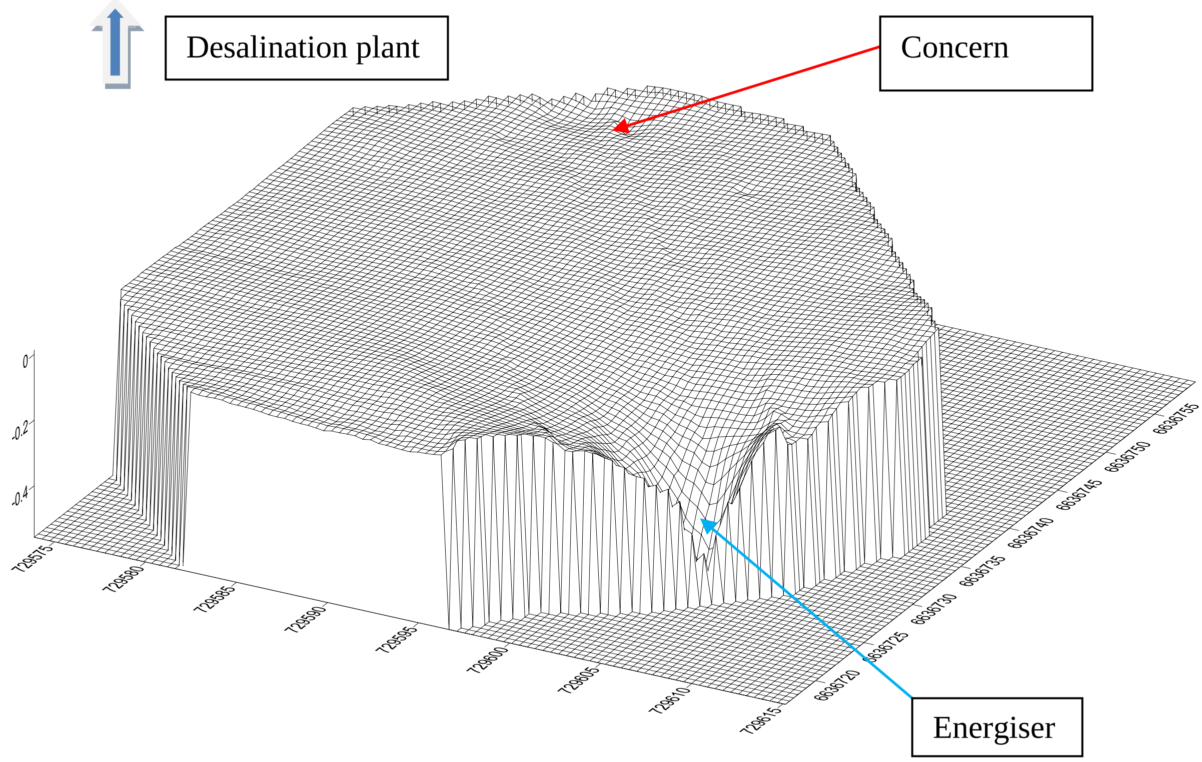
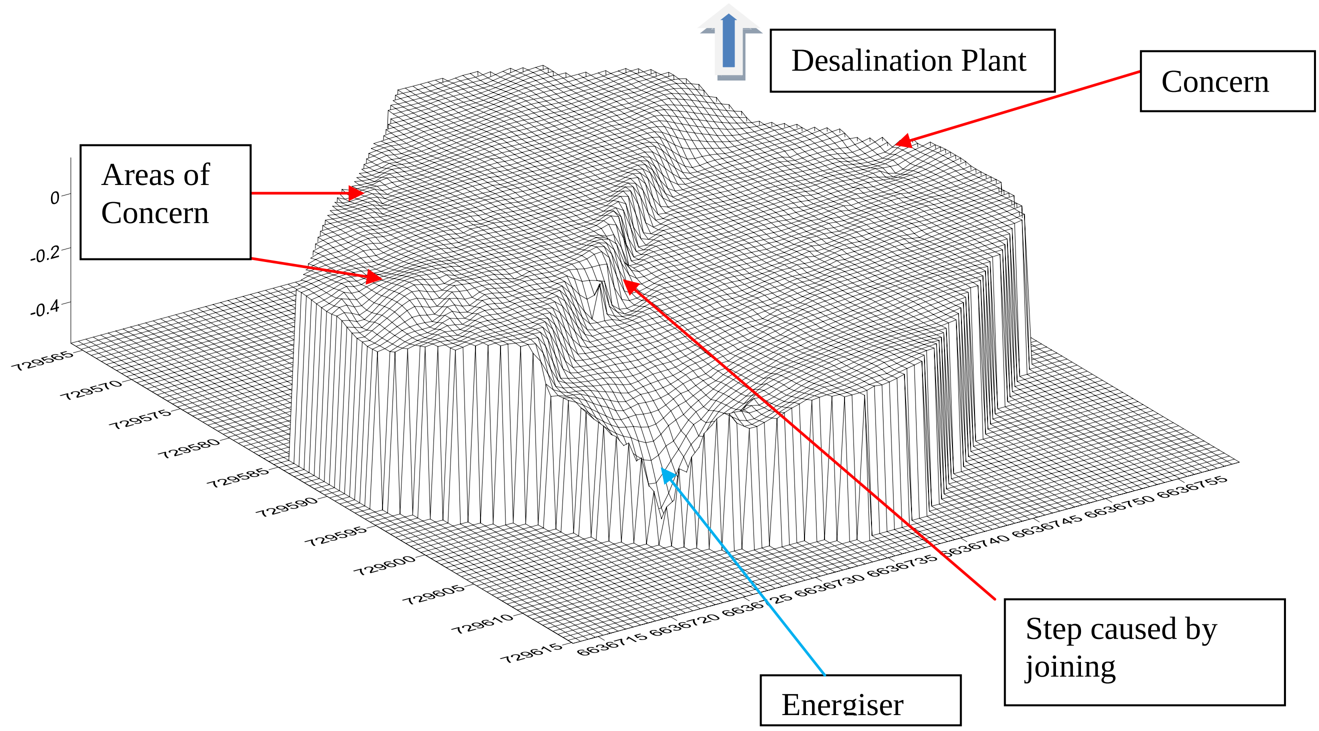


Pond 2 - Survey 2



Pond 2 - Survey 3

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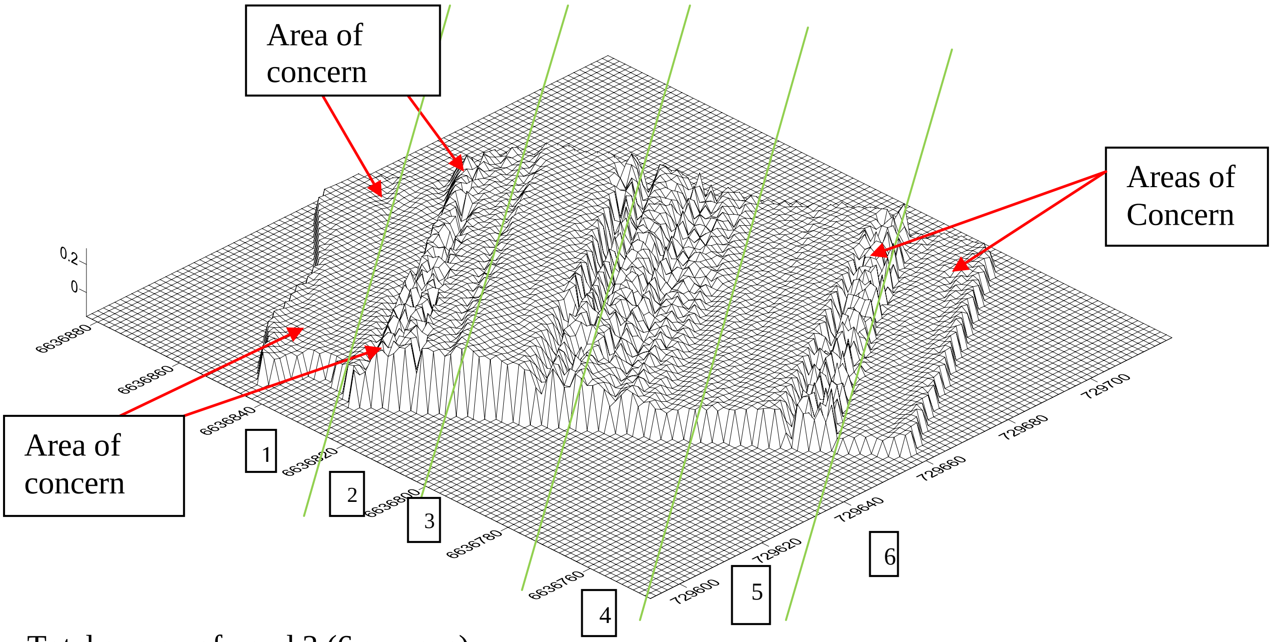
SURVEY PLOT – POND 3

Diagram 1 is the combination of six separate diagrams to cover the total area of the pond. Given the large area concerned and the high salinity of the pond we were only able to highlight areas that indicated high conductivity. We believe given the quality of the workmanship there are many areas that were not obvious during the survey or were masked by other anomalies within the pond. Each of the areas has been highlighted with a red arrow where the greatest conductivity was detected.

Each of the six diagrams have been marked up on the overall plan for eased of general positioning.



Total survey of pond 3 (6 surveys)

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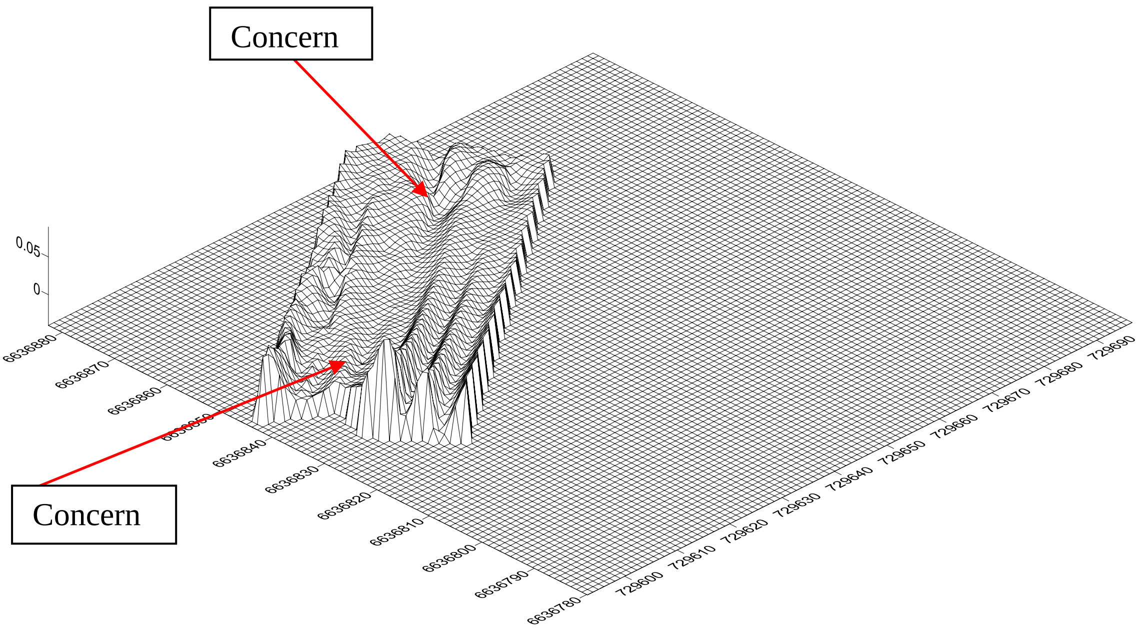
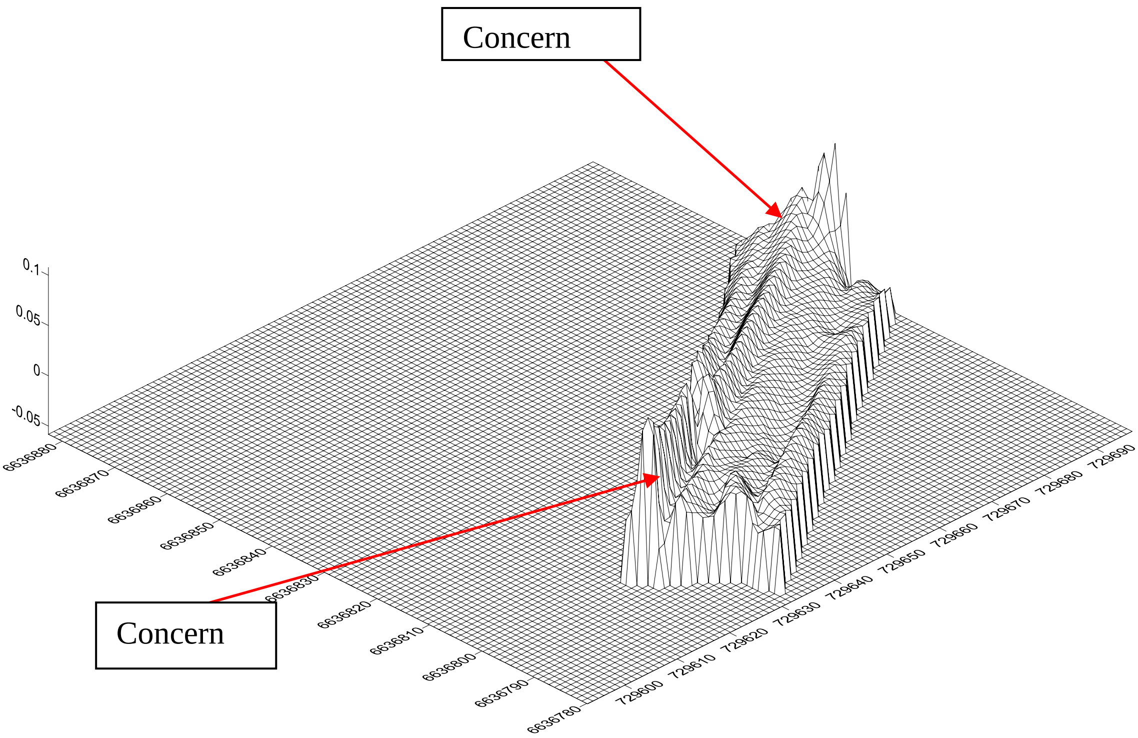


Survey 1 Pond 3



Survey 2 Pond 3

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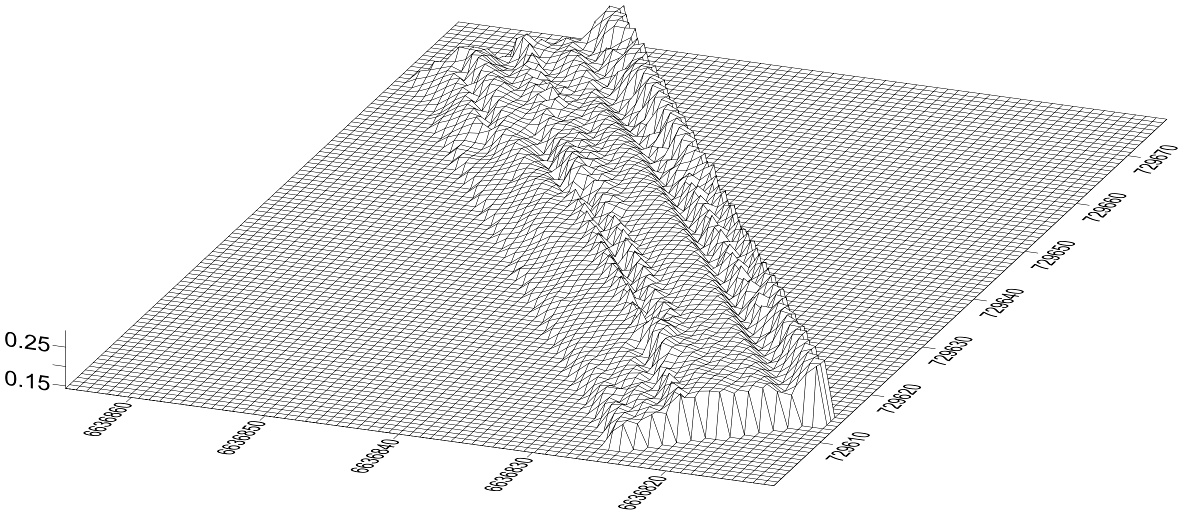
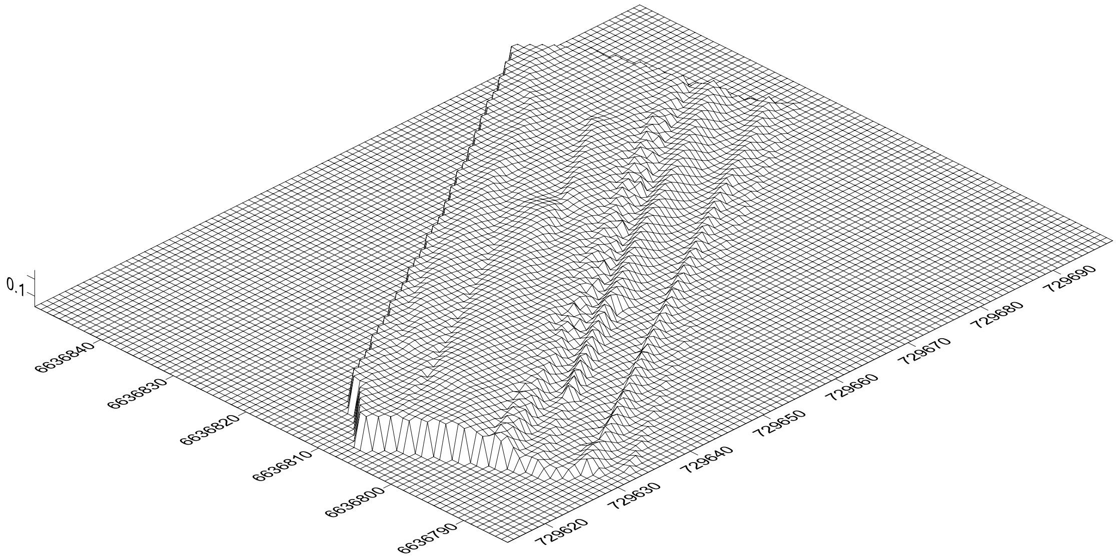
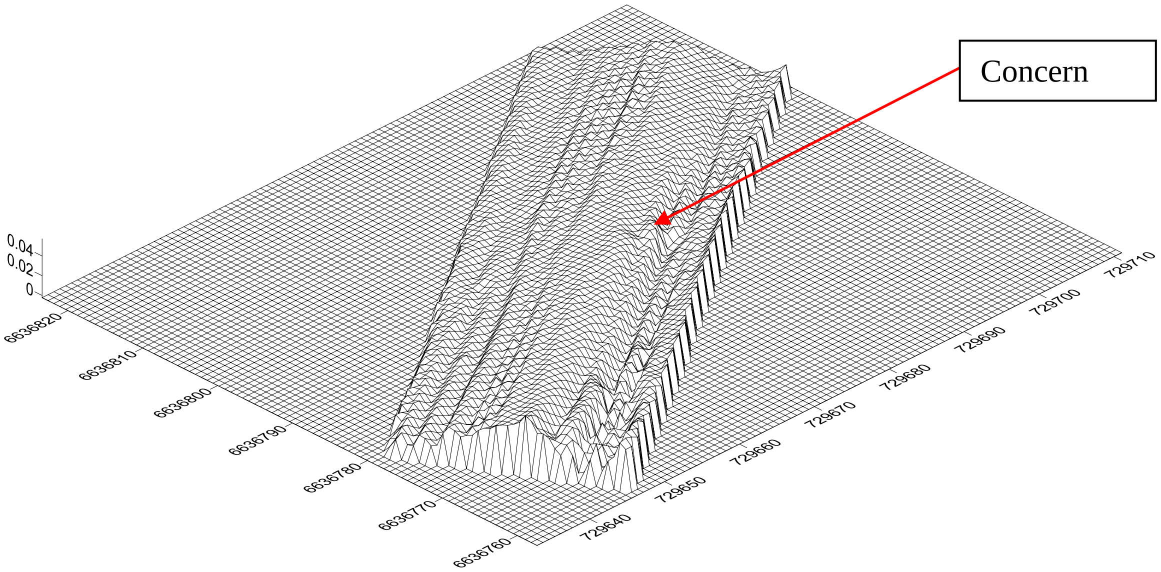


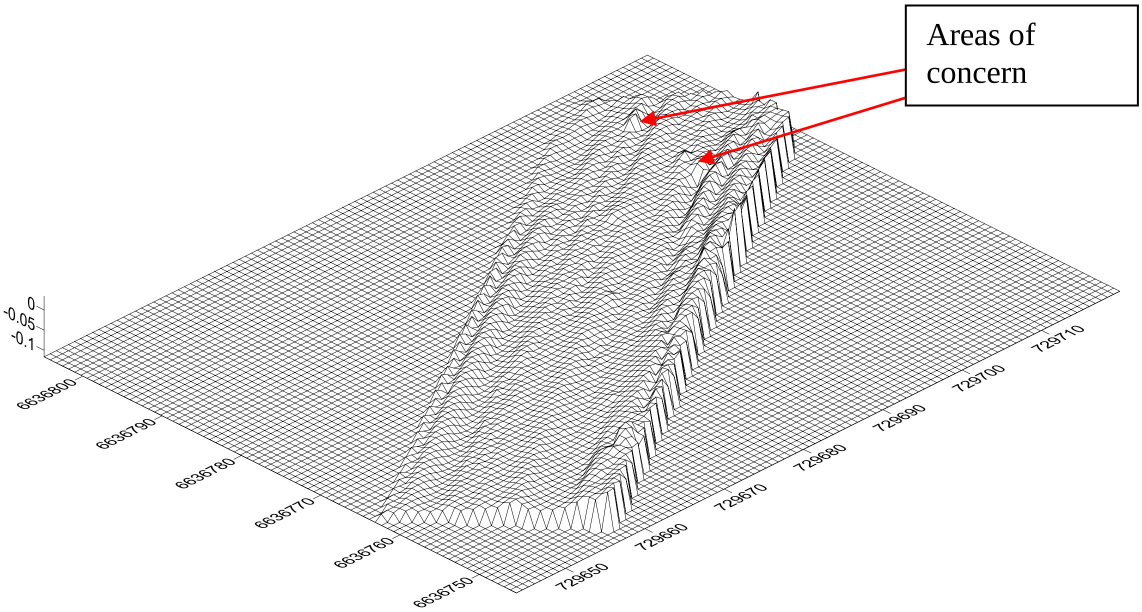
Survey 3 Pond 3



Survey 4 Pond 3



Survey 5 Pond 3



Survey 6 Pond 3

Should you require any additional information or clarification regarding these results please contact Phil Bennett of Geotest.

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Scout Report

Dewhurst 8, 8A, 14, 15, 16H, 17H and 18H
Lot 1 DP771141

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Report Number: PR113567
Version / Date: 29 June 2012

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Document Status

Version	Purpose of Document	Orig	Review	Review Date
Rev0	Client Issue	TM	CH	29 June 2012

Approval for Issue

Name	Signature	Date
Tim Moore		29 June 2012

Contents

Figures

Plates

Attachments

Attachment 1: Title Plan
Attachment 2: Parish Plan Extract

1.1 Introduction

A scout was undertaken over 3 to 4 hours on Wednesday 7 June 2012 of the Dewhurst lease areas (16H, 17H and 18H) that are to be subject to future re-entry drilling, as well as the existing well heads at Dewhurst 14 and 15, and the tank farm adjacent Dewhurst 14. Dewhurst 8A – a skid-over from existing Dewhurst 8 was also inspected,

The purpose of the scout was to investigate the ecological, cultural heritage and all other environmental factors relevant to the existing and proposed activities to be relied upon in the preparation of future REFs concerning further re-entry horizontal drilling as well as the handling and storage of produced water. The following report provides a summary of the key issues investigated by representatives of RPS environmental planning, ecology and cultural heritage teams.

All of the land investigated has been the subject of earlier clearing, drilling and construction work and is therefore highly disturbed. Each site was physically inspected by walking across the disturbed and predominantly fenced area.

In summary, the results of the site investigations, together with associated desk top research indicate that there are no ecological, cultural heritage or other environmental constraints that would prevent further activities for re-drilling, tank construction and surface facilities. The site investigations identified a number of areas where site rehabilitation and improved environmental management practises should be adopted to rectify the previous activities undertaken at the sites. Some issues with the location of existing access tracks with respect to the boundaries of the subject land and the location of existing road reserves have also since been identified which are likely to require rectification, as discussed below.

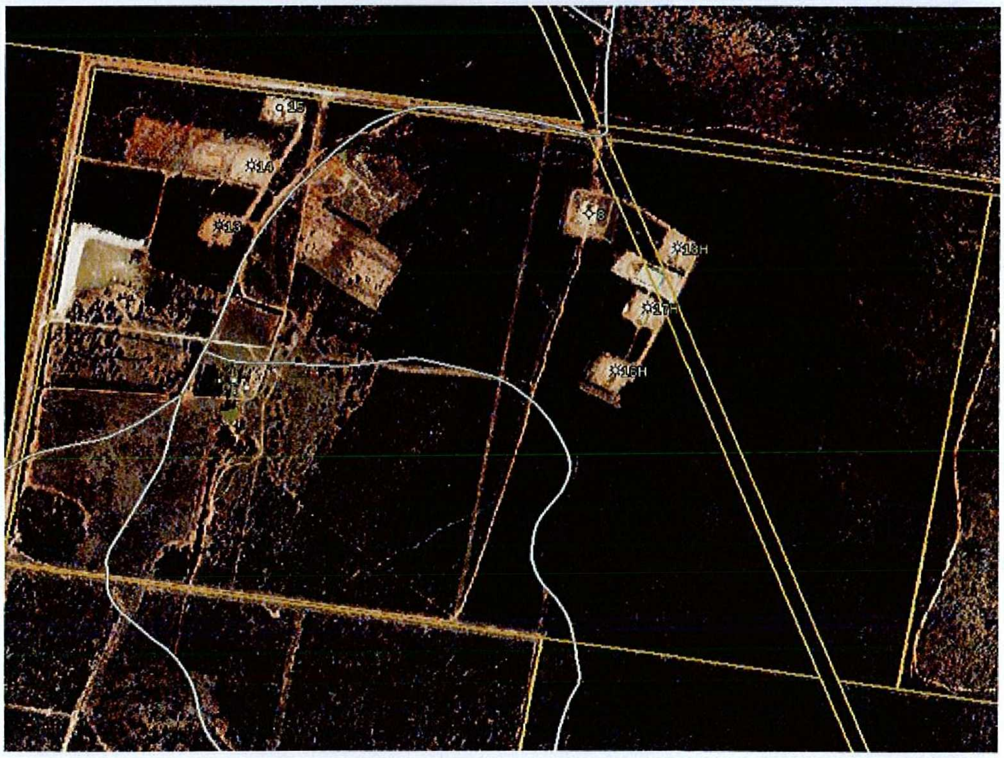


Figure 1: Subject Property showing all lease areas inspected

1.1.1 Ecology

The ecology is common to all sites investigated and comprises the delineated vegetation community 'Ironbark shrubby woodlands of the Pilliga area, Brigalow Belt South' (Namoi CMA Vegetation Mapping) with a variation in the ecotone in the western and northern portions of the community. The dominant canopy species within the variant ecotone are Brown Bloodwood (*Corymbia trachyphloia*) and Dirty Gum (*Eucalyptus chloroclada*) as opposed to Narrow-leaved Ironbark (*Eucalyptus crebra*) which dominates the remaining vegetated area. This is a common vegetation group and contains no EEC. No significant ecological constraints were identified on each of the Dewhurst sites.

1.1.2 Cultural Heritage

A search of the Office of Environment and Heritage (OEH) Aboriginal Heritage Information Management System (AHIMS) was conducted on Lot 1 DP 771141 with a buffer of 200m. This search revealed that there are zero Aboriginal sites recorded in or near Lot 1 DP 771141 and zero Aboriginal places declared in or near Lot 1 DP 771141. The search is limited to whether any Aboriginal sites have previously been recorded in the search area, and does not mean that Aboriginal sites or places are not present. Field investigations are discussed below with respect to each individual site.

1.1.3 Access

Access to the property is via a public road known as Killara Road. Within the private property, access is via previously constructed track that predominantly exist in a sound and well formed state, with minor exceptions where some upgrades will be required, as discussed below.

1.2 Dewhurst 8 and 8A

A lease area of approximately 100m x 100m was inspected. A single well head is centrally located within the cleared lease with an associated flare line offset approximately 20m. The following observations were made at this site.

- A second fenced drill location for 8A was also observed approximately 10m from the existing Dewhurst 8.
- No ecological or cultural heritage constraints were identified to impact the proposed re-drilling requirements.
- Imported fill material, including blue metal has been used to form the lease pad.
- No sumps were observed.
- Soil is stored in array of piles within the lease area.
- There were no visible natural watercourses in the vicinity and the topography is generally flat.
- No cultural heritage or ecological constraints were identified as present within the cleared lease area. As part of the skid over to Dewhurst 8A, potential exists to limit the area where vehicles manoeuvre within the site and surface equipment is stored and thereby reduce the area of the lease to allow natural rehabilitation to commence.

1.3 Dewhurst 18H

This site is located off the corner of the main access track where it turns to head to the south. A lease area of approximately 100m x 100m was inspected. A single well head is centrally located within the cleared lease with an associated flare line offset approximately 20m to the west. The following observations were made at this site.

- The well head was not raised above the natural topography which is generally flat with a slight fall for run off to the north west.
- 3 sumps with poorly constructed bund walls are holding water and have been breached in some locations to run overland across and off the cleared lease area.
- Some patches of coal fines were noted adjacent one of the sumps.
- No cultural heritage or ecological constraints were identified as present within the cleared lease area. In preparation for re-entry, potential may exist to limit the area where vehicles manoeuvre within the site and surface equipment is stored and thereby reduce the area of the lease to allow natural rehabilitation to commence.

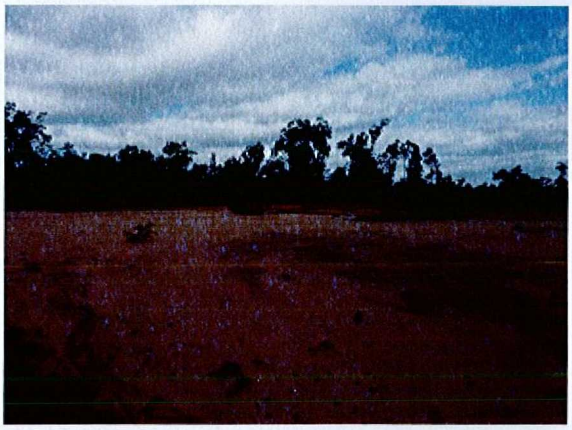


Plate 1: Dewhurst 18H – fenced well head, centrally located within lease area

Plate 2: Bund walls surrounding one of the sumps

1.4 Water Holding Pond

A pond of approximately 30m x 15m is located between 18H and 17H and was the subject of a preliminary inspection with the following points noted.

- The source of the water held in the pond was not known but is presumed to be produced water from previous operation of the well heads.
- The pond has a PVC liner which appears to have been breached in some locations, at the north western corner and along the southern side.
- A bund wall formed with the material from the site surrounds the pond to a height of approximately 1 m above the water surface level.
- A secondary pond exists to the west of the site which was not lined and appears to be formed by slumping and a collection of rain and surface water, contained by the surrounding bund wall.
- No cultural heritage or ecological constraints were identified as present within the disturbed area of the pond.

Plate 3: PVC lined holding pond

Plate 4: Bund wall forming northern edge of holding pond

1.5 Dewhurst 17H

Located south of the holding pond, a lease area of approximately 100m x 100m and fenced along 3 sides (north east and west) was inspected. A single well head is centrally located within the cleared lease with an associated flare line offset approximately 20m. The following observations were made at this site.

- The site is generally flat with slight fall for runoff toward the north east.
- No cultural heritage or ecological constraints were identified as present within the cleared lease area. In preparation for re-entry, potential may exist to limit the area where vehicles manoeuvre within the site and surface equipment is stored and thereby reduce the area of the lease to allow natural rehabilitation to commence.
- Some minor earthworks would be required to improve access and vehicle manoeuvring within the site. In this regard and additional gate may be installed in the south eastern corner of the fenced lease area to allow a drill rig to move into, through and exit the sit4e in a single movement, allowing a reduced disturbed area.
- A single sump with a low poorly formed bund wall was containing some water.
- Adjacent the sump and within a low and poorly constructed bund was a large pile of coal fines and drill cuttings (approximately 1 m high by 10m across). The pile was highly visible from the main access track and would be easily visible from the air. The fines and cuttings contain a mixture of a torn fragments plastic sheet, presumed to be sump lining material.
- An immediate clean-up of the spoil pile, together with pump-out of the sump should be a priority, or included with works as part of any future environmental approvals and Environmental Management Plan (EMP).

Plate 5: View from entry gate showing spoil and coal fines near orange fencing

Plate 6: Bunded sump area with coal fines and waste

1.6 Dewhurst 16H

This is the southern-most lease area, located at the end of the main access track. A double gate provides entry to the lease area of approximately 100m x 100m. A single well head is centrally located within the cleared lease with no associated flare line. The following observations were made at this site.

- Some minor earthworks would be required to improve access and vehicle manoeuvring within the site, noting that to turn around a rig would most probably need to loop around the well head. Any reforming would most likely be achieved with material from the site.
- Some natural slumping has contributed to ponding in an area to the south of the well head.
- No sumps were visible within this lease area.
- A pile of rubbish comprising hard wood pallets was located adjacent the main gate entry which could be quickly and easily cleaned up and disposed of properly.
- No cultural heritage or ecological constraints were identified as present within the cleared lease area.

Plate 7: View from entry gate showing fenced well head

Plate 8: Rubbish located adjacent entry gate

1.7 Dewhurst 14 – Tank Farm

This update and discussion of options is provided further to RPS correspondence of 24 April 2012 which focussed on ecological matters.

The tank farm is located on cleared land approximately 100m to the east of the Dewhurst 14 well head. The tank farm comprises six water tanks of a type normally used for agricultural purposes. Four of the tanks are completed including a corrugated zinc-alum roofing material. The water level of these tanks was not inspected but they are presumed to be near capacity with produced water. A fifth tank is nearing completion with the exception of the roof and contains a mixture of rainwater and lifted water. A sixth tank is completed up to the 1st (of 3) bands of the zinc-alum metal side walls. It is understood that the tank construction commenced some time ago. From site inspection the following observations were made.

- No ecological or cultural heritage constraints were identified in relation to remedying existing works and/or potential future works that may need to occur on the previously cleared and disturbed land.
- The tanks are a type primarily used for agricultural purposes and are formed with 3 bands of zinc-alum sheeting fastened together to form the overall height of 3.5m. The metal tank is lined with a PVC liner.
- Based on drawing N-5000-10-DP-015 titled *Dewhurst Produced Water Tank Farm Piping* and *Instrumentation Diagram* the tanks have a capacity of 358,000Leach.
- A 'lay-flat' flow line is connected to the eastern most tanks which was observed to head in a southerly direction towards Dewhurst 13. The pipe contains lifted water but the exact source of this water was not identified at this time.
- A low formed bund wall is located around 3 sides of the formed tank pad. The eastern end permits vehicle entry. The bund wall is estimated at approximately 0.3m in height.
- Some surface runoff and a breach of the low formed bund wall was identified. Some evidence of die back from previous ecological investigations remained inside and outside the bunded area.
- A leaking fitting was observed on one of the tanks. Due to rain the bucket used previously to mitigate this leak is now sitting in a pond of water. Urgent attention to make good the leak is required to minimise exposure to the environment.
- The bund construction appears to have been broken to enable vehicle access for deposit of blue metal gravel.

The following photographs illustrate some of the above observations.

Plate 9: The six tanks with the partially completed tank to the right. Ponding within the low bund wall can be seen in the foreground

Plate 10: Cleared land to the north of the tanks, looking south

Plate 11: Line between the previous cleared land (now regenerated with successional regrowth of Acacia and some scattered Eucalypt species) and the maintained cleared land, north of the tanks.

Plate 12: 'Lay flat' pipe entering the eastern most tanks

Plate 13: Leaking tank fitting

Plate 14: Ponding on the surface of the tank pad

Plate 15: Looking north east showing ponding from bund wall and previous breach of bund wall

Plate 16: Looking north along top of western bund wall showing ponding and breach of bund.

1.7.1 Options to Mitigate Issues

There are environmental remediation works that should be implemented immediately with the aim of: preventing any further breaches of the bund; completing the roof of the 5th tank; and eliminating leaks from all others.

Longer term options need also to be considered, given that the tanks are primarily the type used for agricultural purpose. Furthermore the bund wall construction is not adequate as a risk mitigation measure to take into account 100% of tank capacity if there was a failure of the tanks. If details of the engineering specification of the base material on which the tanks are located can be determined, and if it is to an appropriate standard, improved bund walls may be constructed to create a an appropriate bunded holding capacity. This may be an approach that would meet regulatory requirements.

Alternatively, the following package of works could be considered to improve the current site water storage standards and overall storage capacity on the tank farm site.

- A large cleared area of approximately 80 to 100m x 100m exists to the north of the existing tanks. Of this approximately 40m x 100m is completely cleared, the balance being successional regrowth of acacia species with scattered eucalypt species.

- From preliminary investigations there is sufficient space within the cleared land for the construction of 2 new tanks to a size and specification similar to tanks existing at the Kahlua site which have a capacity of 5ML each.
- Access to new tanks for construction and operational purposes could be via existing tracks with minor improvement works.
- The newly constructed tanks would enable the storage of water from existing tanks.
- Existing tanks could then either be decommissioned, or improved and monitored closely to provide additional water handling.

An REF could be prepared which sets out this strategy for mitigating the existing environmental issues and providing a proven and long term solution to the water storage needs for this site.

1.8 Access Tracks and Potential Land Titling Issues

Due to the potential existence of a reserved road or 'paper road' (as it is sometimes known), showing outlined in yellow on the GIS aerial; layer included at **Figure 1** above, RPS were requested to make further land title searches and investigations. A copy of the current Title plan for Lot 32 in DP757104 is included at **Attachment A**. As shown on the plan, the area coloured yellow has been identified as a 'Reserve Road', this has been confirmed on the Parish Maps for WHITE-BRIGALOW and WHITE-GORMAN included at **Attachment B**.

The road noted upon the crown plan (**Attachment A**) as 'Road 200 wide' to the left (west) of the parcel boundary denoted AD and above (north) of the line denoted AB would appear to be a public road. It is important to highlight that the Road 200 wide requires verification before one could say emphatically, that it is public road. A search of dedication statements and government gazettal notices would confirm this and would be required as part of a potential process to seek closure of the Reserve Road.

From the information shown on Figure 1 above, together with the title plans attached, it would appear that the exiting access tracks that run north south and east west, have been constructed within this presumed reserve road, outside of the boundaries of the subject property.

In terms of activities allowable within the 'reserve road', legal advice is recommended to check the terms of the existing exploration licence and also to confirm whether or not the activities undertaken, including lease pad construction, access track construction, drilling and surface facilities are authorised within this land. Such advice may also propose a means by which any land titling issues may be rectified.

If there are no rights for activities over the reserve road, it may be necessary to pursue an application for closure of the reserve road. An enclosure permit is not an option as it would only provide permissible use for grazing livestock.

There is a good case for the closing of this portion of the 'reserve road' as the land to the North East is state forest and all other surrounding land has either road or reserve road access, however public road status would need to be checked. The application process is not a difficult one, however, as this is a closure under the *Roads Act 1933* there are a number of steps required and the minimum timeframe is 9 months. If this is something that Santos wish to pursue further RPS can provide further outline of the process and steps to manage this.

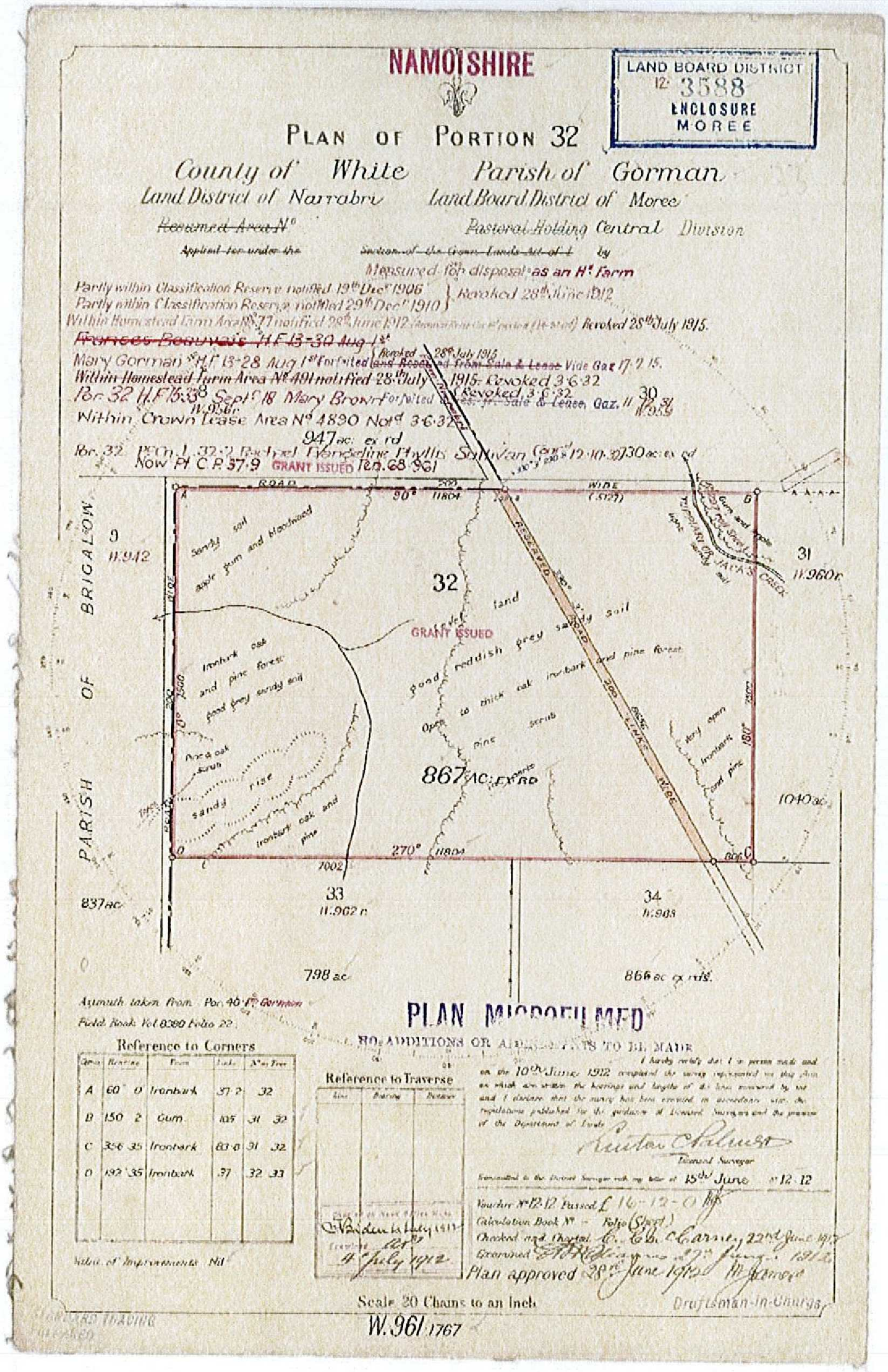
Attachment A

Title Plan

RPS

Dewhurst Scout Report
Lot 1 DP 771141
29 June 2012

Req:E638866 /Doc:CP 961-1767 /Rev:8-Sep-2008 /Sts:OK.OK /Prt:14-Jun-2012 15:20 /Pgs:ALL /Seq:1 of 1
Ref:QUOTE CPM /Src:M



Attachment B

Parish Plan Extract

The following lands are exempted from Occupation under any Miner's Right or Business Licence:-

All Crown Lands defined, reserved, or left as a road, street or lane; and also all Crown Lands shown on Office maps as retained for drainage and not notified as reserved - R 1445 Notified 20th July, 1917

Crown Lands within any City, Town or Village or site for same proclaimed, reserved or set apart, present or future, not being within a Gold or Mineral Field, Gazette 75th June 1918

State Forests and Timber Reserves, present and future, Gazette 21st March, 1919

Crown Lands of which the subjacent lands are the subject of a lease to mine for coal or shale, present and future. Gazette 18th November 1921.

Lands which have been, or may be acquired for Settlement or Village purposes - R 1819 Notified 19th October 1928

Crown Lands covered by Tidal Waters and extending landwards 100 feet from High Water Mark - R 1943 Notified 12th January, 1934.

The Land within a radius of one mile from any school is constituted a district under the Fauna Protection Act, Nº 47, 1948 (Section 22(a))

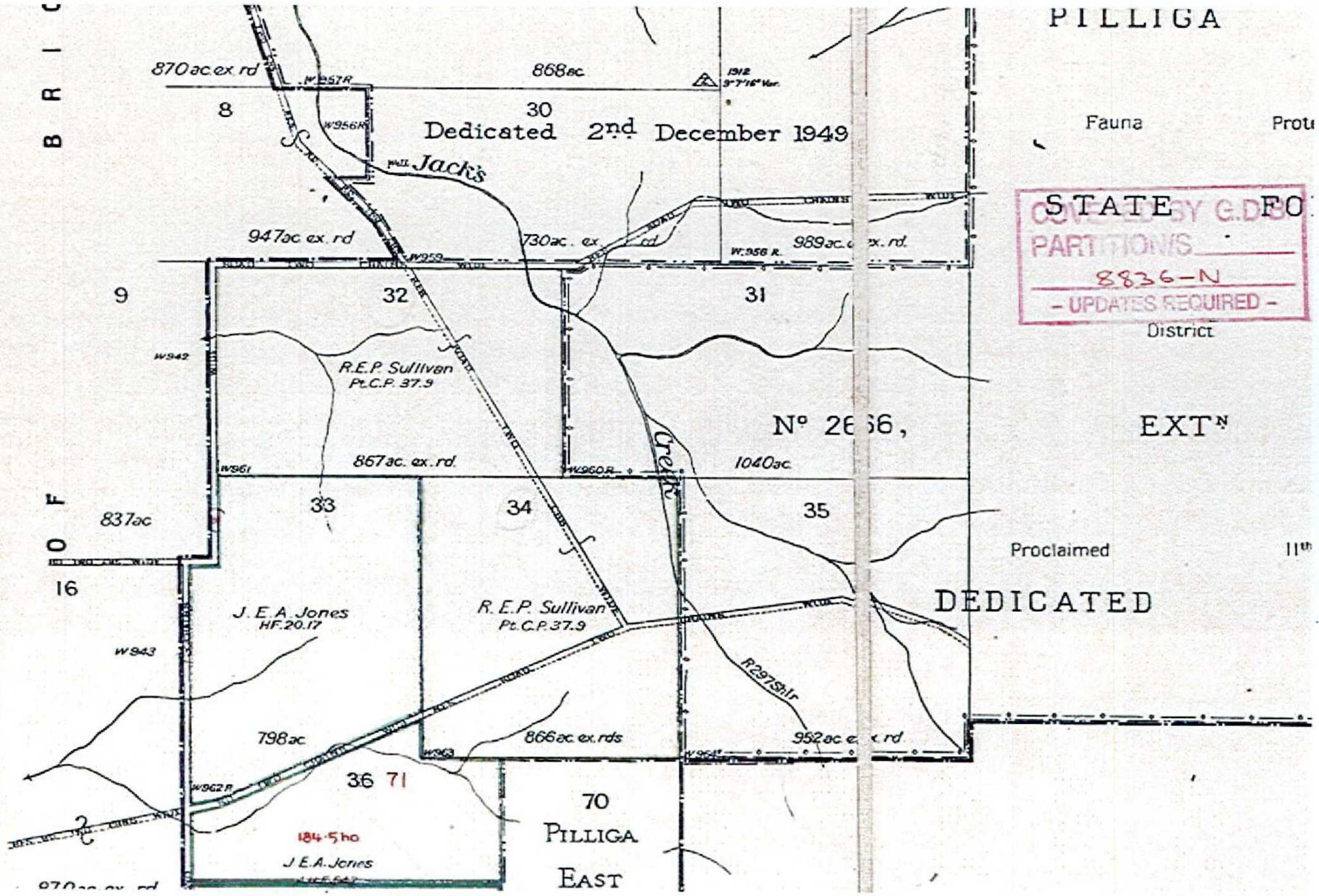
No tree situated within, or within one chain of the bed or bank of any river or lake or section of a river as prescribed (see notifications Gazettes 9th Apl, 1948, 30th Sept, 1949 and 30th May, 1952) shall be ringbarked, cut down, felled or destroyed except with the permission of the Forestry Commission - Sec 26D Water Act, 1912-1946.

All lands dedicated as State Forests, Timber Reserves and Flora Reserves under the Forestry Act, 1916-1949, proclaimed districts under the Fauna Protection Act, 1948, Gazette 2nd February, 1951.

'ARISH NUMBERS USED

Small Number 1767

PLAN		VOL	FOL	Nº	PLAN		VOL	FOL	Nº	PLAN		VOL	FOL
W1242		5369	24	51					101				
-1251		6751	171	52					102				
-1252				53					103				
				54					104				
				55					105				
W 320		4854	29	56					106				
-1253		10560	153	57					107				
- 321		7480	77	58					108				
- 315		7765	175	59	W 980R				109				
- 316				60	981R				110				
- 322		6201	39	61					111				
- 323		6201	39	62					112				
- 317		5279	175	63					113				
- 318		5041	126	64					114				
- 319		7235	245	65					115				
- 345		C/F		66	W1001R				116				
- 350		7103	143	67	- 1002R				117				
- 326				68	- 1003R		13856	9	118				
				69	- 966				119				
W 327		4761	216	70	- 967R				120				
- 328		5080	38	71	1374		19404	116	121				
- 329		1992	177	72					122				
- 330		1992	177	73					123				



MGPA.001.001.0596.pdf

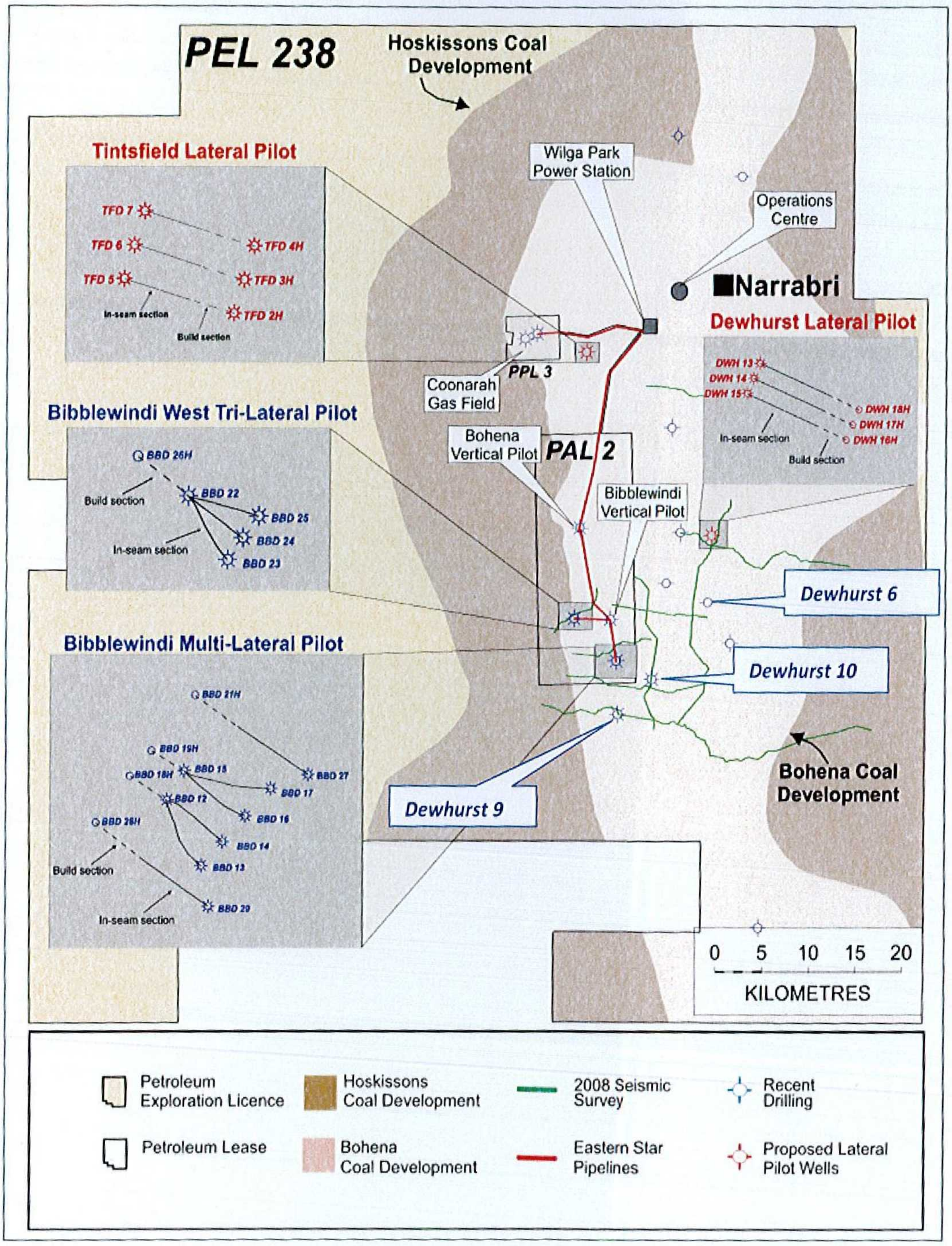
EasternStar
GAS

Narrabri Coal Seam Gas Project

Site Audit – January 2010

Supplementary Information

January 2010


PEL 238
Hoskissons Coal Development
Tintsfield Lateral Pilot
TFD 7
TFD 6
TFD 5
TFD 4H
TFD 3H
TFD 2H
In-seam section
Build section
Wilga Park Power Station
Operations Centre
Narrabri
Dewhurst Lateral Pilot
DWH 13
DWH 14
DWH 15
DWH 18H
DWH 17H
DWH 16H
In-seam section
Build section
Coonarah Gas Field
PPL 3
Bibblewindi West Tri-Lateral Pilot
BBD 26H
Build section
BBD 22
BBD 25
BBD 24
BBD 23
In-seam section
Bohena Vertical Pilot
PAL 2
Bibblewindi Vertical Pilot
Dewhurst 6
Dewhurst 10
Dewhurst 9
Bibblewindi Multi-Lateral Pilot
BBD 21H
BBD 19H
BBD 15
BBD 27
BBD 18H
BBD 17
BBD 12
BBD 16
BBD 20H
BBD 14
BBD 13
Build section
BBD 29
In-seam section
Bohena Coal Development
0 5 10 15 20
KILOMETRES
Petroleum Exploration Licence
Petroleum Lease
Hoskissons Coal Development
Bohena Coal Development
2008 Seismic Survey
Eastern Star Pipelines
Recent Drilling
Proposed Lateral Pilot Wells

Description and images of Site Audit (07.01.2010)

Well	Description	Image
Dewhurst 8	Mid pits at 90% capacity, No evidence of runoff or washout. Temp fence in good condition, southern 2/3 of site is elevated and well drained, north 1.3 shows evidence of sheet flow towards the north west but no impact on existing site installation	

Well	Description	Image
Dewhurst 13	Mud pits approx 75% capacity, minor runoff from site into pits, no evidence of overflow, temp fencing in good condition	

Well	Description	Image
Dewhurst 14	Mud pits approx 75% capacity, minor runoff from site into pits, no evidence of overflow, temp fencing in good condition	

Well	Description	Image
Dewhurst 15	Over 90% full, significant sheet flow across the site from behind flare pit suggesting local drainage from southeast to northwest over the site, evidence of inflows from site in pits, number of small overflow rills in north western corner and away from pits, no evidence of this flow exiting site, some pooling of sheet flow in north western corner as at January 15 Water Sample: TDS – 2730mg/L EC – 5.44 m/S pH – 8.2	

Well	Description	Image
Dewhurst 16	Pits at 90% capacity, minor inflow rills from site, no evidence of pit overflow, site is well draining and showing little or no evidence of sheet flow across well pad	

Well	Description	Image
Dewhurst 17	Pits over 90% capacity, site showing clear signs of sheet flow from south eastern edge of well site towards north west, considerable residual water on northern edge and north western corner, not clear of its origin although with TDS of 750 mg/L, EC of 1.49 m/S and pH of 6.99 suggesting either no influence of mud pits or significant dilution	

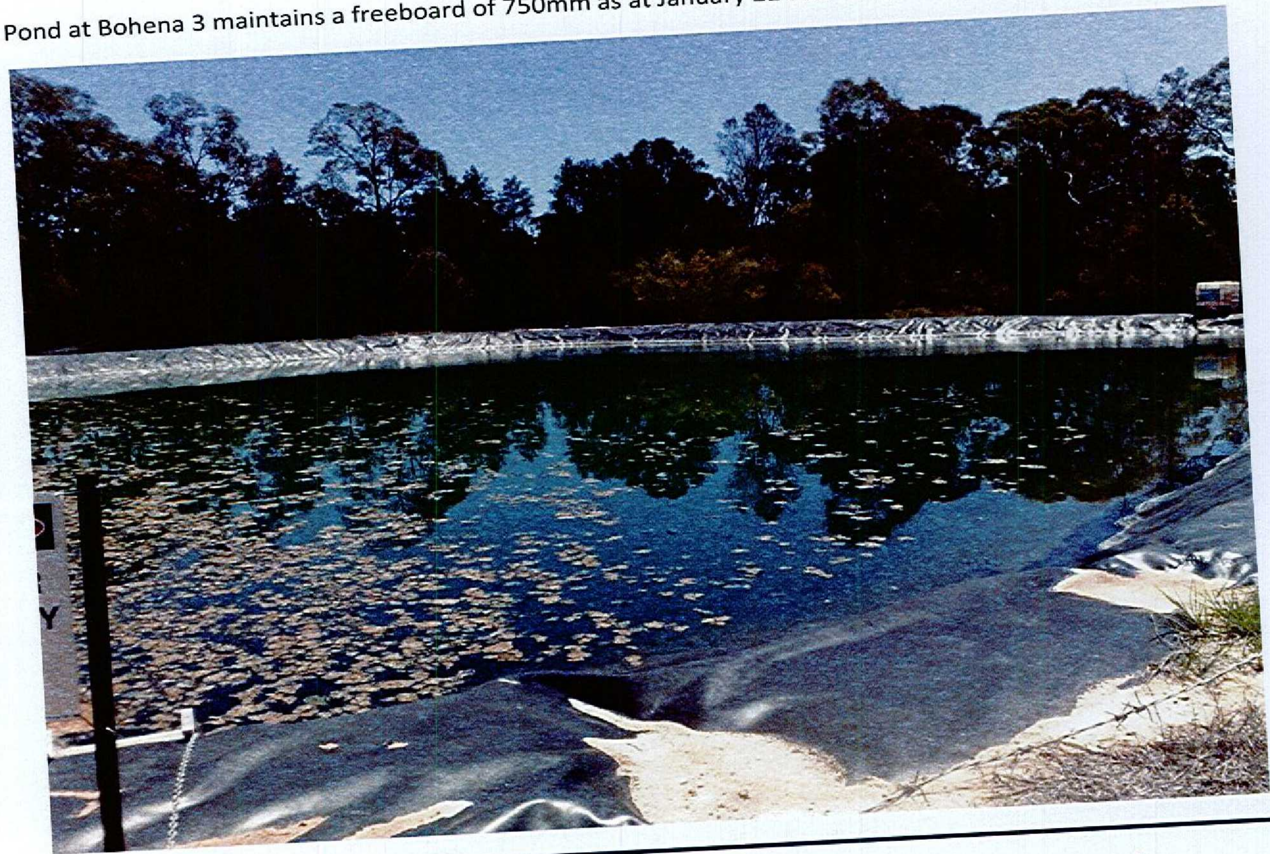
Well	Description	Image
Dewhurst 18	90% Full; clear evidence of water inflows but no over flow, fence in good repair	

Assessment of Water Storage Containment

The following section quantifies the current storage volumes and estimated current capacity of all evaporation ponds. **Note:** Bibblewindi Pond 2 is currently 99% empty while undergoing cleaning and maintenance. Water from this pond was transferred to Bohena South under the modified water management plan.

Bohena 3

Pond at Bohena 3 maintains a freeboard of 750mm as at January 21 and receives nil inflow from production wells



Bohena 6

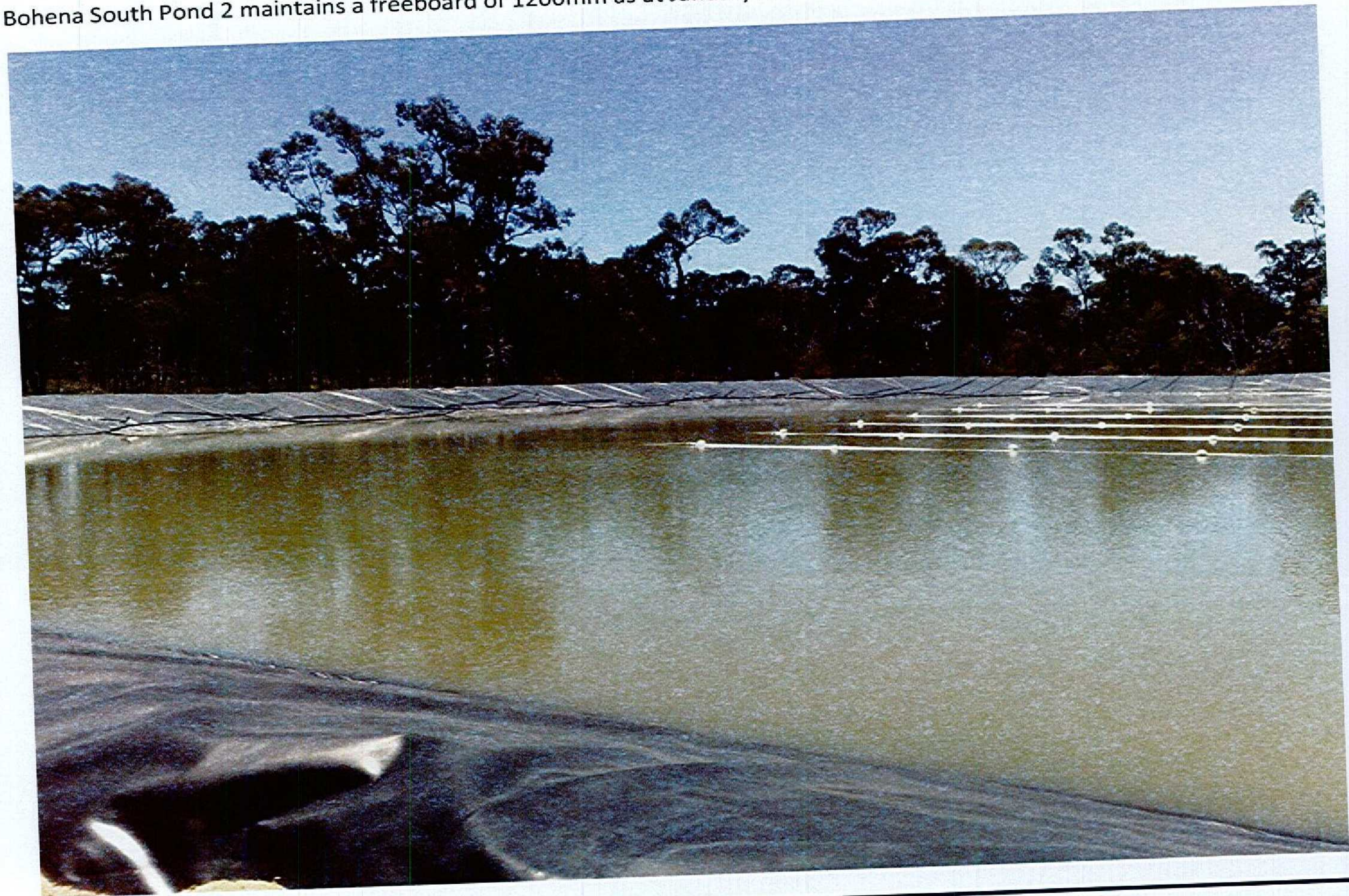
Pond at Bohena 6 maintains a freeboard of 600mm as at January 21

Bohena South Pond 1

Bohena South Pond 1 maintains a freeboard of 850mm as at January 21

Bohena South Pond 2

Bohena South Pond 2 maintains a freeboard of 1200mm as at January 21



Bibblewindi Pond 1

Bibblewindi Pond 1 maintains a freeboard of as at January 21. The water in this pond is fresh water discharged from the water treatment plant

Bibblewindi Pond 3

Bibblewindi Pond 3 maintains a freeboard of 1.5 m as at January 21.

INVESTIGATION REPORT
– Santos Limited & Eastern Star Gas Pty Limited –

ALLEGATION:
Pollution of two groundwater aquifers (shallow and deep) as a result of leaking ponds at the Bibblewindi Water Treatment Facility (WTF), near Narrabri NSW.

SUSPECTS:
- Santos NSW (Eastern) Limited – ABN 80 007 550 923?? (Santos)

BACKGROUND:
The Bibblewindi WTF has previously been used to treat produced water from surrounding coal seam gas activities occurring within Petroleum Exploration Lease (PEL) 238 and Petroleum Assessment Lease (PAL) 2. The operations were previously owned by Eastern Star Gas Limited.

In November 2011 Santos acquired Eastern Star Gas and all of its operations including those within including PEL 238 and PAL2. In December 2011 Santos ceased all coal seam gas operations in the Pilliga including the operations of the Bibblewindi WTF.

The Bibblewindi WTF contains three ponds:
- Pond 3 has an approx capacity of 170ML and is currently used to store brine water with a total dissolved solid (TDS) concentration of approximately 26000mg/L.
- Pond 2 has a capacity of 19ML and contains produced water with a TDS concentration of approx 10100mg/L.
- Pond 1 has a capacity of 4ML and was previously used to hold drillers fluid/mud. It is currently being used for the disposal of vacuum truck wastewater.

All ponds are immediately surrounded by the Pilliga East State Forest.

Notification:
The EPA was notified on 26 March 2013 that sampling of groundwater around the Bibblewindi WTF had occurred in February 2013. The sampling data indicated two areas of concern. These are:

1. Elevated electrical conductivity (EC) levels were measured in the shallow perched groundwater at depths down to 22m as well as depths to 33m to the North West of Bibblewindi Pond 3.

2. A number of naturally occurring elements in the shallow perched groundwater well to the north west of Bibblewindi Pond 3 were found to be elevated. The source of these elements appears most likely to be the interaction between the pre-existing localised weathered clay and perched groundwater underlying the site as a result of the previously notified saline water spills and existing water pond integrity issues at the site arising from activities that occurred prior to Santos acquiring Eastern Star Gas Limited in November 2011.

It is these two issues that are the subject of this investigation.

Note – The EPA was previously notified that there were concerns about the integrity of the liner in Pond 3. No information was provided at the time to suggest any pollution had occurred.

SUMMERY OF INVESTIGATION:

Date	Action taken	Who Involved	Outcome
26 March 13	Phone conversation	- EPA and Santos Rep	Notification that monitoring has indicated elevated levels. A letter with details to be sent.
27 March 13	Letter Received	Santos	Confirming information told in previous phone conversation
27 March 13	Email to NSW Health notifying of incident		Resulted in a number of emails back and forth. Issue was exposure pathways and whether drinking water bores within vicinity.
27 March 13	Email sent to NOW to obtain bore location and usage within area		Shapefiles were received from NOW with this data.
28 March 13	S191 Notice Issued to Santos		
28 March 13	Email Received		Initial Response to Notice included Technical memorandum by CH2MHILL Water quality data for Bibblewindi Pond 3 Soil sampling for soils adjacent to area
10 April 13	Response to s191 received from Santos		
30 May 13	Meeting with NOW to discuss groundwater report		Further questions resulted
30 May 13	Phone call to - Santos		Requested further information
5 June 13	Email received from Santos		Further information to NOWs request
21 October 2013	Meeting with NOW to discuss report		Minor comments

INFORMATION & EVIDENCE GATHERED:

ISSUE 1 - Elevated EC and TDS Levels

Santos drilled piezometers in December 2012 into shallow, intermediate and deep aquifers as follows:

- Shallow (depth approx 20m) – bores 1, T2 and 12S.
- Intermediate – bore 12I
- Deep (depth approx 35m) – bore 3, 6D, 4D, 8D, 12D and 13D

Attachment A shows the location of these bores.

The bores were sampled in February 2013 by Santos and the following was noted:

- The pH results for all piezometers were close to neutral.
- The groundwater quality in the deep aquifers showed a low EC and TDS with an average of 376uS/cm (low quality). 12D however was recorded as having a higher EC of 2480uS/cm.
- In the shallow aquifer the majority of the piezometers were dry except for in the north-west corner of Pond 3 which showed the following:

Bore	EC (uS/cm)	TDS (mg/L)
12S	29259	22900
12I	5640	4330
T2	2422	1690
1	15109	9100

The full set of results is found in **Attachment B**.

These results are showing a saline impact on the north-west corner of Pond 3 that is decreasing with depth.

Pond 3 has historically been used to hold produced water as well as brine that resulted from the reverse osmosis treatment process. A study[1] undertaken of Pond 3 in 2012 shows that it contains extremely high TDS and EC levels (40000uS/cm in lower layers) that are well in excess of the ANZECC and Namoi Catchment guideline trigger values for aquatic systems. At the time of testing the piezometers Pond 3's water quality was recorded as having an EC of 36830uS/cm and a TDS of 30044mg/L.

ISSUE 2 - Elevated pollutant levels:

It was initially reported that some elevated heavy metals, anion and cations were detected in the aquifers to the north west of Pond 3. Santos reported that the source of the elevated levels is likely to be from Pond 3 as well as from an accumulation of those naturally occurring elements found in the soils that have leeched through with the pond water.

[1] 'Assessment of Water and Sediment Quality in Selected Pilliga Ponds' Prepared for Neale House, Santos Limited by Johns Environmental Pty Ltd May 2012.

According to the report provided by Santos titled 'Hydro geological Definition Study – Bibblewindi' dated March 2013 *'the water contained in Pond 3 reported elevated levels of barium, nickel, strontium and slightly elevated levels of copper'.* The report also stated that *'the sources of minor heavy metal concentrations'* in the groundwater *are considered to be Pond 3 water, which contains detected concentrations of several heavy metals, including Barium and strontium, and the naturally occurring concentrations of heavy metals in soil.' It is possible that due to the chemistry of the pond water, naturally occurring concentrations of select heavy metals in soil are dissolving into solution, resulting in minor concentrations of heavy metals in groundwater that aren't detected in the pond water'.*

The report indicates that soil samples were taken from the cores from the drilling of the peizometers and analysed. Soil samples were also taken from cores from drilling occurring at the company owned Leewood property, located north of the WTF. According to the report the *soil samples from both Bibblewindi and Leewood, at multiple depth profiles, reported minor concentrations of several heavy metals in soils; including barium, strontium and uranium.*

The results of the groundwater quality testing, Pond 3 water quality testing and the soil samples have identified the following:

- Barium - 12S and 1 (Shallow) recorded barium levels of 20mg/L and 14mg/L, which is well above the Health Guidelines recommendation of 2mg/L.. No levels are listed for irrigation and livestock. The Barium levels in Pond 3 are recorded as 23.6mg/L. Soil samples were also collected and analysed at the Bibblewindi site. These showed a <10mg/kg recording for Barium until a depth of 28m where a level of 20mg/kg was recorded.
- Lead – 12I and deep bore 3 recorded levels above the 2011 Health guideline of 0.01mg/L. Deep bore 8 showed levels that were above both the irrigation and livestock water quality levels. The lead levels in Pond 3 are recorded as <0.005. The lead levels in the soil samples were recorded as ranging between nil detection and 9mg/kg.
- Strontium – 12S, 12I, 12D and 1 all showed elevated levels of strontium when compared to the results from the other piezometers. The highest level was recorded in 12S. This reading was 0.536mg/L. The strontium levels in Pond 3 were found to be 3.4mg/L whilst there was nil detection of strontium in the Bibblewindi core soil samples.
- Nickel – 12S, 12I and 1 are showing elevated levels of Nickel with the highest level being 0.298mg/L which was found in 1. Nickel levels in Pond 3 were recorded as <0.005. In the soil nickel was detected with a level of 2mg/kg at 16m deep.
- Aluminium – elevated levels were recorded in 12I and T2 (both shallow) as well as 3, 4D and 8D. The highest recording was in 8D at 210mg/L. The recommended level for livestock and irrigation is 5mg/L. Aluminium in Pond 3 was recorded as being nil detection or <0.05mg/L. The soil samples however showed high levels of aluminium with the average of the core samples being 5462mg/kg. These levels are similar to those levels detected at Leewood (average was 7167mg/kg) and therefore could be indicative of background conditions.
- Boron – 12D and 12I registered levels for Boron above the ANZECC 1992 irrigation levels. Pond 3 detected a level of 1.836mg/L. No levels of boron were detected in the soils.
- Uranium – 12S, 12I, 12D and 1 all recorded elevated levels of Uranium that were above the 2011 Health guidelines (set at 17ug/L). The highest concentration was recorded was 335ug/L in 12S. Pond 3 recorded nil detection of uranium whilst

Pond 2 recorded a level of 2mg/L. The soil samples detected levels ranging from 0.3mg/kg to 0.7mg/kg. This is similar to the levels detected in soil samples collected from Leewood.
- Arsenic – 12S recorded a slightly elevated level of arsenic at 0.019mg/L. Arsenic was detected in one soil sample (11m deep) with a level of 8mg/kg. Pond 3 detected a level of arsenic as 0.0065, which is below the Health and stock water levels of concern.

An email from Santos dated 9 May 2013 confirms that the site has been not been in operation since December 11. The only additions of water to Pond 3 since then has been the transferred of water from Ponds 1 and 2, to allow decommissioning of these ponds, and small additions from the shut in wells that is necessary to keep the pressure down in these wells.

Information about the groundwater aquifers:

The water bearing zones have been identified as:
- 16 – 20mbGL – Sandstone, poorly cemented fine grained sand (known as the Shallow aquifer)
- 29 – 34mbGL – Sandstone, course grained sand with gravelly clay component, red with significant iron staining[2].

Based on the report titled Hydrological definition study – Bibblewindi prepared by CH2MHILL for Santos the seepage velocity in the deeper groundwater zone is 0.03m/year. This combined with a flat gradient indicates '*a low groundwater flow rate within the deep horizon*'[3]. The report also explains that the EC levels decrease with depth.

A meeting was held between the EPA and hydro geologists with NSW Office of Water (NOW) to discuss whether the reported seepage rate as well as the conclusions drawn within the Hydrological definition study have been reasonably estimated. At a meeting held on 21 October 2013 NOW commented that from the data presented in the report it appeared as though the flow rate of the aquifer and the risks to other users were low however the report is very technical and NOW would need to fully review the documents to be able to provide a full report. As the report was obtained under Notice the EPA cannot forward this report on. NOW also commented that it would be beneficial to require an ongoing groundwater monitoring requirements to monitor and manage the groundwater.

Heath and Community Concerns:

Of the four registered groundwater bores that are located within 5km of the site; they are of mixed usage – stock and domestic, industrial and oil exploration. None are listed as drinking water. These four bores are at targeted depths greater then 30m below ground level.

NSW Health was notified of the complaint and a copy of the initial Technical Memorandum was sent to them. Health was concerned about exposure pathways and whether there were any drinking bores within the vicinity of the Bibblewindi WTF.

[2] Hydrological Definition Study – Bibblewindi, Santos Limited 2013, CH2MHILL – Lithological logging

[3] Hydrological Definition Study – Bibblewindi, Santos Limited 2013, CH2MHILL – Hydraulic parameters

Information received from NSW Office of Water was that the closest bore to the site is over 5km away with the shallowest at a depth of 48.7m deep.

Health did respond with general knowledge about the site, in particular that *they are not aware of any private drinking water supplies in the area. Nearest public drinking water supply is 27 km away (Narrabri) and does not appear to be currently affect by the Bibblewindi site.*

NSW Health would not comment on the conclusions made in the report provided by Santos and instead made the following comments:
It would be appropriate that the NSW Office of Water be invited to independently review the Technical Memorandum. As the Technical Memorandum was obtained from Santos through an EPA Notice, it would be appropriate for your office to refer the Technical Memorandum through to the NSW Office of Water (at a local level – Tamworth Office) to establish that the conclusions in the report are likely to be accurate. This is considered somewhat justified given that the report has some comprehensive limitations attached.

In addition to the above, it would also be appropriate for the EPA to require a monitoring program aimed at verifying the extent of the seepage. Monitoring, as opposed to modelling would be helpful in gaining confidence that the contamination is not more extensive than currently thought or will not become more likely to affect public or private ground water sources into in future. This would assist the EPA in ensuring that there is no actual high-risk off-site contamination. There should also be testing of the nearby bores as there is potential for these to be used, even on very odd occasions for purposes of domestic consumption.

It would be appropriate for the EPA to require a longer term monitoring program if the source of the contamination remains in situ. The report discusses decommissioning of pond 3 but it is unclear whether this will stop further seepage of contaminated water. The timeframe for decommissioning of pond 3 is also unclear.

Comments provided by the Office of Environment and Heritage – Water Quality Assessment Unit are as follows:

Based on the report titled Hydrogeological Definition Study – Bibblewindi, prepared by CH2MHill for Santos in March 2013:

- *seepage velocity in the deeper groundwater bearing zone is about 0.03m/year (s4.1.1, pg 4-2)*
- *Groundwater monitoring data (Table 4-2, pg 4-3) shows EC levels decrease with depth at the most affected site (BWDMW12) with EC decreasing from >22,000 μS/cm (similar to EC in pond) in the shallow piezometer (13.39m) to 2,480 μS/cm in the deep piezometer (33.5m).*

'The satellite photo provided in Item C of the information provided by Santos Pty Ltd shows that the closest private bores (which access deeper aquifers) are located greater than 4 kilometres away from the Bibblewindi water treatment facility.

Given that salinity is decreasing with depth, the reported seepage velocity, and the distance to the nearest private bore it is unlikely that seepage from Pond 3 is affecting private bores'.

<u>Integrity of Pond 3:</u>

On 18 May 2012 Santos provided the EPA with a copy of a letter to the Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) outlining concerns about the integrity of the liner in Pond 3.

Pond 3 is lined with 1mm think high density polyethylene plastic however a electrical potential survey indicated that there is a direct connection between saline water in the pond and the sub-grade beneath the liners.

The water quality results suggest it is likely that pond 3 is leaking into the shallow aquifer at or near the NW corner of Pond 3.

In May 2012 an electrical survey[4] was undertaken of the HDPE geomembrane liners within Pond 3 to identify any breeches within the liner. The survey concluded that *the inspection of pond 3 and the state of the liner along with the results obtained during the electrical testing indicates the liner installation is of poor quality and shows no evidence of field testing or CQA in accordance with industry standards.*

The survey also found '*that there is a direct connection between the saline water in the pond and the sub grade beneath the liner'.*

The plots shown within the survey indicated that the northern boundary of pond 3 as well as the south west corner was identified as the area of greatest concern.

<u>Comments from Water Quality Assessment Unit</u>
The EPA requested the Water Quality Assessment Unit within OEH to review the groundwater data received as part of the s191 Notice response. The following comments were provided from the Unit:

The water quality data:

- *on satellite photo from Item C indicates that TDS concentrations in shallow aquifers under the NW section of Pond 3 at BWDMW12S (22,99 mg/L) are similar to TDS concentrations in Pond 3 (30,044 mg/L), and that TDS concentrations at shallow piezometer BWDMWT2 located approximately 50 metres south of these other shallow wells is relatively low at (1690 mg/L)*

- *in Table 4-4 of the report Hydrogeological Definition Study – Bibblewindi shows that barium levels in Pond 3 and the shallow piezometer BWDMW12S at the NW corner of Pond 3 are similar (23.6mg/L and 19.6 mg/L respectively), but barium levels at shallow piezometer BWDMWT2 approximately 50 metres south of these other shallow wells is relatively low (0.261 mg/L).*

These water quality results suggest that <u>it is likely</u> that Pond 3 is leaking into the shallow aquifer at or near the NW corner of Pond 3, but further expert opinion or evidence eg on the likely attenuation of pollutants in soil and/or forensic chemical analysis of pond water and groundwater, would be needed to make a more definitive opinion that water pollution has occurred or what has caused any pollution.

Note that Table 4-4 shows elevated nickel and uranium concentrations in BWDMW1 and BWDMW12S, but that Pond 3 concentrations were substantially lower suggesting these elements have not been contained in any leakage.

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[4] 'Santos Bibblewindi Electrical Survey Technical Report HDPE Geomembrane Liner' dated June 2012 and prepared by Phillip Bennett of Geotest Pty Ltd for Santos Limited

It might also be useful to obtain some shallow aquifer ground water quality data from a site that is not affected by any pond leakage, to enable a comparison between BWDMW12S results and likely background ground water quality. The report Hydrogeological Definition Study – Bibblewindi (Table 4-2) includes some water quality data for TDS and some metals for BWDMW1 and BWDMWT2, but these sites are located within about 50 metres of BWDMW12S and it is unclear whether the water quality data at these sites represents background levels in the shallow aquifer or water quality that is affected by a possible leakage of high salinity from the pond.

The report Hydrogeological Definition Study – Bibblewindi CH2MHill (s1.1, pg 1-1) provides some information that may be used to demonstrate any water pollution may be caused by direct leakage between Pond 3 and the shallow aquifer including:

- *reference to an electrical potential survey recently completed by Geotest Pty Ltd in 2012 (Geotest Pty Ltd, Santos Bibblewindi Pond 3 Electrical Survey Technical Report HDPE Geomembrane Liner, 28 June 2012) which showed a direct connection between saline water in each pond and the sub-grade beneath the liners existed, and*
- *the statement that CH2MHill inspected the pond liner installation and observed that it is of poor quality.*

Vegetation Concerns:
Concerns have been raised by the OEH Water Quality Management Unit (WQMU) about the impact on the vegetation communities surrounding the ponds from the shallow aquifer - *Vegetation communities surrounding Pond 3 are likely to utilise the shallow, alluvial groundwater. Groundwater monitoring data (Table 4-2, pg 4-3) of the shallow piezometers shows elevated EC at BWDMW1 (15,109 µS/cm) to the E of the most affected area at BWDMW12. This suggests there is some lateral movement of the shallow groundwater, but there is inadequate data presented in Table 4-2 to assess the likely extent and shape of any salinity plume. It is unclear whether the surrounding vegetation communities are being affected, but these groundwater dependent vegetative communities should also be protected.*

Santos had previously identified an issue with dying trees surrounding the Bibblewindi WTF with a section of the dying trees being subject to a separate prosecution being undertaken by OCSG.

Santos has provided a report to the EOA titled 'Bibblewindi Water Treatment Plant – Preliminary Remediation Plan' dated March 2012 and prepared by CH2MHILL and Halcrow for Santos. This report is a remediation plan that outlines the plan for management of the source of the contamination and the restoration of the impacted bushland'. This plan was approved for action by OCSG.

ELEMENTS OF THE OFFENCE:

Protection of Environment Operations Act 1997 –

s120 Pollution of Waters: 'a person who pollutes any waters is guilty of an offence'
Pollute – cause or permit any waters to be polluted

Person: Santos Limited acquired all of the shares of Eastern Star Gas Limited on 17 November 2011. This included the activities at Bibblewindi WTF. (Cover letter from Santos' Notice). Santos also hold the current Petroleum Exploration Lease (PEL238) and Petroleum Assessment Lease (PAL2) for the site.

Pollutes: Elevated levels of salinity, heavy metals and cations and anions (Santos hydrological report prepared by CH2MHILL); technical memorandum prepared by CH2MHILL; Sampling results provided by Santos under Notice; Cover letter sent to EPA on 28 March 2013

Waters: Shallow and Deep groundwater aquifers as shown in the Hydrological report submitted by Santos Limited. The report includes bore logs, water sample results etc

Cause or permit: Pond 3 is determined to be the cause (Sampling results from Pond 3 submitted by Santos; Pond liner integrity report submitted by Santos; Hydrological report prepared by CH2MHILL; cover letter provided by Santos on 28 March 2013).

ACTIONS TAKEN BY THE COMPANY:

The following information has been provided by Santos on 31 October 2013:

- *Santos has been actively assessing the existing ESG Water treatment facilities since acquiring in November 2011.*
- *In order to gain a better understanding of the hydro-stratigraphy and the mechanisms controlling groundwater flow, a groundwater investigation was undertaken between November 2012 and April 2013 involving the installation and assessment of 16 NEW monitoring bores (complemented the existing 7 monitoring bores) surrounding Bibblewindi Pond #3.*
- *Subsequently, an in-depth chemical assessment of saline water found to be present in a number of bores to the south west corner was carried out.*
- *In July-Aug 2013, a perched water abstraction trial was conducted on the shallow perched bores to the south west of Bibblewindi Pond #3 in. The objective of the trial was to evaluate pumping yields from the monitoring bore, BWDMW12S, to ascertain the viability of a long term perched water recovery operation.*
- *The abstraction trial showed that the impacted lithology's have very low permeability rendering a long term perched water recovery using a pump to abstract water from the monitoring bores impractical. Approximately 1270 litres was recovered and returned to BBW pond 3. Quality monitoring was also conducted on a daily basis.*
- *Officers of the OCSG have visited the site and were informed about the trial particulars during their visit.*
- *The hydraulic conductivity (permeability) of the shallow sediments, being in the order of 10-3 m3/day, were considered too low to create any significant recovery, or yield, and hence have a significant impact on the apparent volume of saline water that may have migrated from the base of Bibblewindi Pond #3.*
- *The results of the trial concluded that recovering the perched water by abstraction in the surrounding shallow perched bores is impractical.*
- *Water quality monitoring was conducted throughout the trial.*

Discussions held with the OCSG on 30 October 2013 revealed that since the plume was moving slowly and relatively contained to the shallow aquifer they had agreed to Santos trialling the pumping of the groundwater out.

Santos has committed to continue monitor and manage the site as follows:

- *As we continue to monitor and manage impacted saline water in the shallow perched groundwater system at Bibblewindi, additional nested monitoring bore pairs down hydraulic gradient of the north-west corner of Bibblewindi Pond #3 (to the north north-east) will be installed. These wells are designed to provide the additional monitoring facilities to assist in demonstrating that shallow lithology's located near to and beneath the site boundary are not impacted by saline water originating from Bibblewindi Pond #3.*
- *Additionally, we will decommission an historical ESG well located hydraulically down gradient to ensure no vertical migration of impacted perched water enters underlying saturated permeable zones.*
- *Subsequent to these activities, additional groundwater monitoring events (to allow the establishment of trend data) will be undertaken on a 6-monthly basis.*

RECOMMENDED ACTION:
It is recommended the following action is taken against Santos Limited:

- A Penalty Notice be issued to Santos Limited for a breach of s120 of the Protection of the Environment Operations Act 1997. or the pollution of groundwater near the Bibblewindi WTF.

- A PRP is included on the Santos EPL that requires a groundwater monitoring and site management plan be developed by Santos in consultation with EPA and NOW for groundwater quality monitoring at and around the site. The plan should be for long term monitoring of the groundwater with update report to be provided to the EPA on a 6 monthly basis. The plan should also have contingencies in place for action to be taken if monitoring demonstrates migration of the plume.

JUSTIFICATION FOR THIS RECOMMENDATION:
There are a number of factors that have been taken into consideration to justify the recommendation for the issuing of a Penalty Notice instead of Prosecution or no action. These factors, as listed in the EPA Prosecution Guidelines, are addressed as follows:

a) The seriousness or the triviality of the alleged offence or that is it of a technical nature only – the matter is pollution of waters.

b) Harm or potential harm to the environment caused by the offence - According to the documentation provided the majority of the leak has been captured in the shallow aquifer. The shallow aquifer is reported to be isolated. There are no listed users of the shallow aquifer however vegetation is likely to source their water from this aquifer.
The data is indicating that the deeper aquifer has a velocity of 0.003m/year. The closest bore to the site is a stock and domestic listed bore that is located over 4km away.

c) Mitigating or aggravating circumstances – There is a high level of community concern regarding coal seam gas activities and there has been both community and media interest in the investigation.

d) The degree of culpability of the alleged offender - Santos Limited took over operations of the site in November 2011 and ceased operations in December 2011 so little produced water has been put into Pond 3 since this time. Santos then approached the NSW Government with concerns about the pond liner integrity and began monitoring to discover possible impacts. Whilst evidence suggests the groundwater has been polluted from Pond 3, it is unsure for how long the pollution has occurred and whether Santos should be to blame for this. The ponds were installed in 2006.

e) Availability and efficacy of any alternatives to prosecution – Yes a Penalty Notice which is what is recommended.

f) The antecedents' of the alleged offender and whether the alleged offender had been dealt with previously by prosecutorial or non-prosecutorial means – Santos have been issued with two Penalty Notices for s120 Pollution of Waters for discharge to Bohena Creek from the same site. These were issued in 2012 and were for offences that occurred before the company took ownership.

g) Whether the alleged offender has been or is being prosecuted by another department - Santos are currently being prosecuted by the OCSG for matters that have occurred also at the Bibblewindi WTF relating to vegetation dieback from a 10000L spill. These matters are unrelated to this investigation.

h) Whether the breach is a continuing or repeat offence – No. The dam is being remediated with all water being sent to Leewood in order to allow for its decommissioning.

i) Whether the issue of Court orders are necessary – No, the EPA can add pollution reduction programs (PRPs) to the EPL for the site. The EPA has received an application for an EPL from Santos for this site. It is recommended that a PRP is added for clean up and monitoring.

j) The prevalence for the alleged offence and need for deterrence – A PN will be a satisfactory deterrence in this situation. The company appear to be aware of the seriousness of the matter and have initiated cleanup prior to any direction to do so.

k) Length of time since the alleged offence – still within statute timeframe.

l) Age, physical and mental health of offenders – company so NA

m) Whether there are counter productive features of a prosecution – Minimal – company are currently applying resources to rehabilitate the site. A penalty Notice will serve as punishment whilst a site monitoring and management plan will require monitoring and management of the site.

n) The length and expense of a court hearing – these were considered and contribute to the justification for issuing a penalty notice.

o) The likely outcome in the event of a finding of guilt – the best outcome would be for the cleaning up of the pollution and long term monitoring to ensure the site has been fully rehabilitated. This will be achieved through the use of the PRPs.

p) Any precedent which may be set by not instituting proceedings – there are a number of both local and land and environment court cases relating to pollution of ground waters.

q) Whether the consequences of any conviction would be unduly harsh or oppressive – NA – recommendation for PN

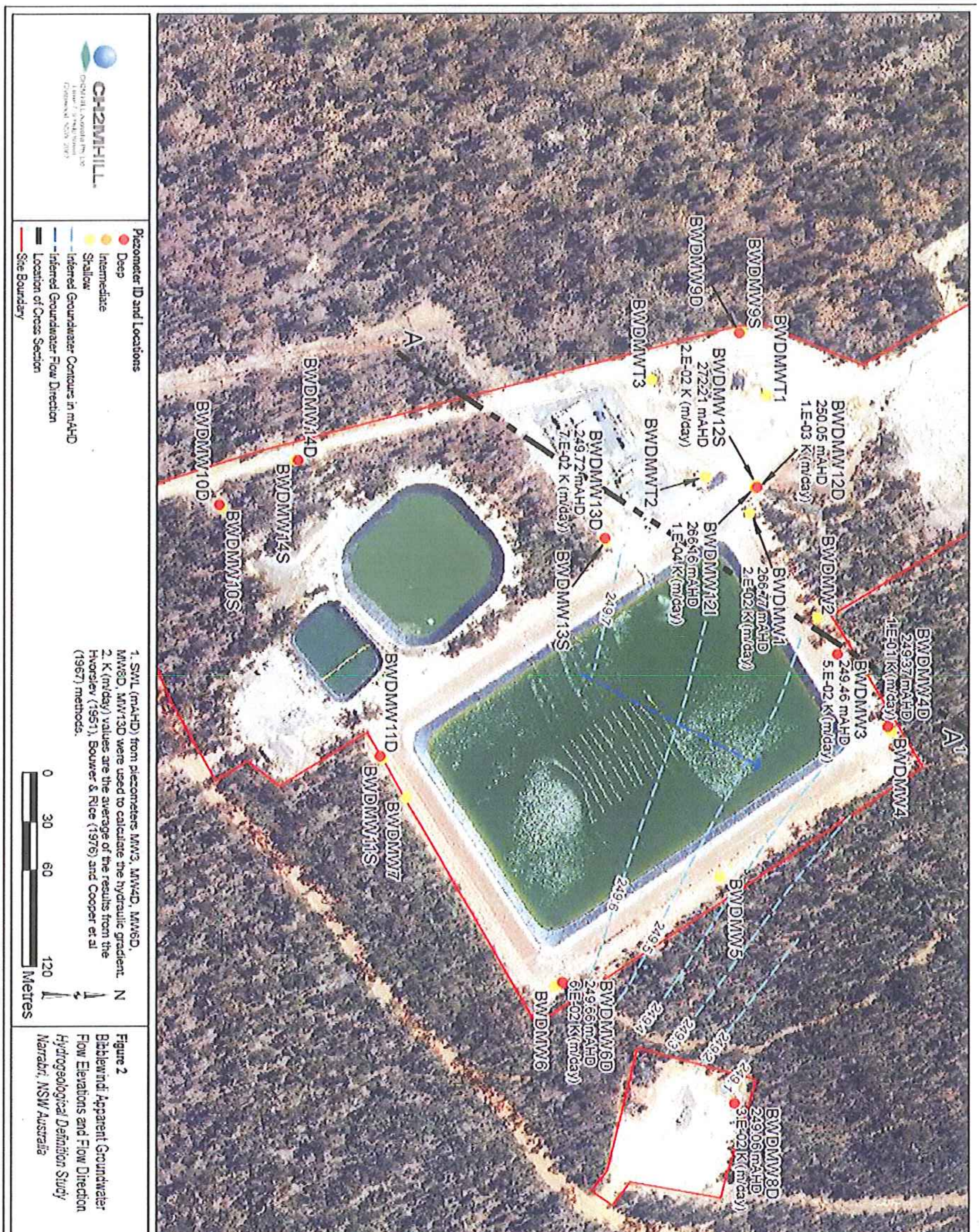
r) Whether proceedings re to be instituted against others arising out of the same incident – no

s) Whether the alleged offender acted in accordance with EPA or another department's advice – the issue has resulted from poor installation and maintenance of the pond liner. Original standards were set by Government for the liner. The liner however was installed in 2006 therefore Santos has not gone against the advice provided. It was through maintenance checks that they found the issue.

t) Whether the alleged offender is willing to co-operate – Santos has cooperated with the EPA through the investigation.

In accordance with the Prosecution Guidelines a penalty notice is recommended as the facts are incontrovertible, the breach has resulted from activities that occurred prior to the company taking over, remediation activities have commenced and the issue of a penalty notice is likely to be a practical and viable deterrent.

ATTACHMENT A – MAP OF BIBBLEWINDI BORE LOCATIONS

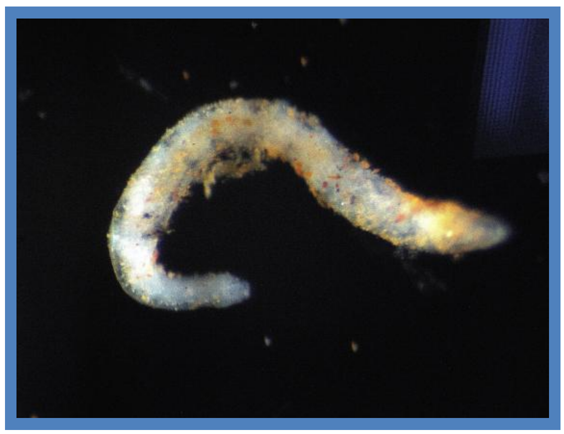


ATTACHMENT B – POND 3 MONITORING RESULTS

Stygoecologia

Baseline Stygofauna Survey Report for Rockdale

May 2012.



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Baseline Stygofauna Survey Report for Rockdale
May 2012.

Introduction

Rockdale is a pastoral property located approximately 20km south of Narrabri, within the Pilliga State Forest. On the18th of March the property owner experienced a rapid decline in water quality from the house bore used for domestic consumption. This is the second recorded change in groundwater condition, with the first occurring in 2006 with the failure of the original house bore. In order to investigate the cause behind the decline in water quality Divstrat Pty Ltd. (representing the owner of Rockdale) commissioned StygoEcologia to conduct a biological survey of the bores on the property as an indicator of the groundwater conditions to compliment the water chemistry analysis conducted in the same period and to liaise with Divstrat Pty Ltd. to provide advice on the possible cause of the water quality change. Three bores were sampled on the 17th May 2012 for stygofauna and possible biological contamination using rapid assessment techniques. This is the 1^st^ environmental assessment of the aquatic ecosystems of the Pilliga sandstone aquifer within the Pilliga Forest area.

Sites

Site/Location	No. species
"New house bore" - GW969324, Rockdale, pump sample, 17/5/2012	6
"Old house bore" - GW038774, Rockdale, stygofauna, net, 17/5/2012	0
"Far Bore" - GW003587, Rockdale, stygofauna, net, 17/5/2012	3

Method

Each site was sampled using two standardized methods and one non standard method.

1) The Phreatic/Hypogean zone

The phreatic zone is the subsurface area within an aquifer where voids in the rock are completely filled with water. This is occupied by phreatobites – i.e. groundwater aquatic invertebrates called 'stygofauna' that are restricted to the deep groundwater substrata of alluvials, fractured rock and karst aquifers (phreatic waters). They have specialized morphology and physiology and occupy a diverse range of niches within the aquifer. These adaptations include the ability to tolerate suboxic conditions (dissolved oxygen concentration (DO) less than 3.0 milligrams per litre) or limited food supply (Malard and Hervant 1999, Hervant and Renault 2002, Datry et al. 2003) and even hypoxia (DO less than 0.01milligrams per litre) (Thomlinson & Boulton, 2008). Dissolved oxygen (DO) concentrations below 1.0 to 0.5 mg/l are the critical threshold for most groundwater fauna (metazoans) (Hahn 2006). The stygofauna community was sampled using two standardised methods.

1) The first technique is the Phreatobiology net. This is the standard technique that has been used successfully overseas and in Australia (Bou, 1974). The method used conforms to WA guideline [2003 & 2007] requirements. This method involves using a weighted long haul or plankton net with a 150 μm mesh. Sampling consisted of dropping the net down to the bottom of the bore and taking at least three consecutive hauls from the entire water column at each bore. Upon removal from the bore the net is washed of sediment and animals and the contents of the sampling jar (the weighted container at the

bottom of the net) are decanted through a 150 μm mesh sieve. The contents of the sieve are then transferred to a labeled sample jar and preserved with 100% ethanol.

2) The second method is the use of a water bailer. A bailer is typically used by hydrogeologists to taken water samples from bores for water quality/water chemistry analysis. The bailer used for this study is 1 meter long by 40mm clear plastic tube with a running ball valve at the bottom. The advantage of using a bailer is twofold. The main reason for using a bailer is that it is able to sample the bottom sediment of a bore that cannot be sampled by a haul net and therefore enables the collection of cryptic invertebrates that do not inhabit the water column or sides of the bore. The second advantage is that in shallow bores down to 5 meters in sediments with low transitivity porosity) a bailer is able to empty the entire contents of a bore and thereby confidently collect all animals within the bore. The contents of the bailer are emptied into a cleaned bucket from which the water is then decanted through a 150 μm mesh sieve. The contents of the sieve are transferred to a labeled sample jar and preserved as above. Following sampling and preservation of the sample and prior to the next sampling all equipment including the bailer, net and sieves must be rinsed clean with clean water via a spray bottle to remove any sediment and animals that may have remained attached to the sampling devices. This is to reduce the possibility of cross contamination of organisms (stygofauna or bacteria) or pollutants from one aquifer or bore to another.

3) The third (non standard) method was used on the “new house bore” only due to access restrictions with the other two methods. This involved pumping water through the house pump to the surface for approximately ten minutes, which removed an estimated two bore volumes. This was drained through a 150µl sieve. The resulting sediment was washed into a container and preserved in 100% ethanol. Three one litre samples were also collected during the collection for water chemistry analysis and processed using the same method. The pump and pipe work was not removed from the bore and therefore the entire water column was not sampled using either the bailer or phreatobiology net as in the other two sites.

Measurement of physico-chemical parameters
A full water chemistry sampling was conducted prior to the biological sampling with the results pending.

Identification
All samples are preserved in the field with 100% ethanol and returned to the laboratory where each sample was sorted or separated from the collected sediment under a stereomicroscope and stored in 100% alcohol. The preservation of specimens in 100% ethanol enables the specimens to be included in future DNA analysis studies.

Results
Three sites were sampled on the 17th of May 2012 with two registering the presence of fauna. The results are presented in the table below. The old house bore did not record any fauna. It appeared clean with a water depth comparable to the adjacent new house bore.

The “New House Bore (GW96324) recorded the highest diversity with 6 species. The species included a number of terrestrial fauna that have entered the bore and used it as a refuge due to the microclimate contained within bores or accidentally falling in through the small opening in the top of the bore.

The “Far Bore (GW003587)” located approximately 900m to the north east of the house also contained both terrestrial invertebrates and stygofauna. The fauna collected included three groups: terrestrial ground surface/soil invertebrates, vertebrate remains (termed Stygoxenes); and groundwater stygofauna (termed Phreatobites or stygobites). Here they will be referred to as Phreatobites.

Fauna List

Locality Description	Specimen Condition	Class	Order	Family	*Genus*	*Habitus*	Habitat
***New house bore" - GW969324**	**Complete**	**Araneae**	**Prostigmata**	**Halacaridae**	**Not determined**	***Phreatobite***	**Interstitial**
New house bore" - GW969324	Well decomposed bones	Amphibia	Not determined	Not determined	Not determined	*Terrestrial*	Refugia
***New house bore" - GW969324**	**Complete**	**Annelida**	**Oligochaeta**	**Naididae**	***Not determined***	***Phreatobite***	**Interstitial**
New house bore" - GW969324	Well decomposed	Insecta	Ants	Not determined	Not determined	*Terrestrial*	Refugia
***New house bore" - GW969324**	**Complete**	**Annelida**	**Oligochaeta**	**Enchytraeidae**	**Not determined**	***Phreatobite***	**Interstitial**
"Old house bore" - GW038774	0	0					
***"Far Bore" - GW003587**	**Complete**	**Annelida**	**Oligochaeta**	**Enchytraeidae**	**Not determined**	***Phreatobite***	**Interstitial**
"Far Bore" - GW003587	Complete	Insecta	Ants	Not determined	Not determined	*Terrestrial*	Refugia
"Far Bore" - GW003587	Complete	Insecta	Diplura	Campodeidae	Not determined	*Edaphobites*	Refugia

*The bolded rows indicate those species that are regarded as being stygofauna.

Stygoxenes

Stygoxenes are species that are not adapted to living within the groundwater environment and are usually collected or occur in this environment by accident. The two groups collected were terrestrial insects and vertebrate remains. The insects collected consisted predominantly of ants with a minor percentage of terrestrial Coleoptera (beetles), Diptera (Flies), and soil invertebrates (Edaphobites) including Diplura. Their presence in the sample are accidental either through falling in while walking in and around the bore opening or building a colony within or adjacent to the bore (e.g. Ants within the new house bore) and the ants being knocked in or falling in once dead.

The large number of ant remains within the “New House Bore” indicates that they have been in residence within or had access to the upper section of the bore for some time, although this length of time could not be determined. All ant material was uniformly decomposed with no whole ants recovered at this site unlike the the “Far Bore” site. This implies that the ant either: 1) all died at the same time by through fumigation or 2) that although the bodies accumulated over time the pump was only able to sample water from near the bottom of the bore where the ant remains accumulated or 3) the filter on the pump was too small to allow the large intact ant bodies to enter. However, as ant bodies are generally of a similar diameter to the heads the first two options seem more likely. The presence of the ant bodies is solely restricted to the “New Bore” and could not have been transported through the aquifer from another locality as the structure of the aquifer precluded voids spaces large enough to allow the passage through it. As the aquifer is composed of a sand and gravel matrix, it would act as a fine filter confining any solid biological remains to the void within the bore.

It would appear that although the ants were not observed actively entering the bore through the small open hole in the top of the casing/steel plate holding the bore works, they may have been entering the bore from the underneath the concrete mountings implying that the bore casing may be insufficiently sealed or cracked.

The two specimens of ants collected (Photo 1) from the "Far Bore" were different species and intact i.e. did not demonstrated signs of decomposition indicating they were either alive when collected or had only recently entered the bore. There was a distinct lack of decomposed ants within this bore.

Photo 1. Ants collected from Far Bore.

The other terrestrial fauna present within the "Far Bore consisted of one specimen of Diplura (Photo 2). These are obligate soil invertebrates that often enter bores for the humid microclimate. These specimens were also intact and showed no sign of decomposition.

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Photo 2. Diplura collected from Far Bore.

The last terrestrial components of fauna collected within any of the bores were bone fragments (Photo 3) of a vertebrate. The bones are suggested to belong to a small frog species given the small size and structure of the bones. The bones were highly decomposed with no tissue remaining and the bone showing signs of decomposition themselves indicating that they had been in the bore for some time, although this period can only be estimated to be within the last one to two months.

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Photo 3. Bone fragments collected from New House Bore.

Phreatobites

The presence of stygofauna was recorded at two of the bores. This included the "new House Bore" and the "far Bore". This is the **first known record** of stygofauna from the Pilliga Sands Formation and possibly from a confined aquifer, i.e. an aquifer which is overlain by an semi porous or impervious layer of rock that restricts access from the surface. It is a new and unexpected discovery as the aquifer type from which they were collected from is a confined/semi confined aquifer and would normally preclude the existence of a subterranean ecosystem due to the low dissolved oxygen levels. They were also collected from a greater depth than is normal for these species. The species composition of the site would indicate (and confirm) the existence an unconsolidated aquifer (which is probably a palaeochannel of an ancient river bed consisting of inter-bedded medium to course grained sands and gravels. The aquifer will have moderate to high connectivity throughout the system and is likely to be connected with the associated river system in some locations, supporting baseflow and an active hyporheic zone. The species also indicate moderate to high water quality. The presence of only Oligochaeta (worms) and Acarina (mites) and the absence of crustaceans and molluscs, may be an indicator of consistently mildly acidic groundwater conditions or an indicator that the aquifer has been impacted/disturbed in some way that has eliminated the the other common elements of the stygofauna community. These two groups have previously been found to be the only fauna within mild (ph 5-6) to highly acidic (ph 4-2) groundwater environments.

Apart from the significance of the new find, it demonstrates a connectivity within the aquifer between the two bores ie. the new bore and far bore. That is, both bores appear to be connected to the same water source. The implication of this is that if the aquifer had been impacted by a general contamination it would be detected in both bores unless it is a localized, point source impact/contamination or if the flow path precludes one or other bore.

The obligate groundwater fauna is characterised by the two Oligochaete Families, the Enchytraeidae and Naididae and the Astigmata water Mites. The Enchytraeidae (Photo 4) are a small families of aquatic worms that are poorly known although they have been found in freshwater environments in Victoria, NSW and recently in groundwaters in Queensland. They are a poorly known group that requires further taxonomic work (Pinder & Brinkhurst, 1994). This is possibly the first record of this family in groundwaters in NSW.

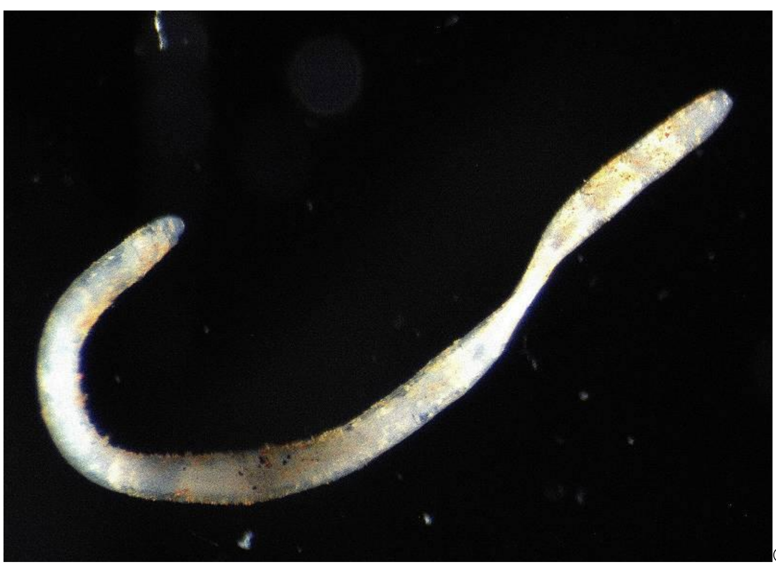


Photo 4. The worm Family

The family Naididae is a common aquatic family of freshwater worms, which currently contains approximately 23 genera and 59 species. In terms of their use within current environmental sensitivity indices such as the SIGNAL Index ranking, they can only be assessed at the Order level of Oligochaeta which has a ranking of 2. This equates to a family which is quite tolerant of environmental disturbance. This, however, is misleading as the family is usually associated with high water quality environments.

The Naididae typically inhabit and swim in the water column just above the substratum, whereas other aquatic oligochaetes that do not burrow, crawl along the substratum. The feeding habit of most aquatic oligochaetes is to ingest detritus and sediments some species of Naididae may be carnivorous, while others are parasitic. Naididae species reproduce by a process of budding from a special segment (Pinder & Brinkhurst, 1994).

The Australian naidid fauna consists mostly of cosmopolitan species, although there are indications of greater endemicity than currently recognised. Increasingly, new Naidid species are being collected from seasonal habitats on granite outcrops in the south-west and from refugial habitats (caves, groundwater and permanent river pools) in drier regions. A complete picture of oligochaete distributions will require much more work and patterns suggested by current data are presented here as hypotheses. (Pinder, 2001).

The other species of stygofauna collected belongs to the Acarina or water mites (Photo 5). There is at least one species of water mite present belonging to the Family Halacaridae. Although subterranean water mites are classed as phreatobites they have their highest biodiversity within the riverine, hyporheic zones and are also classed as members of the "permanent hyporheos or the community that occurs within the deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They typically characterize the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment. *(Boulton* & *Hancock, 2006,* Gilbert, 1994, Humphreys. 2006, Serov, *et al*, 2011.). It is therefore unusual to find this group within the deep phreatic zone (deep groundwater). It is another indication that this aquifer is or has been connected to surface water sources as a discharge source where the discharge can be either point source springs or diffuse discharge through a moderate to course grained substrate such as sand or gravels (Gilbert, 1994). The presence of both of these species/groups within the phreatic or deep groundwater zone is therefore a direct indicator of groundwater connectivity not only between the "New House Bore" (GW969324) and the "Far Bore" (GW003587) but also between the local rivers systems and shallow unconfined aquifers.

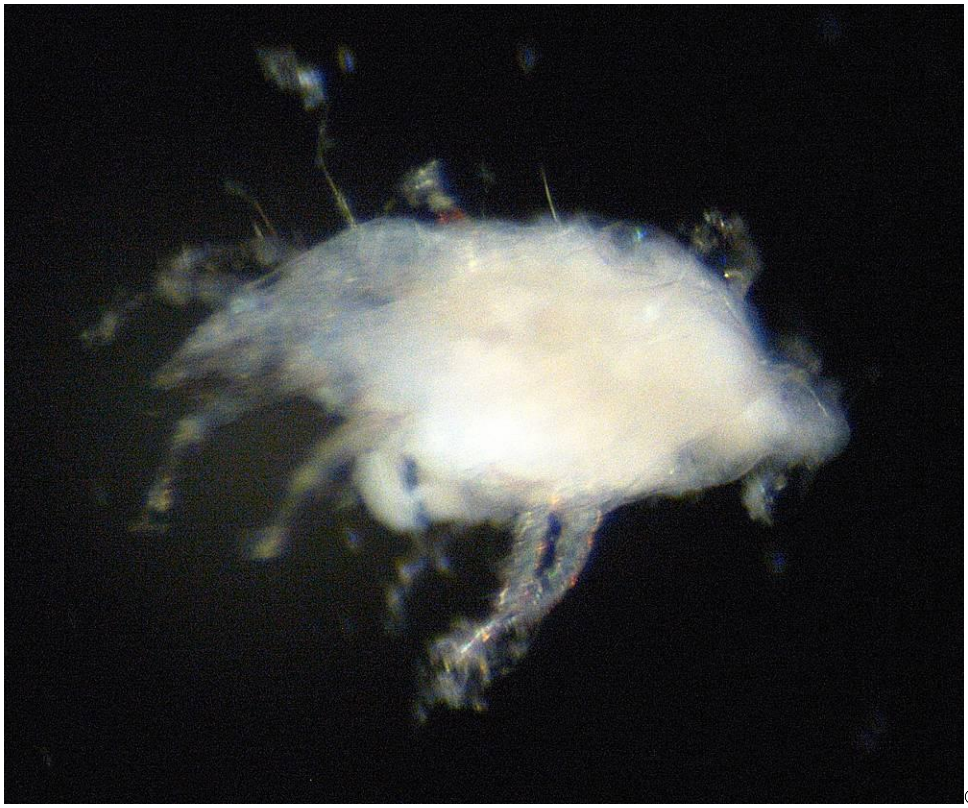


Photo 5. Aquatic Water Mite collected at New Bore.

Management

This survey identified the presence of a significant subterranean fauna within this aquifer, notably within Bores GW969324 and GW003587. This bore and the fauna within it represent a biodiversity hotspot that indicates water quality sufficient to sustain life, connectivity with the adjacent river system and the persistent longevity of the community (Danielopol, *et al*, 2003, Serov, *et al*, 2011.). The presence of these species also strongly suggests there may be a higher biodiversity covering a larger area within the aquifer within suitable habitats than has been indicated by the current locations surveyed.

Key points from the Investigation so far

- All three bores appear to be accessing the same water source/aquifer based on the presence of the same stygofauna species within the “New House Bore” and “Far Bore”. It is not known why at this point stygofauna were not collected within the “old Bore”, except that the sampling may not have been adequate and needs to be repeated. It is also quite a common occurrence for very close bores that appear to be drawing from the same aquifer to have completely different survey results due to a number of causes such as the complexity of the subterranean environments, including slightly different water chemistry or a lack of appropriate pore space (fine sediment lenses) to allow the invertebrate to pass through the matrix.
- Stygofauna are present within the water bearing zone
- Stygofauna indicate moderate to high water quality across the aquifer i.e. overall good aquifer health.
- The ant and frog remains appear to be incidental and have arrived in the bores by accident or used the bores as a refuge due to a more suitable microclimate (higher humidity) and may be a symptom and not the cause of the poor water quality experienced in March. The large

accumulation of ants and smaller numbers of frog bones are all well decomposed, which could have occurred at the same time but it is not possible to determine.

- As there was no active monitoring of water levels or water chemistry occurring at the time of either of the episodes of water quality decline any evidence collected may only be circumstantial..
- It is therefore advised that an ongoing monitoring program be established using insitu water level, water quality and air quality (in bore) probes be installed.
- It is also suggested that a seismic investigation be included in the analysis to determine if there has been any destabilization of the unconsolidated sediments within the aquifer from either earth quakes/tremors or the result of fracking at the time of the events. Although the Pilliga Sands Formation is expected to be quite stable in terms of geological activity, movement of the unconsolidated sands and gravels may have caused a mobilization of entrapped organic materials causing a release of hydrogen sulphides, volatiles and other organic components. If this is the case the water quality should continue to improve as the beds stabilize and the mobilized material is filtered out within the matrix and entrapped again and the volatiles have dispersed. If the change is the result a contamination event it is expected that it will have also occurred in other bores on the property as well as adjacent properties. If this is the case water chemistry analysis of all effected bores may show a consistent contaminant signature.

Suggested Actions

The suggested next stage is:

1) An examination of water quality and subterranean ecosystem health from as many adjacent bores as possible. Even if no contamination is found it will provide a benchmarked network of bores for future comparisons.

2) The establishment of a monitoring program on both the Rockdale property and surrounding properties in order to ensure appropriate measurements are recorded if this event occurs again. It is much easier to determine cause and effect if there is reliable time series data before and after an impact.

The sites that have been surveyed and analysised for water chemistry should be regarded as the first benchmarked sites for this aquifer in the area. Benchmarking is necessary and essential in order to characterize the natural distribution and environmental ranges within the aquifer and therefore the requirements of this subterranean ecosystem and the overall health of the aquifer for human consumption.

The aquifer should be characterised by:

- The structure/lithology of the aquifer by obtaining bore log/works details of the bores;
- The full water chemistry and water levels of the groundwater (including temperature) over time to establish the natural annual ranges and seasonal fluctuations;
- The aquifer flow paths to determine the connectivity (gaining or loosing) with the associated river above and below the potential area of impact.
- Identify the obligate stygofauna to species (those listed as phreatobites) to determine levels of endemicity of the stygofauna community within the aquifer as this community is the most disturbance sensitive environmental indicators for changes in aquifer conditions;
- Conduct further surveys in other bores and hyporheic zone of the associated river, if available, within this aquifer and adjacent aquifers to determine the range of the species.
- Identify other groundwater dependent ecosystems in the area such as springs and groundwater discharge zones within nearby steams.
- Conduct water level mapping across the site/aquifer to determine the linkages with the river systems and other users of the groundwater source such as the local community through the need for stock and domestic water and other potential GDE’s such as terrestrial vegetation or wetland communities that also rely on consistent water levels and water quality.

References

Bou C, 1974. Les méthodes de recolte dans les eaux souterrainnes interstitielles. Annales de Spéologie, 29, 4, 611–619.

Datry T, Malard F, Gibert J, 2005. Response of invertebrate assemblages to increased groundwater recharge rates in a phreatic aquifer. Journal of the North American Benthological Society, 24, 3, 461–477.

Danielopol, D.L., Griebler, C., Gunatilaka, A and Notenboom, J. 2003. Present state and future prospects for groundwater ecosystems. *Environmental Conservation* 30 (2): 104–130.

Gibert, J., Danielopol, D., & Stanford, J.A. (Eds), 1994, Groundwater Ecology, Academic Press.

Hahn, H. J. 2006. A first approach to a quantitative ecological assessment of groundwater Habitats. The GW-Fauna-Index. Limnologica 36, 2, 119–137.

Hervant F, Renault D (2002) Long-term fasting and realimentation in hypogean and epigean isopods: a proposed adaptive strategy for groundwater organisms. *Journal of Experimental Biology* 205, 2079-2087.

Malard F, Hervant F, 1999. Oxygen supply and the adaptations of animals in groundwater. Freshwater Biology 41, 1–30.

Pinder, A. 2001. Notes on the diversity and distribution of Australian Naididae and Phreodrilidae (Oligochaeta: Annelida). Hydrobiologia. 463: 49-64.

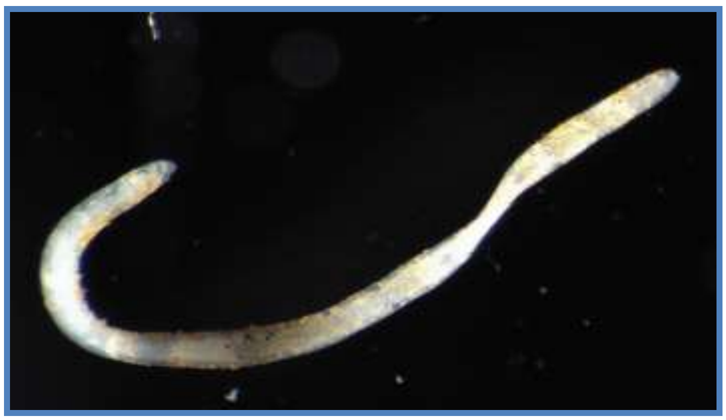
Pinder, A.M. & Brinkhurst, R.O. (1994) *A preliminary guide to the identification of microdrile oligochaetes of Australian freshwaters.* Identification Guide No. 1, Cooperative Research Centre for Freshwater Ecology: Albury.

Serov, P., Kuginis, L., Byrne, G.T., Williams, J.P. 2012. Risk Assessment Guidelines for Groundwater Dependent Ecosystems in NSW. NSW Office of Water.

Thomlinson and Boulton, 2008. Subsurface Groundwater Dependent Ecosystems: a review of their biodiversity, ecological processes and ecosystem services. University of New England. Waterlines Occasional Paper No 8, October 2008. National Water Commission.

Williams, W.D. 1981. Australian Freshwater Life. The Invertebrates of Australian Inland Waters. Macmillan Education Australia Pty Ltd. Melbourne.

The Second Baseline Stygofauna Survey Report for Rockdale
June 2012.



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The Second Baseline Stygofauna Survey Report for Rockdale June 2012.

Introduction

This report presents the results of the 2nd biological assessment of the groundwater ecosystems of the Pilliga sandstone aquifer beneath the Rockdale pastoral property within the Pilliga Forest area south of Narrabri. The investigation is being conducted to confirm the presence of stygofauna within confined/semi-confined aquifer within the Pilliga Sandstone formation and continue the examination of the decline in water quality experienced by the property owner. Divstrat Pty Ltd. (representing the owner of Rockdale) commissioned StygoEcologia to conduct a biological survey of the bores on the property as an indicator of the groundwater condition to compliment the water chemistry analysis conducted in the same period by Divstrat Pty Ltd as well as to provide advice on the possible cause of the water quality change. Three bores were sampled on the 27th June 2012 for stygofauna and possible biological contamination using rapid assessment techniques.

Study Sites

The sites surveyed during the first round of sampling were repeated with the addition of a small seepage located on the northern side of the road leading to the entrance to Rockdale. The seep is positioned on the southern side of a hill and discharges at the surface for approximately 50m downslope. A series of small pools occurs below the discharge point of the seep and these were sampled for aquatic fauna.

Site/Location	No. species
"New house bore" - GW969324, Rockdale, pump sample, 17/5/2012	2
"Old house bore" - GW038774, Rockdale, stygofauna, net, 17/5/2012	0
"Far Bore" - GW003587, Rockdale, stygofauna, net, 17/5/2012	3
Roadside seep near entrance to Rockdale	4

Table 1. Locations surveyed on 27th June 2012.

Method

Each site, except the seep, was sampled using two standardized methods and one non standard method.

1) The Phreatic/Hypogean zone

The phreatic zone is the subsurface area within an aquifer where voids in the rock are completely filled with water. This is occupied by phreatobites – i.e. groundwater aquatic invertebrates called 'stygofauna' that are restricted to the deep groundwater substrata of alluvial, fractured rock and karst aquifers (phreatic waters). They have specialized morphology and physiology and occupy a diverse range of niches within the aquifer. These adaptations include the ability to tolerate suboxic conditions (dissolved oxygen concentration (DO) less than 3.0 milligrams per litre) or limited food supply (Malard and Hervant 1999, Hervant and Renault 2002, Datry et al. 2003) and even hypoxia (DO less than 0.01milligrams per litre) (Thomlinson & Boulton, 2008). Dissolved oxygen (DO) concentrations below 1.0 to 0.5 mg/l are the critical threshold for most groundwater fauna (metazoans) (Hahn 2006). The stygofauna community was sampled using two standardised methods.

1) The first technique is the Phreatobiology Net. This is the standard technique that has been used successfully overseas and in Australia (Bou, 1974). The method used conforms to WA guideline [2003 &

2007] requirements. This method involves using a weighted long haul or plankton net with a 150 μm mesh. Sampling consisted of dropping the net down to the bottom of the bore and taking at least three consecutive hauls from the entire water column at each bore. Upon removal from the bore the net is washed of sediment and animals and the contents of the sampling jar (the weighted container at the bottom of the net) are decanted through a 150 μm mesh sieve. The contents of the sieve are then transferred to a labeled sample jar and preserved with 100% ethanol.

2) The second method is the use of a water bailer. A bailer is typically used by hydrogeologists to taken water samples from bores for water quality/water chemistry analysis. The bailer used for this study is 1 meter long by 40mm clear plastic tube with a running ball valve at the bottom. The advantage of using a bailer is twofold. The main reason for using a bailer is that it is able to sample the bottom sediment of a bore that cannot be sampled by a haul net and therefore enables the collection of cryptic invertebrates that do not inhabit the water column or sides of the bore. The second advantage is that in shallow bores down to 5 meters in sediments with low transitivity porosity) a bailer is able to empty the entire contents of a bore and thereby confidently collect all animals within the bore. The contents of the bailer are emptied into a cleaned bucket from which the water is then decanted through a 150 μm mesh sieve. The contents of the sieve are transferred to a labeled sample jar and preserved as above. Following sampling and preservation of the sample and prior to the next sampling all equipment including the bailer, net and sieves must be rinsed clean with clean water via a spray bottle to remove any sediment and animals that may have remained attached to the sampling devices. This is to reduce the possibility of cross contamination of organisms (stygofauna or bacteria) or pollutants from one aquifer or bore to another.

3) The third (non standard) method was used on the “new house bore” only due to access restrictions with the other two methods. This involved pumping water through the house pump to the surface for approximately ten minutes, which removed an estimated two bore volumes. This was drained through a 150µl sieve. The resulting sediment was washed into a container and preserved in 100% ethanol. Three one litre samples were also collected during the collection for water chemistry analysis and processed using the same method. The pump and pipe work was not removed from the bore and therefore the entire water column was not sampled using either the bailer or phreatobiology net as in the other two sites.

4) The seepage pools were sampled using a 250µm gauge sieve. The sieve was passed through the water column and over the bottom substrate. The contents were decanted into a preserving jar, labeled and preserved in 100% ethanol.

Measurement of physico-chemical parameters

A full water chemistry sampling was conducted prior to the biological sampling with the results pending.

Identification

All samples are preserved in the field with 100% ethanol and returned to the laboratory where each sample was sorted or separated from the collected sediment under a stereomicroscope and stored in 100% alcohol. The preservation of specimens in 100% ethanol enables the specimens to be included in future DNA analysis studies.

Results

Four sites were sampled on the 27th of June 2012 with three registering the presence of fauna. The results are presented in the table below.

The old house bore again did not record any insitu fauna, ie. any fauna that would have been living within the groundwater. It did however, record several well decomposed incidental taxa that included a terrestrial snail, fragments of snake or large reptile skin, hair clumps of what appears to be a mouse (*Mus musculus*) and several bones of small vertebrates including a vertebra and a rib bone. The water appeared clean with a water depth comparable to the adjacent new house bore.

The “New House Bore (GW96324) recorded the same two main species recorded in the first survey. The species included a number of fragments of terrestrial fauna such as ants and beetles that have entered the bore and used it as a refuge due to the microclimate contained within bores or accidentally fell in through the small opening in the top of the bore. This result confirms that the two stygofauna (an Oligochaeta (worm) and an Acarina (mite)) species recorded early are active residents within the groundwater at this location. As the specimens of both species were intact and not showing any signs of decomposition they were alive at the time of collection.

The large number of ant remains still present within the “New House Bore” also confirms that they had and may still be occupying the interior of the bore casing although no new, less decomposed bodies were collected.

The “Far Bore (GW003587)” located approximately 900m to the north east of the house also recorded specimens of single species (an Oligochaete) of stygofauna once again confirming the results of the first survey.

The fourth site surveyed the small surface pools created by a small roadside groundwater seepage near the entrance to the Rockdale property. The species recorded here belong to the surface aquatic macroinvertebrates. These species are found in a variety of surface water bodies. They included two species of water beetles (Coleoptera) and two species of aquatic flies (Diptera). These groups all have flying adults that are able to easily disperse and colonize new surface aquatic habitats easily. There were no interstitial fauna recorded at this site. All of these species are predators except for the beetle family Hydraenidae, which is an algal grazer. The two fly species occupy the bottom sediments and have moderate tolerance to disturbance although the Tipulidae and the Hydraenidae are generally found in aquatic ecosystems of good water quality (Williams, 1981)

Fauna List

Locality Description	**Specimen Condition**	**Class**	**Order**	**Family**	**Habitat**
New house bore" - GW969324	Complete	**Annelida**	**Oligochaeta**	**Enchytraeidae**	***Phreatobite***
New house bore" - GW969324	Complete	**Araneae**	**Prostigmata**	**Halacaridae**	***Phreatobite***
"Old house bore" - GW038774	Well decomposed	Mollusca	Gastropoda	Land snail	Stygoxene
"Old house bore" - GW038774	Well decomposed	Vertebrata	Snake skin, mouse hair clumps, vertebra & rib bones	Vertebrata	Stygoxene
"Far Bore" - GW003587	Complete	**Annelida**	**Oligochaeta**	**Enchytraeidae**	***Phreatobite***
Roadside seep nr Rockdale.	Complete	Insecta	Coleoptera	Dytiscidae	Stygoxene
Roadside seep nr Rockdale.	Complete	Insecta	Coleoptera	Hydraenidae	Stygoxene

Roadside seep nr Rockdale.	Complete	Insecta	Diptera	Ceratopogonidae	Stygoxene
Roadside seep nr Rockdale.	Complete	Insecta	Diptera	Tipulidae	Stygoxene

*The bolded rows indicate those species that are regarded as being stygofauna.

Phreatobites

The presence of stygofauna was recorded at two of the bores. This included the "new House Bore" and the "far Bore" again. This is the first known record of stygofauna from the Pilliga Sands Formation and the first known records of stygofauna occurring within an apparently confined aquifer. It is a new and unexpected discovery as the aquifer type from which they were collected from is a confined/ semi confined aquifer and would normally preclude the existence of a subterranean ecosystem due to the low dissolved oxygen levels. They were also collected from a greater depth than is usual for stygofauna. The species composition of the site would indicate (and confirm) the existence of an unconsolidated aquifer (which is probably a palaeochannel of an ancient river bed) consisting of inter-bedded medium to course grained sands and gravels. The finding also indicates that the aquifer is only semi-confined with a connection to surface water ways or the upper unconfined aquifers. The aquifer will have moderate to high transmissivity and connectivity throughout the system and is likely to be connected with the associated river system in some locations. It will also support baseflow within local streams including the hyporheic zone, terrestrial vegetation through the upper porous (sandy) soils and shallow perched aquifers. The species also indicate moderate water quality. The presence of only Oligochaeta (worms) and Acarina (mites) and the absence of the normally dominant groups such as the crustaceans and molluscs, may be an indicator of either naturally moderate to high acidic groundwater conditions or a rapid change to these conditions that has eradicated the other more sensitive groups . These two groups have previously been found to be the only fauna within mild (ph 5-6) to highly acidic (ph 4-2) groundwater environments (see discussion).

Apart from the significance of the new find, it demonstrates a direct connectivity within the aquifer between the two bores ie. the new bore and far bore as well as a strong connection between the aquifer and the surface environments. That is, both bores appear to be connected to the same water source and the water source appears to be connected to the either or both the overlying shallow unconfined aquifers or the surface water bodies. The implication of this is that if the aquifer had been impacted by a general contamination it would be detected in both bores unless it is a localized, point source impact/ contamination or if the flow path precludes one or other bore. As the same fauna was detected in the two bores it is expected that any contaminants will also be detected in all bores.

The obligate groundwater fauna is characterised by the two Oligochaete Families, the Enchytraeidae and Naididae (from the previous survey) and the Astigmata water Mites. The Enchytraeidae is sa mall family of aquatic worms that are poorly known although they have been found in freshwater environments in Victoria, NSW and recently in groundwaters in Queensland. They are a poorly known group that requires further taxonomic work (Pinder & Brinkhurst, 1994). This is possibly the first record of this family in groundwaters in NSW.

The other species of stygofauna collected belongs to the Acarina or water mites. There is at least one species of water mite present belonging to the Family Halacaridae. Although subterranean water mites are classed as stygobites they have their highest biodiversity within the riverine, hyporheic zones and are classed as members of the "permanent hyporheos or the community that occurs within the deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They have however, been frequently found in unconsolidated aquifers coastal sandbed aquifers as well (Serov, unpublished data).

Water mites typically characterize the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment. *(*Boulton & Hancock, 2006, Gilbert, 1994, Humphreys. 2006, Serov, *et al*, 2011.). It is therefore unusual to find this group within the deep phreatic zone (deep groundwater). It is another indication that this aquifer is or has been connected to surface water sources as a discharge source where the discharge can be either point source springs or diffuse discharge through a moderate to course grained substrate such as sand or gravels (Gilbert, 1994). The presence of both of these species/groups within the phreatic or deep groundwater zone is therefore a direct indicator of groundwater connectivity not only between the "New House Bore" (GW969324) and the "Far Bore" (GW003587) but also between the local rivers systems and shallow unconfined aquifers.

Discussion

Knowledge of groundwater dependent ecosystems in eastern Australia is limited and patchy (E.g. Eberhard and Spate 1995, Thurgate et al 2001, Hancock 2002, 2004, Hancock & Boulton 2008, Hose et al 2005, SMEC 2006, Watts et al 2007). With the exception of a small number of studies in the sandstone environments of the Blue Mountains and the Upper Nepean areas (Hose 2008, SMEC, 2006) and the coastal sands of the mid North coast (Serov Unpublished data) and recent work in the Maules Creek and Namoi catchments (Serov et al, 2009, Thomlinson and Boulton, 2008) we are unaware of other studies of groundwater dependent ecosystems in porous sandstone aquifers in eastern Australia. Even internationally, studies of groundwater ecosystems in in porous rock are scarce.

The striking feature of the fauna collected in this series of surveys is the:
1) The presence of stygofauna at all;
2) The very low diversity of the stygofauna;
3) The fauna composition consisting of disturbance tolerant groups that have been found in other studies to be able to tolerate and preferential occupy habitats that have moderate to very high acidic conditions (3-5 ph units), very low dissolved oxygen, as well as being able to tolerate high salt loads.

This discussion will present a brief review of studies that have been conducted in NSW and general discussion of the use of stygofauna as indicators of environmental condition and change.

Drivers of groundwater ecology (Extract from Tomlinson, M., Boulton, A. 2008)
"Dissolved oxygen is a key environmental parameter in interstitial environments (Danielopol et al. 1994, Ward et al. 1998), although Malard and Hervant (1999) state that dissolved oxygen is not a limiting resource for all animals in groundwater, as faunal distribution in many studies does not match oxygen gradients, and further, not all groundwater habitats have low dissolved oxygen. However, Hahn (2006) found oxygen concentrations of one milligram per litre to be a critical limit for subsurface fauna.

Although a correlation between an easily-measured variable, such as dissolved oxygen, and a measure of community condition, such as species richness, would be ideal for the purpose of management, such a relationship is seldom apparent or consistent. Some studies show weak correlations between individual water quality variables and stygofaunal community composition or species distribution (Dumas et al. 2001, Hahn 2006, Castellarini et al. 2007b). Others studies illustrate contrasting results. For example, Mauclaire et al. (2000), studied a glacio-fluvial aquifer some 20 kilometres east of Lyon, France, found that, while bacterial activity and abundance were correlated with dissolved organic carbon (DOC) concentrations, faunal abundance was relatively homogeneous and only weakly correlated with DOC. However, in the same aquifer, but at sites closer to the Rhône River, Datry et al. (2005) reported that groundwater invertebrate assemblages were more abundant and diverse in sites artificially recharged with storm water compared with reference sites recharged by rainfall infiltration. Concentrations of dissolved organic carbon (DOC) were significantly higher in the recharge sites than in reference sites, where the thickness of the vadose zone was less than 10 meters in all sites, although mean concentrations of DOC were no greater than one milligram per litre at any site. In contrast, Masciopinto et al. (2006) reported that, in wells affected by artificial recharge of waste water in southern Italy, increased DOC at similar concentrations to the Datry study was associated with a decline in faunal biodiversity. DOC concentration in bedrock zone groundwater is typically quite low; Wetzel (2001) cites a median DOC content of groundwater as 0.65 milligrams per litre. This is comparable to a median value of 0.7 milligrams per litre recorded in a survey of 100 bores and springs in 27 states of the US (Kaplan and Newbold 2000).

These results might indicate differences in the quality rather than quantity of DOC (Sobczak and Findlay 2002). The bioavailability of DOC varies, and depends on its source and chemical composition. DOC consists of an extremely complex mix of organic compounds of varying structure and molecular weight. The more labile, simpler compounds are metabolized more rapidly by bacteria, although there is some evidence that more complex compounds support higher bacterial numbers over longer time periods (McDonald et al. 2007). Although organic matter supply may be necessary to sustain life, species richness, faunal community composition and spatial patterning are likely to be determined by multiple interacting factors: transmissivity, oxygen, dissolved organic carbon, redox and pH accounted for 52 per cent of the variability in faunal abundance in two French alluvial riverbank aquifers (Mauclaire and Gibert 2001). The conflicting results could also be due to the limitations of measuring water quality variables from pumped groundwater in which mixing effects mask small-scale heterogeneity in aquifer conditions (Strayer 1994).

Physico-chemical variables are also unlikely to be the sole determinants of species distributions and community assemblages. Dispersal constraints (Belyea and Lancaster 1999), such as hydrological disconnection (Sheldon and Thoms 2006), could isolate parent populations from which populations observed at any particular sampling time are derived. Lag effects are likely, so that the species presence and abundance data collected at any sampling time could result from previous rather than current physico chemical conditions. There might also be multiple points of population or community stability due to varying influences of different combinations of driving variables as environmental conditions change.

Chemical elements cycle through organisms and their abiotic environment in a series of reactions termed biogeochemical cycles (Clapham 1973, Brewer 1988) of which the carbon, nitrogen and phosphorus cycles are most pertinent from the perspective of this review. As most subterranean food webs are heterotrophic, transfer of carbon from particulate and dissolved organic matter to invertebrates is mediated by biofilms coating sediment particles and rock surfaces (Bärlocher and Murdoch 1989, Chafiq and Gibert 1996, Claret et al. 1998, Findlay and Sinsabaugh 1999). Biofilms transduce nutrients and energy (Battin et al. 2003) through processes including abiotic adsorption of molecules to the biofilm matrix and biological uptake by enzymatic hydrolysis. The bacterial uptake and repackaging of carbon and nutrients constitutes a microbial loop (Sherr and Sherr 1988) through which dissolved and particulate organic matter is made available to grazing protozoans and invertebrates. Carbon and nitrogen cycles are linked because most nitrogen in aquatic systems is bound in organic matter and is unavailable until it is mineralised to ammonium (NH4+) by the breakdown of organic matter (Duff and Triska 2000).

Microbially-mediated geochemical cycles involve the transfer of electrons between compounds. The rate and direction of geochemical cycling depends on the availability of electron donors and acceptors. Under aerobic conditions, oxygen acts as an electron acceptor, but under anaerobic conditions other compounds are used as donors in a reduction sequence of nitrate, manganese, iron, sulphate and carbon dioxide (Wetzel 2001). Different reactions occur in oxic and anoxic conditions, and the co-occurrence over small spatial scales of coupled processes contributes to the characteristic patchiness of SGDEs.

Microbially-mediated nitrogen cycling can occur as coupled nitrification-denitrification reactions along gradients of oxygenation (Baldwin and Mitchell 2000). Phosphorus dynamics are closely related to the cycling of iron, and therefore require anaerobiosis (Baldwin and Mitchell 2000). Rates of biogeochemical transformations are affected by factors such as temperature, pH or the presence of heavy metals.

Nitrification is the bacterial oxidation of ammonium ($NH4 +$). Ammonium is produced by excretion or the decomposition of organic matter. Denitrification is the bacterial reduction of nitrites and nitrates (NOx) either back to ammonium, or to nitrogen gas, which is then lost from the system. (Wetzel 2001)

The spatial availability of electron donors is determined by patterns of water flow, which in turn, are driven by hydrologic connectivity and hydraulic conductivity (Baker et al. 2000a), key factors in our proposed typology. Water is a transport agent (Bakalowicz 1994) that percolates through the vadose zone, or pulses through the hyporheic zone, to deliver dissolved and particulate organic matter and dissolved oxygen to biofilms. Microbial activity is typically highest near the source of recharge and declines along a gradient with distance from it (Kaplan and Newbold 2000). In aquifers connected to surface waters, the hyporheic zone is a crucial interface for fluxes of nutrients (Boulton et al. 1998, Dahm et al. 1998, Fischer et al. 2005).

Flood pulse inundation in a semiarid catchment in New Mexico altered rates of nutrient retention and organic matter processing in floodplain groundwater (Baker et al. 2000b). Local lateral exchange processes such as cycles of bank discharge and recharge can also play an important role in the timing and direction of nutrient processing in floodplains (Lamontagne et al. 2005b). In unconfined alluvial aquifers with fluctuating watertables, a significant portion of organic carbon metabolism can occur in oxic–anoxic cycles in the zone of intermittent saturation (Vinson et al. 2007).

Hydraulic conductivity also determines the availability of electron donors for biogeochemical processes. Interstitial storage of dissolved organic matter and the availability of dissolved oxygen are influenced by particle size and pore size (Maridet et al. 1996). Larger particle size and high porosity allow higher flows and higher availability of oxygen but reduce entrapment and retention of nutrients.

In fractured rock and karstic aquifers, uneven porosity due to the distribution of fissures, fractures and solutional conduits creates preferential flow paths, which create spatial heterogeneity in biogeochemical cycling (Ayraud et al. 2006). Spatial and temporal variability in groundwater flow paths is also influenced by surface microtopography (Pfeiffer et al. 2006) and by stream channel morphology (Dahm et al. 1998). The functional diversity of subsurface ecological processes is thus determined by shifting gradients in oxygen, nutrients and physico-chemical conditions, which create pockets of oxia and anoxia, nitrification and denitrification.

As in other ecosystems, heterogeneity in subsurface environments is a critical determinant of ecosystem function (McCarty et al. 2007). Disturbance to the groundwater regime, including disruption of patterns of hydrological connectivity (Baker et al. 2000b) and sediment wetting/drying cycles (Baldwin and Mitchell 2000), might potentially alter spatial and temporal patterns of groundwater flow, flux and quality, with implications for rates of organic matter mineralisation and nutrient cycling. Pumping from a fractured rock aquifer in north-west France caused physical disturbance to water flux in the aquifer, reduced groundwater residence time and subsequent drastic modification to the water chemistry resulting in less active biogeochemical processes (Ayraud et al. 2006).

Prolonged desiccation of sediments caused by watertable drawdown is likely to alter the balance between aerobic and anaerobic processes and change the composition of microbial populations, reducing the incidence or rate of anaerobic metabolism. Fischer et al. (2005) concluded that carbon and nitrogen cycling in hyporheic sediments were central to the metabolism of a large lowland river in Germany, and designated the hyporheic zone as the ‘river’s liver’. Disturbance to the groundwater regime can alter the rate and nature of subsurface ecological processes, resulting in reduced availability of carbon, nitrogen and phosphorus, with flow-on effects for biodiversity and ecosystem services, not only within the aquifer, but also in connected ecosystems including rivers, riparian zones and estuaries.”

Changes in biological diversity
The quantity and quality of the various kinds of pressures on GW systems are able to induce drastic changes in the diversity of organisms living underground. Two types of such changes can impact a aquifers water quality parameters and its associated ecosystem, namely (1) decline in GW-dwelling organism populations leading to species extinctions and (2) penetration of alien species belonging to surface-water communities. Both processes determine changes in the functioning of GW systems, generally reducing the efficiency of some ecosystem processes.

Microbes are highly abundant in subsurface waters. Although little is yet known about microbial diversity, contamination in almost every case causes a shift in the composition of the microbial community (Bekins *et al.* 1999; Ludvigsen *et al.* 1999; Rooney-Varga *et al.* 1999). Loading of the aquifer by hazardous chemicals also leads to a decrease or increase in abundance (Haack & Bekins 2000). Changes in abundance and diversity of GW organisms are also suggested in the case of overpumping, which also induces structural changes in the water-saturated habitat.

A reduction in the self-purification potential and therefore water quality was observed within the bank filtration area along the Danube at Vienna after the major part of the sediment-associated microbial biomass was removed together with the habitat, namely the fine sediment fraction, by overpumping of the water (Frischhertz 1979). Intensive withdrawal of GW for irrigation purposes leads to local decline in animal communities as in coastal aquifers of Greece or alluvial aquifers in southern France (Danielopol 1981; Dumas 2002). The overexploitation of the GW of the Balcones Fault Zone in the Edwards artesian aquifer (Texas) endangers one of the world's most species-rich subterranean assemblages, including many endemic stygobitic crustacean, fish and amphibian species (Longley 1992). Plans for dewatering of local confined aquifers for ore exploitation in Western Australia could lead to the extinction of a unique subterranean crustacean fauna of great scientific value (Humphreys 1999). Organic loading of the subterranean environment may lead, to extinctions of stygobitic animals (Elliott 2000).

Apparently, subterranean animals are sensitive to toxic chemicals like pesticides (chlorophenols), various salts (potassium chloride, potassium nitrate) and heavy metals (Notenboom *et al*. 1992; Mösslacher 2000). In organically polluted habitats located close to surface water there is also potential invasion of cosmopolitan surface dwelling species, which outcompete or temporarily replace the stygobites. Such is the case with a karstic stygobitic fauna in southern France near Montpellier, where the arrival of organic liquid waste caused the colonization of the subsurface system by ubiquitous surface-dwelling species like the tubificid worm *Tubifex tubifex* or the crustacean copepod *Acanthocyclops robustus* (Malard 2001). At the unimpacted sites, many stygobitic species continued to exist.

Groundwater habitats along large rivers, like the Rhône or the Danube, which are polluted not only by organic matter but also by toxic heavy metals, display low biological diversity and are represented mainly by surface-dwelling taxa. The interstitial fauna of the riverbanks in the city of Lyon represent such a case (Gibert *et al.* 1995). River regulation combined with the negative effect of organic pollution alter GW habitats; for example, through stronger siltation and oxygen depletion of the interstitial voids, the free-moving crustaceans (such as stygobitic copepods and isopods) are replaced by assemblages dominated by epigean animals such as nematodes and oligochaetes (Danielopol 1976, 1983). Arid climates like those prevailing in Northern Africa or in Arizona (USA), determine the drying of streams and the interruption of water infiltration into adjacent-shallow subsurface areas. The fauna of hyporheic habitats in such cases is represented by a few epigean species that can survive the dry period until the next rewetting (Boulton & Stanley 1995).

Survey data from studies from within eastern Australia provide useful insight into the characteristics of Australian and more, specifically, eastern Australian groundwater ecosystems. The first study I will highlight was conducted by Jiwan & Serov (2002) on the coastal sands aquifers of the Lime Burners creek area north of Port Macquarie. This is a fine grained, unconfined aquifer that has direct links with Maria River estuary. This study revealed a stygofauna community dominated by Oligochaetes. The water chemistry is characterised by low to very low pH ranging from 6.39 down to 3.01 with most values averaging between 3-4 ph units. Salinity levels were generally very high ranging from 43958 µS to as low as 101 µS and averaging between 5000-14000 µS. The high values were associated with bores in close proximity to the estuary. Dissolve oxygen in the groundwater associated oligochaete and mites with ranged from 3.42 to 0.34 mg/l with an average range from 1.0-2.0 mg/l.

Serov et al, 2009 highlighted the use of stygofauna community composition as an indicator of water quality/water chemistry change within the Maules Creek Catchment within the Naomi Valley.

Extensive groundwater abstractions have led to decreasing groundwater levels in many aquifers around the world, particularly in semi-arid catchments. This abstraction can have severe impacts on flow in streams that are hydraulically connected to the aquifers being pumped. These impacts range from a reduction in base flow to a change from a gaining to a loosing stream or to a complete cessation of flow. The consequences in terms of stream flow are obvious, particular in regards to the ecology of the instream surface water ecosystems. In recent years it has been realised that these changes may also cause changes in groundwater chemistry. e.g. dissolved and particulate organic matter in the stream water may percolate into the streambed and the aquifer and may lead to a consumption of oxygen and reducing conditions. However, the consequences on the groundwater ecosystem in the vicinity of the stream are largely unknown.

All aerobic organisms require a specific range of conditions in order to survive and function including a physical living space, an energy source or food, and oxygen. If these specific parameters for life are changed then a change to the community structure of an ecosystem is to be anticipated. Surface aquatic invertebrate communities for example have long been recognised as being ideally suited for the assessment of environmental health and condition in riverine ecosystems as they are 1) diverse, 2) occupy every available niche within a water body, 3) are one of the major contributors to the processing of energy through an ecosystem and 4) responds directly to physico-chemical changes within the aquatic environment. 5) The composition of these communities reliably reflects both natural and threatening processes operating within a catchment. 6) The specific range of habitat requirements of each species dictate the distribution of each component of both the species and community levels, which 7) enables their diversity to be used as an indicator of a water body's connectivity and condition within a catchment.

The subsurface stygofauna communities possess all of the above features and more. It has long been acknowledged that they are intrinsically adapted to their specialised environment both in terms of their specialised morphology, physiologies, habitat requriements and long life cycles. Therefore the link between flow conditions, geochemical conditions and the abundance, diversity and composition of the stygofauna community should be anticipated and utilised. There have, however, been few studies that have tried to determine the environmental requirements of these communties and fewer studies that have used them as indicators of hydrological groundwater-surface water connectivity or their responses to environmental change. Riverine aquifers have been refered to as Macro Ecosystems due to the aquatic linkages within between the phreatic, hyporheic and epigean environments.

These linkages were investigated along a 1 km reach of Maules Creek, in semi-arid western New South Wales, Australia. Maules Creek is a small, essentially, ephemeral, tributary catchment of the Namoi River. The investigation area includes two tributaries, Maules Creek and Horse Arm Creek that join upstream of Elfin Crossing (a road crossing) and extend below the crossing. This reach was chosen because of the presence of a small number of pools that were reported permanent (P. Laird, pers comm..), in an otherwise dry creek system. A preliminary physicochemical investigation suggested the pools were the result of upwelling groundwater in the up-stream section. The groundwater connection was also strongly indicated by the presence of obligate groundwater species being found in a preliminary survey of the shallow hyporheic zone.

Vertical streambed profiles of hydrochemistry and stygofauna were collected at five different locations along the creek. Hydrochemistry were sampled from the streambed and down to 1.7 m at 10 to 30 cm intervals using a 10 mm diameter steel probe with a 50 mm perforated screen at the end. Pore water samples were pumped to the surface using a 60 ml syringe and O_2, pH, EC and Eh were measured in an inline flow cell. Fe^{2+} and alkalinity was analysed in the field, whereas samples for major and minor cations, anions and DOC were preserved and analysed at a later date. Streambed (hyporheic) fauna was sampled next to the chemical profiles at 20 cm intervals using a 20 mm diameter open ended steel pipe with perforations in the lower 10 cm. 30 L of pore water, fine sediments and organisms were pumped to the surface at each interval using a hand bilge pump and sieved through a 150 µm sieve. The retained fraction was washed poured into sample vials and preserved with 100% ethanol for later species identification.

The results of the stygofauna sampling demonstrated a heterogenous and complex ecosystem with relatively consistent downstream gradients, in terms of overall numbers of animals, number of species, composition of the community and the size of the individual specimens from the upper sites to the lower sites. The total number of specimens and number of species and size of specimens were high at the three upstream sites whereas specimen numbers and species diversity and size decreased along the river towards the lower sites. The upstream sites were almost exclusively dominated by a rich, abundant, endemic stygofaunal or obligate groundwater faunal community throughout the substrate sampling column. This suggests that this is a very stable, long term environment, both hydrologically and chemically, with an active groundwater discharge. The stygofauna community consisted predominantly of crustaceans and a small number of other groups including Oligochaetes and Flat worms. Within the crustaceans, the dominant taxa consisted of stygobitic Copepoda, Syncarida and Amphipoda and Ostracoda. All obligate stygofauna are blind and colourless. The middle sites in both streams recorded a mixture of the above stygofauna with a number of surface aquatic macroinvertebrates indicating a mixing of groundwater/surface waters to depths of at least 100cm although most species were confined to the upper 40cm. The lower site below Elfin crossing were essentially devoid of life to the depth of the sampling except for an occasional terrestrial soil invertebrate or oligochaete suggesting that this is an unstable, highly fluctuating environment.

These changes are directly reflected in the changes in water chemistry results. The major ion distributions showed constant levels from the stream surface water and down into the streambed at all five sites revealing a hydraulic contact between the stream and the streambed sediments. Dissolved redox sensitive chemical species (O_2, NO_3^-, Fe^{2+} and Mn^{2+}) revealed more complex patterns. Generally the streambed pore waters became more reduced in a downstream direction. The three upstream sites were generally oxic to slightly anoxic containing either O_2 or NO_3^- throughout the profiles. The two downstream sites showed a more pronounced redox sequence over depth with O_2 in the upper 20-40 cm replaced by NO_3^- and finally by Mn^{2+} and Fe^{2+} deeper in the profile. The DOC was surprisingly uniform between all five sites and over depth (~ 1.0 mg C/L) and DOC is clearly not in itself a good indicator of stygofauna abundance or diversity.

Surprisingly, there was a weak inverse correlation between specimen numbers (or species diversity) and dissolved O_2 concentrations. Frequently high specimen numbers (and species diversity) were found at sites with low dissolved O_2 (< 0.14 mg/L), indicating that a number of these stygofauna species can thrive or function at low dissolved O_2 levels or even at sub-oxic conditions. One of the specialised physiological features of stygofauna, particularly the crustaceans, is an adaptation to living in low dissolved O_2 environments that would normally preclude surface water invertebrates. Consequently dissolved O_2 seems to be a poor quality indicator for stygofauna abundance and biodiversity. A much clearer inverse correlation was found between specimen numbers and diversity and pore water concentrations of Fe^{2+} and Mn^{2+}. Specimens were rarely found when Fe^{2+} and Mn^{2+} concentrations surpassed 0.1 and 0.5 mg/L, respectively. This suggests that higher invertebrate ecosystem functioning seems to break down only when the system becomes truly anoxic i.e. when iron- and manganese-oxides are being reduced. In turn the distribution of Fe^{2+} and Mn^{2+} seems to correlate to the overall flow patterns of the system with upwelling of relative oxic groundwater in the upper reaches with relatively fast residence times in the streambed sediments preventing the development of reducing conditions ie. a consistent groundwater flow through a porous medium – groundwater discharge zone. In contrast, the lower reaches experiences infiltration of surface water into the streambed presumably containing a higher load of reactive organic matter and fine sediments that glogs the pore spaces of the sediments thus slowing the flow rate that in turn, triggers a sequence of redox reactions. Thus the data tends to suggest that changes in catchment water management such as reducing baseflow through abstraction in a hydraulically connected system can hugely impact streambed and aquifer ecosystems by inducing changes in water chemistry.

This study highlights the direct correlation between water management, water chemistry and ecosystem function and highlights some of the relationships between groundwater and surface water systems in hydraulically connected environments. The study also indicates that stygofauna can be used as biological tracers of groundwater discharges. The results of this study have major implications for the management of both surface ecosystems and groundwater ecosystems.

Management

This 2nd survey once again identified the presence of a significant subterranean fauna within this aquifer, notably within Bores GW969324 and GW003587. This bore and the fauna within it represent a biodiversity hotspot that indicates moderate to good water quality, connectivity with the adjacent river system and persistent longevity of the community (Danielopol, *et al*, 2003, Serov, *et al*, 2011.). The presence of these species also strongly suggests there may have been a water chemistry change that could have adversely impacted the stygofauna community significantly reducing by the eradication of the normally dominant crustacean groups. The community within this aquifer may therefore have had or has in other parts of the aquifer a higher biodiversity covering a larger area within suitable habitats than have not as yet been impacted..

Key points from the Biological Investigation so far

- All three bores appear to be accessing the same water source/aquifer based on the presence of the same stygofauna species within the “New House Bore” and “Far Bore”. It is not known why at this point stygofauna were not collected within the “old Bore”, except that it is likely to be a connectivity issue in terms of substrate porosity. As the sampling has been completed twice and there is still no fauna collected it is reasonable to conclude that this section of the aquifer has an impervious boundary that precluded the movement of stygofauna. It is also quite a common occurrence for very close bores that appear to be drawing from the same aquifer to have completely different survey results due to a number of causes such as the complexity of the subterranean environments, including slightly different water chemistry or a lack of appropriate pore space (fine sediment lenses) to allow the invertebrate to pass through the matrix.
- Stygofauna are present within the water bearing zone
- Stygofauna indicate moderate to high water quality across the aquifer i.e. overall good aquifer health.
- The ant, frog, snake and mammal remains appear to be incidental and have arrived in the bores by accident or used the bores as a refuge due to a more suitable microclimate (higher humidity) and may be a symptom and not the cause of the poor water quality experienced in March. The large accumulation of ants and smaller numbers of frog bones are all well decomposed, which could have occurred at the same time but it is not possible to determine. However, given the fact that not new, (non decomposed) ant

bodies were collected in the second survey it can be suggested that the large number of ants within the new bore is the result of an asphyxia or fumigation event.

- As there was no active monitoring of water levels or water chemistry occurring at the time of either of the episodes of water quality decline any evidence collected may only be circumstantial..
- It is therefore advised that an ongoing monitoring program be established using insitu water level, water quality and air quality (in bore) probes be installed.
- It is also suggested that a seismic investigation be included in the analysis to determine if there has been any destabilization of the unconsolidated sediments within the aquifer from either earth quakes/tremors or the result of fracking at the time of the events. Although the Pilliga Sands Formation is expected to be quite stable in terms of geological activity, movement of the unconsolidated sands and gravels may have caused a mobilization of entrapped organic materials causing a release of hydrogen sulphides, volatiles and other organic components. If this is the case the water quality should continue to improve as the beds stabilize and the mobilized material is filtered out within the matrix and entrapped again and the volatiles have dispersed. If the change is the result a contamination event it is expected that it will have also occurred in other bores on the property as well as adjacent properties. If this is the case water chemistry analysis of all effected bores may show a consistent contaminant signature.

Therefore the threat posed to stygofauna communities by proposed mining activities at within the Pilliga forest area is considered to be high.

Mining developments, in which stygofauna are considered to be a relevant environmental factor, need to be closely assessed with respect to the extent of the proposed groundwater drawdown zone and the likely impacts on groundwater quality. Both of these activities, over time, may cause prospective stygofauna habitat to be degraded or lost with the potential for significant impact on groundwater communities. Stygofauna are able to tolerate natural fluctuations in water parameters such as water level, electrical conductivity, and temperature, and this has been demonstrated experimentally (Tomlinson *unpublished*) for stygofaunal amphipods, copepods, and syncarids. However, changes outside the natural range of water quality, water chemistry and levels such as rapid drawdown or changes to water chemistry such as a pollution plumes are likely to have significant impacts on the community composition, biodiversity and overall sustainability of the community.

Groundwater communities also require links to the surface environment to provide organic matter and oxygen. If that linkage is broken or disrupted, the stygofauna community in the area affected could decline over time. A high degree of endemism can occur in aquifers, even within the same system or between adjacent systems (Hancock and Boulton 2008). However, providing there is sufficient hydrological connectivity within and along the flow path of the aquifer, and the physico-chemical conditions are suitable and remain stable, the distribution of species will not be restricted to small parts of an aquifer.

Cumulative Impacts

Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary significantly, depending on factors such as the type of activity performed, the proximity of activities to each other and the characteristics of the surrounding natural, social and economic environments (Brereton and Moran, 2008). They may also be caused by the synergistic and antagonistic effects of different individual activities, as well as the temporal or spatial characteristics of the activities. Importantly, cumulative effects are not necessarily just additive (SKM, 2010).

The proposed CSG activities in a region are growing thus increasing the potential for an impact on the underlying aquifers. The implication of multiple mining actives in one region is that impacts may overlap and result in larger impacts than would be expected for a single mining operation (cumulative effects).

Suggested Actions

The recommendation of this report is therefore to monitor the aquifers for the spatial and temporal changes in parameters of the stygofauna, water quality and water quantity during the construction, operational and post-mining phases of both projects, both within and outside the potential zone of impact from the current and proposed CSG and other mining activities.

The suggested next stage is:

1) An examination of water quality and subterranean ecosystem health from as many adjacent bores as possible. Even if no contamination is found it will provide a benchmarked network of bores for future comparisons.

2) The establishment of a monitoring program on both the Rockdale property and surrounding properties in order to ensure appropriate measurements are recorded if this event occurs again. It is much easier to determine cause and effect if there is reliable time series data before and after an impact.

The sites that have been surveyed and analysised for water chemistry should be regarded as the first benchmarked sites for this aquifer in the area. Benchmarking is necessary and essential in order to characterize the natural distribution and environmental ranges within the aquifer and therefore the requirements of this subterranean ecosystem and the overall health of the aquifer for human consumption. The aquifer should be characterised by:

- The structure/lithology of the aquifer by obtaining bore log/works details of the bores;
- The full water chemistry and water levels of the groundwater (including temperature) over time to establish the natural annual ranges and seasonal fluctuations;
- The aquifer flow paths to determine the connectivity (gaining or loosing) with the associated river above and below the potential area of impact.
- Identify the obligate stygofauna to species (those listed as phreatobites) to determine levels of endemicity of the stygofauna community within the aquifer as this community is the most disturbance sensitive environmental indicators for changes in aquifer conditions;
- Conduct further surveys in other bores and hyporheic zone of the associated river, if available, within this aquifer and adjacent aquifers to determine the range of the species.
- Identify other groundwater dependent ecosystems in the area such as springs and groundwater discharge zones within nearby steams.
- Conduct water level mapping across the site/aquifer to determine the linkages with the river systems and other users of the groundwater source such as the local community through the need for stock and domestic water and other potential GDE’s such as terrestrial vegetation or wetland communities that also rely on consistent water levels and water quality.

References

Bou C, 1974. Les méthodes de recolte dans les eaux souterrainnes interstitielles. Annales de Spéologie, 29, 4, 611–619.

Datry T, Malard F, Gibert J, 2005. Response of invertebrate assemblages to increased groundwater recharge rates in a phreatic aquifer. Journal of the North American Benthological Society, 24, 3, 461–477.

Danielopol, D.L., Griebler, C., Gunatilaka, A and Notenboom, J. 2003. Present state and future prospects for groundwater ecosystems. *Environmental Conservation* 30 (2): 104–130.

Gibert, J., Danielopol, D., & Stanford, J.A. (Eds), 1994, Groundwater Ecology, Academic Press.

Hahn H J, 2006. A first approach to a quantitative ecological assessment of groundwater Habitats. The GW-Fauna-Index. Limnologica 36, 2, 119–137.

Hervant F, Renault D (2002) Long-term fasting and realimentation in hypogean and epigean isopods: a proposed adaptive strategy for groundwater organisms. *Journal of Experimental Biology* 205, 2079-2087.

Hose, G, 2008. Stygofauna baseline assessment for kangaloon borefield investigationssouthern highlands nsw. Access Macquarie Limited.

Jiwan, J., Serov, P. 2002. Groundwater Dependent Ecosystems of the Maria River, Coastal Sandbeds. Unpublished report, Department of land and Water Conservation.

Malard F, Hervant F, 1999. Oxygen supply and the adaptations of animals in groundwater. Freshwater Biology 41, 1–30.

Pinder, A. 2001. Notes on the diversity and distribution of Australian Naididae and Phreodrilidae (Oligochaeta: Annelida). Hydrobiologia. 463: 49-64.

Pinder, A.M. & Brinkhurst, R.O. (1994) *A preliminary guide to the identification of microdrile oligochaetes of Australian freshwaters.* Identification Guide No. 1, Cooperative Research Centre for Freshwater Ecology: Albury.

Serov, P., Kuginis, L., Byrne, G.T., Williams, J.P. 2012. Risk Assessment Guidelines for Groundwater Dependent Ecosystems in NSW. In preparation, NSW Office of Water.

Serov, P.,, Anderson, M.S., Acworth , R.I., and Berhane, D. 2009. Bio-Indicators of Riverine Groundwater Exchange Zones: Biological Tracers of Groundwater-Surface Water Connectivity and the environmental consequences of Groundwater Abstraction. Presented at Australian Society of Limnology conference, Alice Springs, 2009.

Thomlinson and Boulton, 2008. Subsurface Groundwater Dependent Ecosystems: a review of their biodiversity, ecological processes and ecosystem services. University of New England. Waterlines Occasional Paper No 8, October 2008. National Water Commission.

Williams, W.D. 1981. Australian Freshwater Life. The Invertebrates of Australian Inland Waters. Macmillan Education Australia Pty Ltd. Melbourne.

The Third Baseline Stygofauna Survey Report for 'Rockdale' and the Pilliga Forest.

March 2013.

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The Third Baseline Stygofauna Survey Report for Rockdale June 2012.

Introduction

This report presents the results of the 3rd biological assessment of the groundwater ecosystems of the Pilliga sandstone aquifer beneath the Rockdale pastoral property within the Pilliga Forest area south of Narrabri. The report also includes the baseline results of 3 other locations in the vicinity of Rockdale, including two nearby properties and an examination of pools and the hyporheic zone of a section of Bohena Creek. The investigation is being conducted to confirm the presence of stygofauna within confined/semi-confined aquifer within the Pilliga Sandstone formation and continue the examination of the decline in water quality experienced by the property owner. The owner of Rockdale commissioned StygoEcologia to conduct a biological survey of the bores on the property and nearby as an indicator of the groundwater condition to compliment the water chemistry analysis conducted in the same period Six sites were sampled including 4 bores and 2 river sampled on the 13th March 2013 for stygofauna and possible biological contamination using rapid assessment techniques.

Study Sites

The sites surveyed during this round of sampling included: two of the previously sampled bores, the ‘New House Bore’ and the ‘Far Bore’; a domestic bore on ‘Monbrook’; a domestic bore on a property off Westport Road; and two samples from the midpoint along Bohena Creek from pools and the hyporheic zone.

Locality	No. species
"Far Bore" - GW003587, Rockdale, Pilliga, 13/3/2013	3
New house bore" - GW969324, Rockdale, Pilliga, 13/3/2013	1
Monbrook' Property Bore, Yarrie Lake Rd, Pilliga, 13/3/2013	1
Barry's Property bore. Westport Rd. Pilliga13/3/2013	1
Mond's Crossing, pools in riverbed, Bohena Creek, Pilliga, 13/3/2013	7
Mond's Crossing, hyporheic, riverbed, Bohena Creek, Pilliga, 13/3/2013	4

Table 1. Locations surveyed on 13th March 2013.

Method

The bores were sampled site using two standardised methods.

1) The first technique is the Phreatobiology Net, which was used only at the ‘Far Bore’. This is the standard technique that has been used successfully overseas and in Australia (Bou, 1974). The method used conforms to WA guideline [2003 & 2007] requirements. This method involves using a weighted long haul or plankton net with a 150 µm mesh. Sampling consisted of dropping the net down to the bottom of the bore and taking at least three consecutive hauls from the entire water column at each bore. Upon removal from the bore the net is washed of sediment and animals and the contents of the sampling jar (the weighted container at the bottom of the net) are decanted through a 150 µm mesh sieve. The contents of the sieve are then transferred to a labeled sample jar and preserved with 100% ethanol.

2) The second method was used on the other three bores only due to access restrictions with the other method. This involved pumping water through the bore pump to the surface for approximately ten minutes. This removed an estimated two bore volumes. The water was drained through a 150µl sieve. The resulting sediment was washed into a container and preserved in 100% ethanol.

3) Bohena Creek.
The surface and subsurface waters within Bohena Creek was sampled as a baseline investigation to determine the biodiversity within the available habitats. Although surface water is generally absent several pools were located at the Mond's Crossing which is approximately mid-way along the stream and downstream of the CSG operations. Subsurface water was also located at approximately 30cm depth. These habitats were sampled using the following methods.
a) The Pools. The seepage pools were sampled using a 150µm gauge sieve. The sieve was passed through the water column and over the bottom substrate. The contents were decanted into a preserving jar, labeled and preserved in 100% ethanol.
b) The Hyporheic Zone. The subsurface water within the hyporheic zone was sampled by digging a pit into the sand bed until sufficient water was located. The resultant pool was sampled by collecting the seepage water into a container and filtering the water through a 150µm gauge sieve. The contents were decanted into a preserving jar, labeled and preserved in 100% ethanol.

Measurement of physico-chemical parameters
A full water chemistry sampling was conducted prior to the biological sampling for the bores with the results pending.

Identification
All samples are preserved in the field with 100% ethanol and returned to the laboratory where each sample was sorted or separated from the collected sediment under a stereomicroscope and stored in 100% alcohol.

Results
Fauna List

Locality	Class	Order	Family	Genus	Habitus	Habitat	No.
"Far Bore" - GW003587, Rockdale, 13/3/2013	**Acarina**	**Prostigmata**	**Halacaridae**	***ND***	**Phreatobite**	**Interstitial**	**29**
"Far Bore" - GW003587, Rockdale, 13/3/2013	Insecta	Collembola	ND	*ND*	Edaphobite	Interstitial	1
"Far Bore" - GW003587, Rockdale, 13/3/2013	Insecta	Psocoptera	ND	*ND*	Edaphobite	Interstitial	2
New house bore" - GW969324, Rockdale, 13/3/2013	**Acarina**	**Prostigmata**	**Halacaridae**	***ND***	**Phreatobite**	**Interstitial**	**29**
Monbrook' Property	**Acarina**	**Prostigmata**	**Halacaridae**	***ND***	**Phreatobite**	**Interstitial**	**28**
Barry's Property bore. 13/3/2013	**Acarina**	**Prostigmata**	**Halacaridae**	***ND***	**Phreatobite**	**Interstitial**	**3**
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Crustacea	Copepoda/Cyclopoida	Cyclopidae	*ND*	Phreatobite	Interstitial	36
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Crustacea	Copepoda/Calanoida	ND	*ND*	Pelagic	Surface pools	8
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Insecta	Diptera	Ceratopogonidae	*Bezzia*	Lotic	interstitial	4
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Crustacea	Cladocera	Daphniidae	*ND*	Lotic	Surface pools	2
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Crustacea	Pleocyemata	Palaemonidae	*Macrobrachium*	Lotic	Surface pools	2
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Insecta	Hemiptera	Corixidae	*Micronecta*	Lotic	Surface pools	1
Mond's Crossing, pools in riverbed, Bohena Creek.13/3/2013	Vertebrata	Fish	Poeciliidae	*Gambusia*	Lotic	Surface pools	1
Mond's Crossing, hyporheic, riverbed, Bohena Creek.13/3/2013	Insecta	Coleoptera	ND	*ND*	Stygoxene	Interstitial	3
Mond's Crossing, hyporheic, riverbed, Bohena Creek.13/3/2013	Insecta	Diptera	Chironomidae	*Tanypodinae*	Stygoxene	Interstitial	2
Mond's Crossing, hyporheic, riverbed, Bohena Creek.13/3/2013	Insecta	Collembola sp.1	ND	*ND*	Stygoxene	Interstitial	2
Mond's Crossing, hyporheic, riverbed, Bohena Creek.13/3/2013	Insecta	Collembola sp.2	ND	*ND*	Stygoxene	Interstitial	14

Table 2. Species List. *The bolded rows indicate those species that are regarded as being stygofauna.

Six sites were sampled on the 13th of March 203 with 4 registering the presence of fauna. The results are presented in the table below.

The old house bore was not sampled again as it did not record any insitu fauna, ie. any fauna that would have been living within the groundwater, on two previous occasions.

The “New House Bore (GW96324) recorded only one species during this survey, with an absence of the Oligochaeta. The sample again included aquatic mites belonging to the Prostigmata as the sole living species within the bore as well a number of fragments of terrestrial fauna such as ants and beetles. It is again suggested that terrestrial species have entered the bore and used it as a refuge due to the microclimate contained within bores or accidentally fell in through the small opening in the top of the bore. This result confirms that the Acarina (mites) species recorded early are active residents within the groundwater at this location. As the specimens were intact and not showing any signs of decomposition they were alive at the time of collection. The absence of the Oligochaeta is notable considering it was recorded in two previous surveys.

The large number of ant remains still present within the “New House Bore” also confirms that they had and may still be occupying the interior of the bore casing although no new, less decomposed bodies were collected.

The “Far Bore (GW003587)” located approximately 900m to the north east of the house also recorded the first specimens of a single species of Prostigmata (aquatic mite) for this location and the absence of the Oligochaeta. Once again the absence of the Oligochaeta is notable considering it was recorded in two previous surveys. This result is awaiting confirmation as the bailer that was used as a second method to sample the benthos within the bore sump on the previous surveys became stuck in the bore and it yet to be retrieved.

The other two bores also recorded the presence of only the Prostigmata mites. All bores contained clear water, numerous decomposed ant and general insect parts. The Monbrook site also contained numerous white, colloidal material considered to be the remaining fat deposits from the insects. This white material was not present within the Rockdale bores during this survey. The only other variation in the material collected from the bores was an amount of rust and iron precipitate present within the bore at Westport Rd that was not recorded at the other sites.

The fifth site surveyed included the small surface pools in the middle of the dry sand bed stream located on the downstream side of the road causeway. These pools are created by flow gauging a depression in the streambed that was deeper than the subsurface groundwater flow through the hyporheic zone. They are in effect window pools into shallow groundwater. The species recorded here belong to the surface aquatic macroinvertebrates and one specimen of the fish species, *Gambusia holbrooki*. These species are found in a variety of surface water bodies. They included two species of the microcrustacean Copepoda and Cladocera (water fleas), one species of aquatic flies (Diptera), one species of aquatic Hemiptera (true bugs) and juvenile shrimp. The only interstitial fauna recorded at this site includes the aquatic fly family Ceratopogonidae and the Cyclopoid Copepoda. All species collected are generally found in aquatic ecosystems of good water quality (Williams, 1981).

The last site surveyed was the hyporheic zone approximately 20m upstream of the surface pools. The seepage water from the pool contained a depauperate fauna of interstitial aquatic insects. The fauna included specimens of larval beetle, fly larvae and two species of Collembola or Springtails. All species collected are commonly found in the interstitial habitats of sand bed streams.

Phreatobites

The presence of stygofauna was recorded at all four of the bores. This included repeat results for aquatic mites at the “new House Bore” and new records for mites at the “Far Bore” and two new locations away from the original ‘Rockdale’ area. This confirms that stygofauna are present across at least this area of the aquifer and that there is connectivity within unconsolidated layers (a palaeochannel) consisting of inter-bedded medium to course grained sands and gravels, between the sites. The finding also indicates that the aquifer is only semi-confined with a connection to surface waterways and/or the upper unconfined aquifers. The species recorded also indicate moderate to high water quality. The presence of only Acarina (mites) and the absence of the previous collected Oligochaeta or the normally dominant groups such as the crustaceans and molluscs, may be an indicator of either naturally moderate to high acidic groundwater conditions or a rapid change to the natural conditions that has eradicated the other more sensitive groups . As mentioned in previous reports these two groups have previously been found to be the only fauna within mild (ph 5-6) to highly acidic (ph 4-2) groundwater environments (see discussion in previous report – Second Baseline Survey).

Apart from the confirmation of the original finding of aquatic mites, it also demonstrates a direct connectivity within the aquifer between the four bores and a strong connection between the aquifer and the surface environments. That is, all bores appear to be connected to the same water source and the water source appears to be connected to the either or both the overlying shallow unconfined aquifers or the surface water bodies.

The obligate groundwater fauna collected during this survey is characterised solely by the Prostigmata water Mites. There is at least one species of water mite present belonging to the Family Halacaridae. Although subterranean water mites are classed as stygobites they have their highest biodiversity within the riverine, hyporheic zones and are classed as members of the "permanent hyporheos or the community that occurs within the deep sand and gravel beds associated with areas of groundwater discharge (Gilbert, 1994). They have, however, been frequently found in unconsolidated aquifers coastal sandbed aquifers as well (Serov, unpublished data). Water mites typically characterise the transition zone between the temporary or shallow hyporheic ecozone and the groundwater hypogean environment. *(*Gilbert, 1994, Serov, *et al*, 2012.). It is therefore unusual to find this group within the deep phreatic zone (deep groundwater). This is another indication that this aquifer is or has been connected to surface water sources as a recharge/discharge source where the connection can be either point source springs or diffuse discharge through a moderate to course grained substrate such as sand or gravels (Gilbert, 1994). The presence of this species within the phreatic or deep groundwater zone and it's need for both a moderate to high dissolved oxygen levels is therefore a direct indicator of groundwater connectivity not only between the four bore but also between the local rivers systems and shallow unconfined aquifers.

Discussion

Knowledge of groundwater dependent ecosystems in eastern Australia is limited and patchy. With the exception of a small number of studies in the sandstone environments of the Blue Mountains and the Upper Nepean areas (Hose 2008) and recent work in the Maules Creek and Namoi catchments (Serov et al, 2009, Thomlinson and Boulton, 2008) we are unaware of other studies of groundwater dependent ecosystems in porous sandstone aquifers in eastern Australia. Even internationally, studies of groundwater ecosystems in porous rock are scarce.

The striking feature of the fauna collected in this series of surveys is the:
1) the presence of stygofauna at all;
2) The very low diversity of the stygofauna;
3) A fauna composition consisting of disturbance tolerant groups that have been found in other studies to be able to tolerate and preferential occupy habitats that have moderate to very high acidic conditions (3-5 ph units), low dissolved oxygen, as well as being able to tolerate high salt loads.

This 3rd survey once again identified the presence of a subterranean fauna within this aquifer, notably within Bores GW969324 and GW003587 and the two new locations. These bores and the fauna within it represent a biodiversity hotspot that indicates moderate to good water quality, connectivity with the adjacent river system and persistent longevity of the community (Danielopol, *et al*, 2003, Serov, *et al*, 2012.). The absence of the Oligochaete species from the two 'Rockdale' bores during this round of sampling is a cause for further investigation. The two possible scenarios for their absence include:
1) Insufficient sampling of each bore. As the numbers of worms collected in the first two surveys were both low, addition time collecting may be required to record their presence. The loss of the bailer in the 'Far Bore' may have prevented the adequate sampling of the sump environment; or 2) Environmental Change of the groundwater. The absence of the worms may suggest there has been a water chemistry change that could have adversely impacted the stygofauna community significantly enough to reduce the number of species collected via eradication of the worms.

The implication of the second option is that the aquifer has been impacted by a general contamination resulting in a loss of biodiversity. This loss would be expected to be detected initially as a localised, point source impact/contamination with a possible extension to other bores over time if it could not be metabolized or contained.

Key points from the Biological Investigation so far

- All five bores (including the 'Old House Bore' based on water chemistry and water levels) appear to be accessing the same water source/aquifer based on the presence of the same stygofauna species within the "New House Bore" and "Far Bore" and the new sites. It is not known why at this point stygofauna were not collected within the "old Bore", except that it is likely to be a connectivity issue in terms of substrate porosity. As the sampling has been completed twice and there is still no fauna collected it is reasonable to conclude that this section of the aquifer has an impervious boundary that precluded the movement of stygofauna. It is also quite a common occurrence for very close bores that appear to be drawing from the same aquifer to have completely different survey results due to a number of causes such as the complexity of the subterranean environments, including slightly different water chemistry or a lack of appropriate pore space (fine sediment lenses) to allow the invertebrate to pass through the matrix.
- Stygofauna are present across the aquifer within the unconsolidated, water bearing zone
- Stygofauna indicate moderate to high water quality across the aquifer i.e. overall good aquifer health.
- Stygofauna community is naturally depauperate and consists predominantly of aquatic mites with localised areas of higher biodiversity that includes at least Oligochaeta (worms).
- The ant, frog, snake and mammal remains appear to be incidental and have arrived in the bores by accident or used the bores as a refuge due to a more suitable microclimate (higher humidity) and may be a symptom and not the cause of the poor water quality experienced in March. The large accumulation of ants and smaller numbers of frog bones are all well decomposed, which could have occurred at the same time but it is not possible to determine. However, given the fact that no new, (non decomposed) ant bodies were collected in any of the surveys it can be suggested that the large number of ants died within the new bore at the same time and is the result of a possible asphyxia or fumigation event.
- As there was no active monitoring of water levels or water chemistry occurring at the time of either of the episodes of water quality decline any evidence collected may only be circumstantial.
- It is therefore advised that an ongoing monitoring program be established using insitu water level, water quality and air quality (in bore) probes be installed.
- It is also suggested that a seismic investigation be included in the analysis to determine if there has been any destabilization of the unconsolidated sediments within the aquifer from either earth quakes/tremors or the result of fracking at the time of the events. Although the Pilliga Sands Formation is expected to be quite stable in terms of geological activity, movement of the unconsolidated sands and gravels may have caused a mobilization of entrapped organic materials causing a release of hydrogen sulphides, volatiles and other organic components. If this is the case the water quality should continue to improve as the beds stabilize and the mobilized material is filtered out within the matrix and entrapped again and the volatiles have dispersed. If the change is the result a contamination event it is expected that it will have also occurred in other bores on the property as well as adjacent properties. If this is the case water chemistry analysis of all effected bores may show a consistent contaminant signature.

Therefore the threat posed to stygofauna communities by proposed mining activities at within the Pilliga forest area is considered to be high.

Mining developments, in which stygofauna are considered to be a relevant environmental factor, need to be closely assessed with respect to the extent of the proposed groundwater drawdown zone and the likely impacts on groundwater quality. Both of these activities, over time, may cause prospective stygofauna habitat to be degraded or lost with the potential for significant impact on groundwater communities. Stygofauna are able to tolerate natural fluctuations in water parameters such as water level, electrical conductivity, and temperature, and this has been demonstrated experimentally (Tomlinson *unpublished*) for stygofaunal amphipods, copepods, and syncarids. However, changes outside the natural range of water quality, water chemistry and levels such as rapid drawdown or changes to water chemistry such as a pollution plumes are likely to have significant impacts on the community composition, biodiversity and overall sustainability of the community.

Groundwater communities also require links to the surface environment to provide organic matter and oxygen. If that linkage is broken or disrupted, the stygofauna community in the area affected could decline over time. A high degree of endemism can occur in aquifers, even within the same system or between adjacent systems. However, providing there is sufficient hydrological connectivity within and along the flow path of the aquifer, and the physico-chemical conditions are suitable and remain stable, the distribution of species will not be restricted to small parts of an aquifer.

Cumulative Impacts
Cumulative effects may result from a number of activities interacting with the environment. The nature and scale of these effects can vary significantly, depending on factors such as the type of activity performed, the proximity of activities to each other and the characteristics of the surrounding natural, social and economic environments (Brereton and Moran, 2008). They may also be caused by the synergistic and antagonistic effects of different individual activities, as well as the temporal or spatial characteristics of the activities. Importantly, cumulative effects are not necessarily just additive. The proposed CSG activities in a region are growing thus increasing the potential for an impact on the underlying aquifers. The implication of multiple mining actives in one region is that impacts may overlap and result in larger impacts than would be expected for a single mining operation (cumulative effects).

Suggested Actions
The recommendation of this report is therefore to continue to monitor the aquifers for the spatial and temporal changes in parameters of the stygofauna, water quality and water quantity during the construction, operational and post-mining phases of both projects, both within and outside the potential zone of impact from the current and proposed CSG and other mining activities.

The suggested next stage is:
1) An examination of water quality and subterranean ecosystem health from as many adjacent bores as possible. Even if no contamination is found it will provide a benchmarked network of bores for future comparisons.
2) The establishment of a monitoring program on both the Rockdale property and surrounding properties in order to ensure appropriate measurements are recorded if this event occurs again. It is much easier to determine cause and effect if there is reliable time series data before and after an impact.

The sites that have been surveyed and analysised for water chemistry should be regarded as benchmarked sites for this aquifer in the area. Benchmarking is necessary and essential in order to characterize the natural distribution and environmental ranges within the aquifer and therefore the requirements of this subterranean ecosystem and the overall health of the aquifer for human consumption.
The aquifer should be characterised by:

- The structure/lithology of the aquifer by obtaining bore log/works details of the bores;
- The full water chemistry and water levels of the groundwater (including temperature) over time to establish the natural annual ranges and seasonal fluctuations;
- The aquifer flow paths to determine the connectivity (gaining or loosing) with the associated river above and below the potential area of impact.
- Identify the obligate stygofauna to species (those listed as phreatobites) to determine levels of endemicity of the stygofauna community within the aquifer as this community is the most disturbance sensitive environmental indicators for changes in aquifer conditions;
- Conduct further surveys in other bores and hyporheic zone of the associated river, if available, within this aquifer and adjacent aquifers to determine the range of the species.

- Identify other groundwater dependent ecosystems in the area such as springs and groundwater discharge zones within nearby steams.
- Conduct water level mapping across the site/aquifer to determine the linkages with the river systems and other users of the groundwater source such as the local community through the need for stock and domestic water and other potential GDE's such as terrestrial vegetation or wetland communities that also rely on consistent water levels and water quality.

References

Bou C, 1974. Les méthodes de recolte dans les eaux souterrainnes interstitielles. Annales de Spéologie, 29, 4, 611–619.

Danielopol, D.L., Griebler, C., Gunatilaka, A and Notenboom, J. 2003. Present state and future prospects for groundwater ecosystems. *Environmental Conservation* 30 (2): 104–130.

Gibert, J., Danielopol, D., & Stanford, J.A. (Eds), 1994, Groundwater Ecology, Academic Press.

Hose, G, 2008. Stygofauna baseline assessment for Kangaloon bore field investigations southern highlands NSW. Access Macquarie Limited.

Serov, P., Kuginis, L., Byrne, G.T., Williams, J.P. 2012. Risk Assessment Guidelines for Groundwater Dependent Ecosystems in NSW. National Water Commission.

Thomlinson and Boulton, 2008. Subsurface Groundwater Dependent Ecosystems: a review of their biodiversity, ecological processes and ecosystem services. University of New England. Waterlines Occasional Paper No 8, October 2008. National Water Commission.

Williams, W.D. 1981. Australian Freshwater Life. The Invertebrates of Australian Inland Waters. Macmillan Education Australia Pty Ltd. Melbourne.

PILLIGA STYGOFAUNA REVIEW

Santos Energy NSW Coal Seam Gas Exploration and Extraction Activities

Prepared for
Santos Limited
January 2014

DOCUMENT TRACKING

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Executive Summary

Eco Logical Australia (ELA) was commissioned by Santos Limited (Santos) to conduct a review of stygofauna presence across the proposed Energy NSW Coal Seam Gas (CSG) Exploration and Appraisal Program (the program) near Narrabri in northern New South Wales. The purpose of the desktop review was to assess the likelihood of stygofauna occurring in the program area, and whether gas extraction activities are likely to pose a threat to stygofauna communities.

Stygofauna are known to occur in the Namoi River alluvial aquifer. This aquifer is not part of the project area but is a potential source of colonisation for stygofauna. Thin sedimentary aquifers associated with Bohena, Cowallah and Bibblewindi Creeks extend south into the Pilliga and are potentially suitable habitat for stygofauna. It is possible that communities may be present in permanently saturated parts of these aquifers, especially if they have an occasional hydrological connection to the larger Namoi alluvium.

Stygofauna may also be present in the shallower sandstone aquifers present on-site, such as the Pilliga Sandstone and Keelindi Beds (Orallo Formation). For these to be suitable for stygofauna, they would have to be fractured or weathered enough to allow stygofauna movement and a sufficient flux of water and organic matter. The suitability of these rock aquifers as stygofauna habitat diminishes with depth from the surface because:

- Stygofauna rely on organic matter derived from the surface. Without a good hydrological connection to the surface, there is not likely to be enough organic matter or oxygen present
- The space available for stygofauna movement is reduced significantly with increasing depth
- With depth, there is an overall decline in water quality.

Stygofauna may also be present, although with decreasing likelihood with depth below ground distance from alluvium, in weathered sections of sandstone with high secondary porosity, and in the deeper colluvial sediments.

CSG operations potentially create the following risks to stygofauna:

- impacting suitable habitat during drilling
- impacts to groundwater levels or water quality associated with trans-boundary flow between aquifers due to improper drilling and/or completion techniques
- Depressurisation of underlying aquifers that alters the physical structure of stygofauna habitat and subsequently changes groundwater levels or quality

The proposed exploration and appraisal program does not include exploration wells that require drilling through alluvial aquifers, significantly reducing the potential for impact to stygofauna.

Provided drilling, operation and closure activities are undertaken in accordance with the relevant guidelines and legislation, the proposed CSG Exploration and Appraisal Program activities are highly unlikely to pose a threat to any known or likely stygofauna habitat.

1 Introduction

1.1 BACKGROUND AND SCOPE

ELA was commissioned by Santos NSW (Eastern) Pty Ltd (Santos) to prepare a review on the presence of stygofauna and assess the potential for any impacts from proposed Coal Seam Gas (CSG) activities in the Pilliga region of New South Wales, south of Narrabri. This report reviews what is known of stygofauna communities in the Namoi alluvial aquifer, and assesses the suitability of aquifers in the Pilliga area as possible stygofauna habitat. An assessment is then made of potential impacts to stygofauna from CSG activities.

1.2 SUMMARY OF EXPLORATION & APPRAISAL PROGRAM

Santos is proposing to undertake the Energy NSW Coal Seam Gas (CSG) Exploration and Appraisal Program (E&A Program) in the Narrabri area within Petroleum Exploration Licence (PEL) 238 and Petroleum Assessment Lease (PAL) 2 (referred to as the program). The program commenced in 2013 and will take two to three years. The program consists of a series of CSG exploration and appraisal activities, including recommencing operation of several existing pilot wells, drilling and operating new pilot wells and constructing and operating water and gas management facilities to support the program.

The activities forming the E&A Program include:

- operation of the existing Bibblewindi Multi-Lateral Pilot (Bibblewindi 12, 13, 14, 15, 16, 17, 18H, 19H, 21H, 27, 28H and 29), the 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
- operation of the existing Tintsfield 2-7 Pilot (Tintsfield 2, 3, 4, 5, 6 and 7) and the construction and operation of a flare to support the pilot
- 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
- construction and 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

- construction and 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
- construction and 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
- construction and operation of ancillary and supporting infrastructure to facilitate the above activities and ongoing maintenance.

The proposed activities are necessary for the ongoing exploration, appraisal and evaluation of the CSG hydrocarbon potential in PEL 238 and PAL 2. The program will assist in gaining further knowledge of coal fines, gas composition and flow rates, the deliverability of the reservoir, and investigating well design, drilling and completion technologies. This information is essential to determine whether a commercial gas production project is viable and would be used in development planning for a potential commercial gas production project within the areas of PEL 238 and PAL 2.

CSG exploration, appraisal and production planning is an iterative process whereby the results of early stage activities are used to inform later stages of project development. As such, any future exploration, appraisal or production activities beyond the program will be proposed and assessed at a later stage.

1.3 OBJECTIVES OF THIS REVIEW

The principal objective of this desktop review was to determine whether suitable stygofauna habitat is likely to occur in the proposed Exploration and Appraisal Program area, and then determine whether the proposed CSG activities are likely to pose a threat to any stygofauna communities. The review does not consider the disposal or treatment of CSG water once it is extracted. The specific objectives of the stygofauna review were to:

- Determine whether there is any suitable or potentially suitable stygofauna habitat present
- Define the risks associated with the program on stygofauna communities
- Review the risks associated with the potential impacts associated with drilling and dewatering activities on overlying groundwater systems containing stygofauna

2 Overview of stygofauna habitat requirements

This section summarises the habitat requirements of stygofauna, and provides background to the stygofauna review.

2.1 FACTORS INFLUENCING BIOLOGICAL DISTRIBUTION IN AQUIFERS

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

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

2.1.1 Aquifer type

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

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

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

2.1.2 Hydraulic conductivity

Hydraulic conductivity indicates how rapidly water flows through an aquifer. This is important to stygofauna communities because the flux of water through an aquifer often influences how rapidly organic matter and oxygen concentrations can be replenished. In aquifers, stygofauna diversity is generally higher in areas where hydraulic conductivity is also high provided all other habitat features are suitable (Datry *et al*. 2005).

2.1.3 Depth of water table

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

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

2.1.4 Connectivity to recharge areas

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

2.1.5 A space for living

Stygofauna can only live in aquifers with enough space for them to move around in. Space is present in the solute cavities in karst, between pesolithic sediments in calcrete, and fractures in sandstone and basalt. For rock aquifers such as sandstone and basalt, it is the secondary porosity (that which is due to fracturing) rather than the primary porosity (in pores between sediment grains) that is important. In unconsolidated sedimentary aquifers such as alluvium, the size of pore space between particles often correlates to the size of the animals present, with larger species occurring in aquifers of coarser material (Strayer 1994).

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

2.1.6 Evolutionary history

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

2.1.7 Food availability

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

2.1.8 Water regime

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

2.1.9 Salinity

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

2.1.10 Dissolved oxygen

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

3 Suitability of aquifers in the Exploration and Appraisal Program area as habitat for stygofauna

3.1 STYGOFAUNA KNOWN FROM THE NAMOI RIVER ALLUVIUM AND ITS TRIBUTARIES

There has been a limited amount of sampling conducted for stygofauna in the Namoi River Alluvial aquifer and its tributaries. Nevertheless, previous surveys (summarised below) have established the Namoi as an aquifer with a relatively diverse stygofauna community. The presence of a large river with a well-developed alluvial aquifer make the Namoi comparable to other large rivers in Australia and overseas with diverse stygofauna communities (e.g. alluvial aquifers of the Hunter River, Pioneer River, Burnett River, Macquarie River – Hancock and Boulton 2008).

In 2013, Eco Logical Australia conducted a preliminary stygofauna survey for Santos at 2 bores at 'Leewood' and three bores along Bohena Creek. The Leewood bores had water tables of 21 and 26 m below ground level and sampled the lower section of saturated colluvial sediments, while the Bohena Creek bores had water only 2-3 m below ground level in the alluvial aquifer of the creek. None of the bores sampled had stygofauna.

Andersen (2008) reported at least 3 stygofauna taxa from the alluvial aquifer of Maules Creek, a tributary of the Namoi River. Stygofaunal syncarids, amphipods, and copepods have been collected from the Namoi alluvial aquifer by the NSW Office of Water, and the alluvial aquifer of the Peel River, a tributary of the Namoi, also has a rich stygofauna community with at least 20 species (Hancock and Boulton 2008).

In a study conducted between 2007 and 2008, Korbel (2012) collected at least 7 stygofauna taxa from 15 monitoring bores near Wee Waa, approximately 50 km west-northwest (and downstream) of Narrabri. The taxa collected included Ostracoda, Cyclopoida, Harpacticoida, Amphipoda, Oligochaeta, and three genera of Bathynellaceae.

A baseline survey of three bores at 'Rockdale' in the Pilliga collected three invertebrate taxa in 2012 (Stygoecologia 2013). Two families of worm (Oligochaeta) and one family of mite (Acarina) were collected from an unconsolidated sedimentary aquifer (Stygoecologia 2013). The aquifer sampled is variably referred to as the 'Pilliga Sands' or 'Pilliga Sandstone', so it is unclear whether the specimens come from the shallow colluvial/alluvial sediments or the underlying sandstone aquifers. There are some taxonomic groups known from groundwater samples in the region whose status as stygofauna needs to be interpreted with caution. While crustaceans such as bathynellids, amphipods, and isopods, are unambiguously groundwater obligates because of their aquatic ancestry and troglobitic morphological features, there are other taxa that are likely to be in groundwater accidentally. These are taxa that occur more commonly in the soil profile, but regularly fall into bores/wells and are collected during sampling and include worms and mites, and the larval stages of terrestrial insects. Soil fauna are not considered as significant as stygofauna because species are more widespread and have fewer incidences of short-range endemism.

3.2 SUITABILITY OF AQUIFERS FOR STYGOFAUNA

3.2.1 Shallow alluvial aquifers along creeks

There is a moderate chance that stygofauna occur in the alluvial aquifers of creeks in the Pilliga. The small alluvial aquifers associated with ephemeral creeks in the Pilliga consist of unconsolidated sands and fine gravels extending to depths of up to 40 m (Halcrow 2013). The main creeks in the study area are Bohena, Cowallah, Jacks, Bundock, and Bibblewindi Creeks, and all of these are dry for long periods of time. While parts of these aquifers potentially dry out after extended periods of no rainfall, there are likely to be sections that remain saturated because they hold a sufficient volume of water to resist evapotranspiration. These deeper saturated sediments may be suitable for stygofauna provided the water chemistry is suitable.

3.2.2 Colluvial sediments

Shallow colluvial sediments cover large sections of the northern part of the program area. These form temporary aquifers following periods of heavy rain, but the shallower sections often dry out (Halcrow 2013). It is unlikely that these aquifers have diverse stygofauna communities because they are shallow and probably dry out, however permanently saturated sections may have stygofauna if conditions are suitable. Given the homogenous nature of the colluvium, and the large area covered by colluvium between the program area and the Namoi River, there are unlikely to be any species endemic to the program area. These areas may provide suitable stygofauna habitat but communities are unlikely to have a high diversity. The colluvium is more likely to have stygofauna present in sections close to the Namoi River.

3.2.3 Sandstone aquifers underlying the program area

Pilliga Sandstone and the Keelindi Bed formations (inclusive of the Orallo Formation) underlie the superficial sediments in most of the program area. These have a low to moderate chance of providing suitable stygofauna habitat in the shallow sections where there is sufficient weathering and fracturing (i.e. a high secondary porosity). Habitat suitability increases with proximity to alluvial aquifers and recharge areas, and where there is a large amount of fracturing and interconnectedness between pore spaces. The chance of these sandstone strata being suitable for stygofauna diminishes with depth below ground surface.

4 Impact assessment

4.1 ASSESSMENT OF IMPACTS TO STYGOFAUNA FROM CSG DRILLING AND EXTRACTION

An assessment for the potential impacts to stygofauna from CSG drilling and extraction activities is included in **Table 1**.

Table 1: Risks and their likelihood of occurring as a result of CSG drilling in the Pilliga

Risk	Likelihood
Drilling through potential stygofauna habitat leads to changes in groundwater level or quality, impacting stygofauna	NEGLIGIBLE- While the colluvial and sandstone aquifers may have stygofauna, there are unlikely to be any species endemic to the impact area. Drilling will adhere to the *NSW Code of Practice for Coal Seam Gas Well Integrity*, which means that the risk of aquifer drainage will be negligible.
Drilling through potential stygofauna habitat creates preferential flow paths and cross-transfer of water between aquifers, impacting stygofauna.	NEGLIGIBLE- While the colluvial and sandstone aquifers may have stygofauna, drilling will adhere to the *NSW Code of Practice for Coal Seam Gas Well Integrity*. The use of proper drilling and grouting techniques will mean the risk of changes to water levels within aquifers is negligible.
Extraction of CSG from deep coal seams leads to drawdown or damage to stygofauna habitat	NEGLIGIBLE – Gas removal will occur at depths too great to have a significant impact on the physical structure of aquifers suitable for stygofauna. If stygofauna are present they are likely to occur in the upper 50 m. Depressurisation from extraction will occur much deeper than this and groundwater modelling to date suggest there will be no greater than 0.5m drawdown on alluvial (where present) and sandstone aquifers overlying the project area. The continuous monitoring of groundwater pressures in overlying shallow aquifers across the program area will assist in detecting any unexpected changes in ground, water level during operation of the exploration and appraisal program,
Pollution of shallow aquifers from chemicals used in drilling	NEGLIGIBLE –Drilling will adhere to the *NSW Code of Practice for Coal Seam Gas Well Integrity* and all precautions will be made to prevent contamination from chemicals used in drilling, as such the risk of drilling fluids having an impact on Stygofauna populations is considered negligible

5 Management and mitigation measures

The chance of any stygofauna species being endemic to the program area is low. The cumulative groundwater impact assessment for the Exploration and Appraisal Program shows that depressurisation of the target coal seam as a result of pilot activities indicates a negligible decline in water levels. Therefore the potential for CSG extraction to have a significant impact on stygofauna at the species level is considered negligible. Where risks may be present, **Table 2** provides a list of suggested mitigation measures, to further reduce these risks. An assessment of the potential for residual risks once the suggested mitigation has been implemented is also provided.

Table 2: Suggested mitigation measures.

Risk	Mitigation Measures	Residual risk to any endemic stygofauna populations
Disturbance to overlying aquifer systems during drilling process	Adopt the NSW Drilling Code of Practice. Ensure that aquifers are properly isolated during well drilling and construction, and that the integrity of the isolating barrier is maintained during operation.	NONE
Change to water chemistry in stygofauna habitat due to interconnectivity with aquifers	Adopt the *NSW Drilling Code of Practice.* Ensure that aquifers are properly isolated during well drilling and construction, and that the integrity of the isolating barrier is maintained during operation.	NONE
Structural damage, due to depressurisation, to stygofauna habitat or to the underlying strata of alluvial aquifers	The implementation of a shallow aquifer monitoring bore network across the program area to monitor for changes in water pressure. This will assist in identifying any unexpected changes in groundwater during the operation of the Exploration and Appraisal program.	NONE

6 Conclusions

The small alluvial aquifers flowing through the Pilliga, such as the Bohena Creek aquifer and its feeding streams and tributaries, are the most likely areas to have suitable stygofauna habitat, particularly in sections that remain permanently saturated and have a hydrological link to the main Namoi River aquifer. To date, there have been limited surveys of these aquifers because of restricted access and low bore numbers. Characteristics of the alluvial aquifers that make them suitable for stygofauna include:

- The water table is relatively shallow
- Electrical conductivity in the aquifers is likely to be low
- Sediments in the bed of the creek consist of coarse sand to medium gravel, which is likely to have sufficient porosity below the creek bed to have space for stygofauna.

Stygofauna may also be present, although with decreasing likelihood with depth below ground distance from alluvium, in weathered sections of sandstone with high secondary porosity, and in the deeper colluvial sediments.

The risks of impacting stygofauna through drilling activities includes changing groundwater quality or levels and introducing preferential flow pathways between aquifers. It is noted that the wells will be drilled and constructed in accordance with the methodology presented in the *NSW Code of Practice for Coal Seam Gas Well Integrity* and therefore the likelihood of this potential impact is considered to be negligible.

The cumulative groundwater impact assessment indicates that depressurisation of the target coal seam as a result of pilot activities will result in a negligible decline in water levels (less than 0.5 metres and within the natural range of annual fluctuations) in the Bohena Creek Alluvium and the Pilliga Sandstone groundwater. Therefore it is highly unlikely there will be any impacts to shallow aquifers that may contain stygofauna as a result of CSG extraction.

The monitoring of groundwater pressures in overlying shallow aquifers across the program area will assist in detecting any unexpected changes in ground, water level during operation of the exploration and appraisal program.

References

Anderson, M.S. 2008. *Investigation of surface water groundwater exchange in Maules Creek Catchment.* Presentation to the IAH , 9 Sept, 2009. WRL UNSW Sydney.

Datry, T., Malard, F. and Gibert, J. 2005. Response of invertebrate assemblages to increased groundwater recharge rates in a phreatic aquifer. *Journal of The North Benthological Society* 24(3), 461-477.

Dole-Olivier, M.-J., Marmonier, P., Creuzé des Châtelliers, M., Martin, D. 1994. Interstitial fauna associated with the alluvial floodplains of the Rhöne River (France). In: Gibert J, Danielopol DL, Stanford JA (eds) *Groundwater Ecology*. Academic Press, San Diego, 313–346

Guzik, M.T., Austin, A.D., Cooper, S.J.B., Harvey, M.S., Humphreys, W.F., Bradford, T., Eberhard, S.M., King, R.A., Leys, R., Muirhead, R.A., and Tomlinson, M. 2011. Is the Australian subterranean fauna uniquely diverse? *Invertebrate Systematics* 24, 407-418

Hahn, H.J. 2006. The GW-Fauna-Index: A first approach to a quantitative ecological assessment of groundwater habitats. *Limnologica* 36, 119-137.

Halcrow 2013. *Groundwater Impact Assessment, Narrabri Gas Project*. Report for Santos Ltd.

Hancock, P., Boulton, A., and Humphreys, W. 2005. Aquifers and hyporheic zones: toward an ecological understanding of groundwater. *Hydrogeology Journal* 13, 98-111.

Hancock, P.J. and Boulton, A.J. 2008. Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics* 22, 117-126.

Henry, K.S. and Danielopol, D.L. 1999. Oxygen dependent habitat selection in surface and hyporheic environments by *Gammarus roesli* Gervais (Crustacea, Amphipoda): experimental evidence. *Hydrobiologia* 390, 51-60.

Humphreys, W. F. 2008. Rising from down under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* 22, 85–101.

Jasinska, E. J., Knott, B., and McComb, A. R. 1996. Root mats in ground water: a fauna-rich cave habitat. *Journal of the North American Benthological Society* 15, 508–519.

Korbel, K.L. 2012. Robust and sensitive indicators of groundwater health and biodiversity. PhD Thesis, UTS.

Malard, F. and Hervant, F. 1999. Oxygen supply and the adaptions of animals in groundwater. *Freshwater Biology* 41, 1-30.

Strayer, D.L. 1994. 'Limits to biological distributions in groundwater.' pp. 287-310 In: *Groundwater Ecology,* eds. J. Gibert, D.L. Danielopol, and J.A. Stanford. Academic Press.

Stygoecologia. 2013. Final Baseline Stygofauna Survey Report for Rockdale. January 2013.

Watts, C.H.S. and Humphreys, W.F. 2004. Twenty-six new Dytiscidae (Coleoptera) of the genera *Limnobodessus* Guignot and *Nirripirti* Watts and Humphreys, from underground waters in Australia. *Transactions of the Royal Society of South Australia* 130, 123-185.

Western Australia Environmental Protection Authority. 2003. Guidance for the Assessment of Environmental Factors: Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia. Guidance Statement No. 54. Western Australian Government, Perth, Australia

Western Australia Environmental Protection Authority. 2007. Sampling methods and survey considerations for subterranean fauna in Western Australia. Guidance Statement No. 54. Western Australian Government, Perth, Australia.

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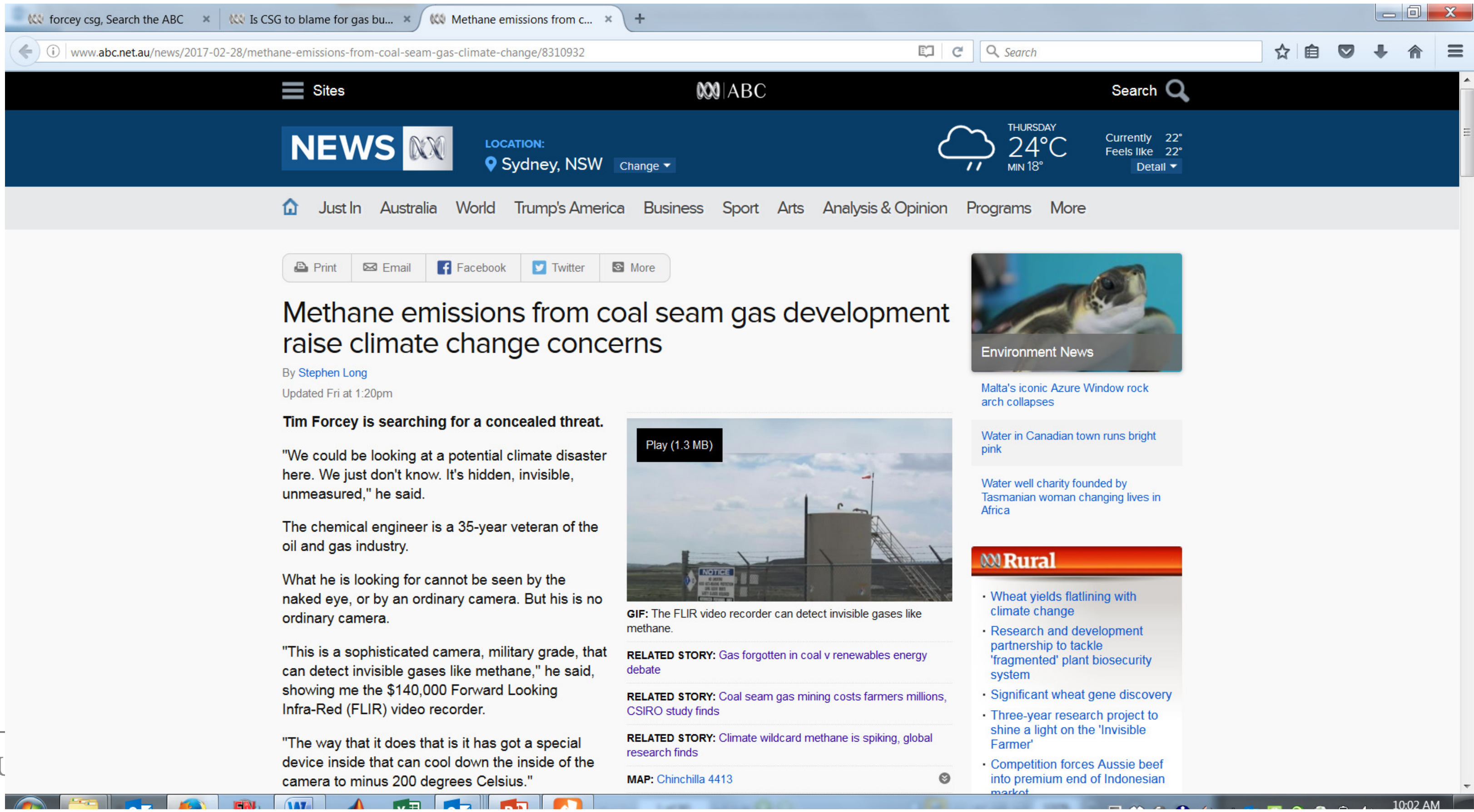
Summary Presentation: Mobile baseline concentration and isotope measurements of methane

Dr Michael Hatch and Associate Professor Murray Hamilton

Melbourne Environment Institute findings and reports on the ABC

- Major finding – it is necessary to a) determine baselines pre-production, and b) measure losses, monitor and maintain infrastructure to minimise losses.



Introduction:

- This talk is about a multi-year baseline study of methane levels:
  - identify possible sources before production. (then characterise the area as development occurs).
  - Put CSG into framework of GHG production by taking similar data over other known and potential CH4 sources.
- Santos ahead of the game - measuring baselines in NSW since 2013.

- Five data collection campaigns: April/May, August and December of 2013; August 2014; and September 2015.

Introduction: Talk outline

1. Makeup of the atmosphere
2. Technology: new technologies are what have made this work possible
3. Motivation for baseline studies
4. Santos: Gunnedah area
5. Santos: Pilliga Forest
6. CH_4 in context – other results
7. Summary

The most important point to make is that our data are snapshots of CH4 concentration.

They will vary depending on a number of factors, including:

- temperature
- wind speed and direction
- time of day (night-time thermal inversions)
- topography
- proximity to a source or sources
- activities at a source / land use
  - Maintenance, construction, earthworks etc.

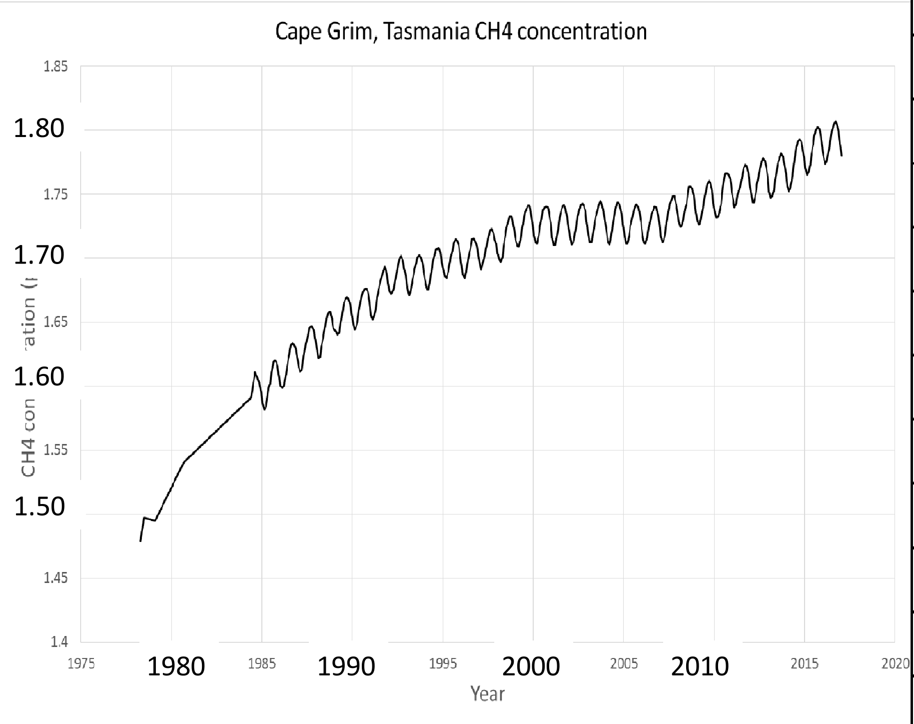
The atmosphere:

- 78% Nitrogen
- 21% Oxygen
- 1% Argon
- 0.04% Carbon Dioxide (CO_2) – 400 ppm
- 0.00018% Methane (CH_4) - 1.8 ppm

More on CH_4

- CH_4 does not burn at concentrations below 50,000 ppm
- CH_4 is ~86x more effective a greenhouse gas than CO_2 over 20 years and ~34x over 100 years, and is now recognised as the 2nd most important contributor to global warming behind CO_2.
- CH_4 does not stay in the atmosphere for long – the ½ life is ~8 years. Compare to >200 years for CO_2.

The atmosphere: Change in CH4 concentration



http://www.csiro.au/greenhouse-gases/

Year	1850	1992
Natural source		
Wetlands	145	145
Termites	20	20
Wild ruminants	5	5
Oceans	10	10
Freshwaters	5	5
Hydrates	5	10
Total natural	**190**	**195**
Anthropogenic source		
Rice paddies	27	80
Domestic ruminants	20	80
Animal wastes	5	30
Landfills	10	40
Wastewater	6	25
Biomass burning	10	40
Energy use	0	110
Total anthropogenic	**78**	**405**
Total	**268**	**600**

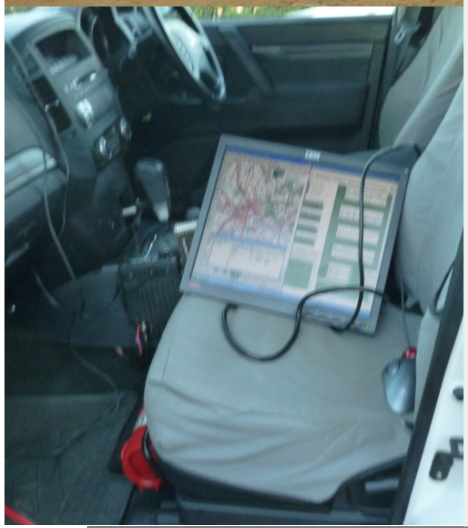
(Tg/year), from Lelieveld et al. (1998)

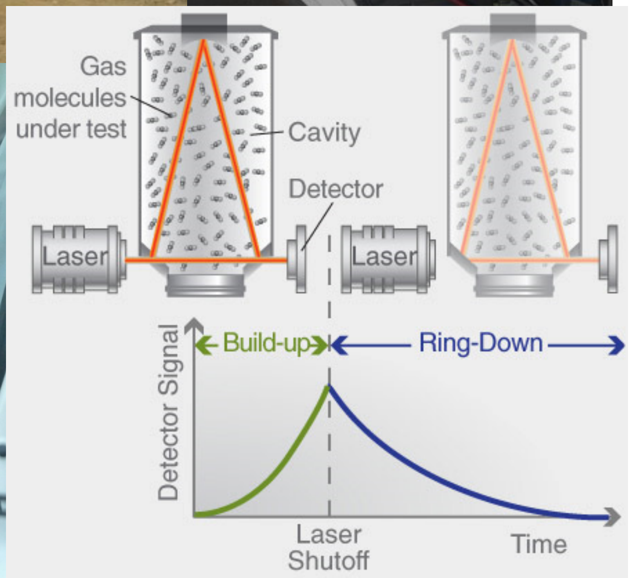
Baseline gas concentration data were very hard to collect and very costly to analyse.

Involved collection of samples in bottles, returning them to the lab, and then analysing them using an ICP GMS or other similar instrument - cost of $100's per sample to analyse, and resulted in data that were sparse – not continuously sampled.

Technology has improved.

Technology: Cavity ring down spectrometry





Cavity Ring Down Spectrometer:

Picarro G2201i

- ppb sensitivity
- mobile
- isotope capable
- continuous monitoring
- sniffer capability

Technology: CRDS – measuring CO2 concentration

The Picarro G2201i is able to measure concentration of CO2 as well. When purchased this seemed like a good feature to have for our driving surveys.

Unfortunately (obviously?) measuring CO2 is less useful than hoped (at least in the field) for at least two reasons:

1. Vehicles produce large quantities of CO2 (and extremely small quantities of CH4 – unless you are following a cattle transporter) – CO2 concentration data may be useful when collected under certain conditions and help to characterise the data collected.

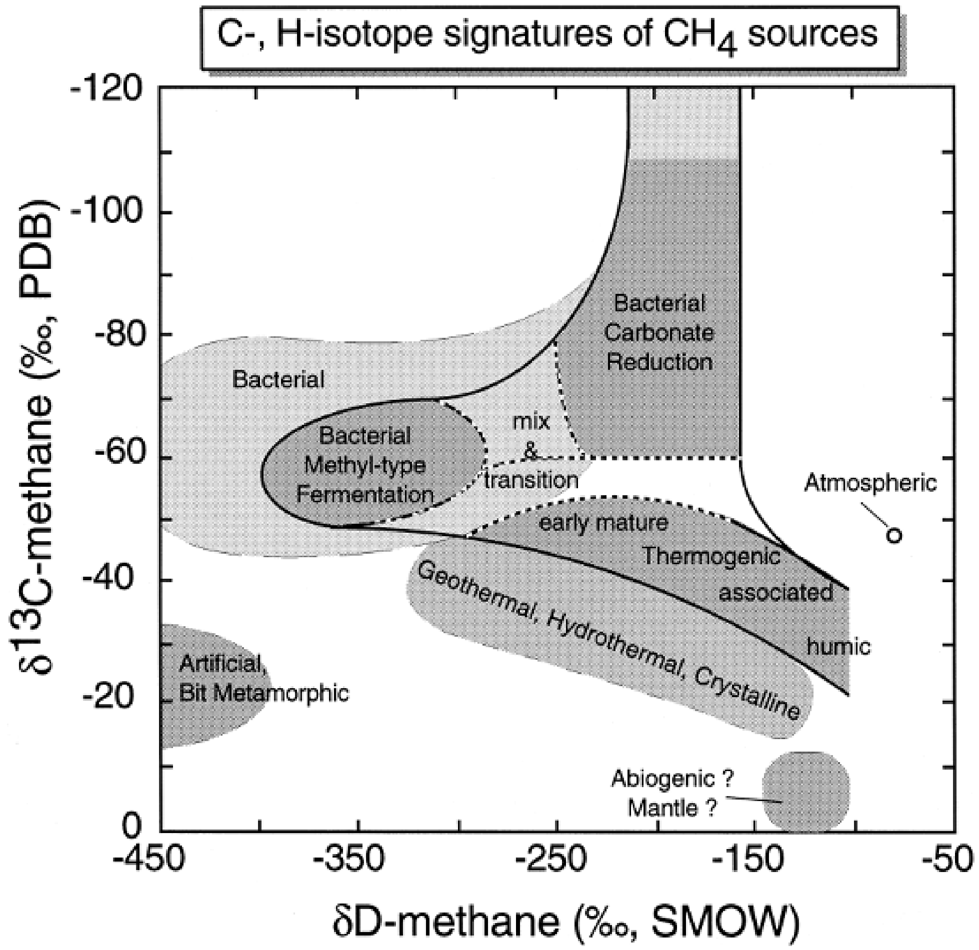
2. Less obviously, CO2 is an important part of the photosynthesis process. CO2 levels are often lower during the day (due to higher rate plant photosynthesis), and higher at night…

Technology: CRDS – measuring isotopes of carbon

The ability to measure carbon isotopic ratios has the potential to allow discrimination of the source of the CH4 (or CO2) that is being measured at a given location.

Values are given in units called "delta" - normalised ratios of ¹⁴C (99% of C) and ¹³C (remaining ~1%).

$$\delta^{13}C = \left(\frac{\text{measured ratio}}{\text{standard ratio}} - 1 \right) \times 1000$$



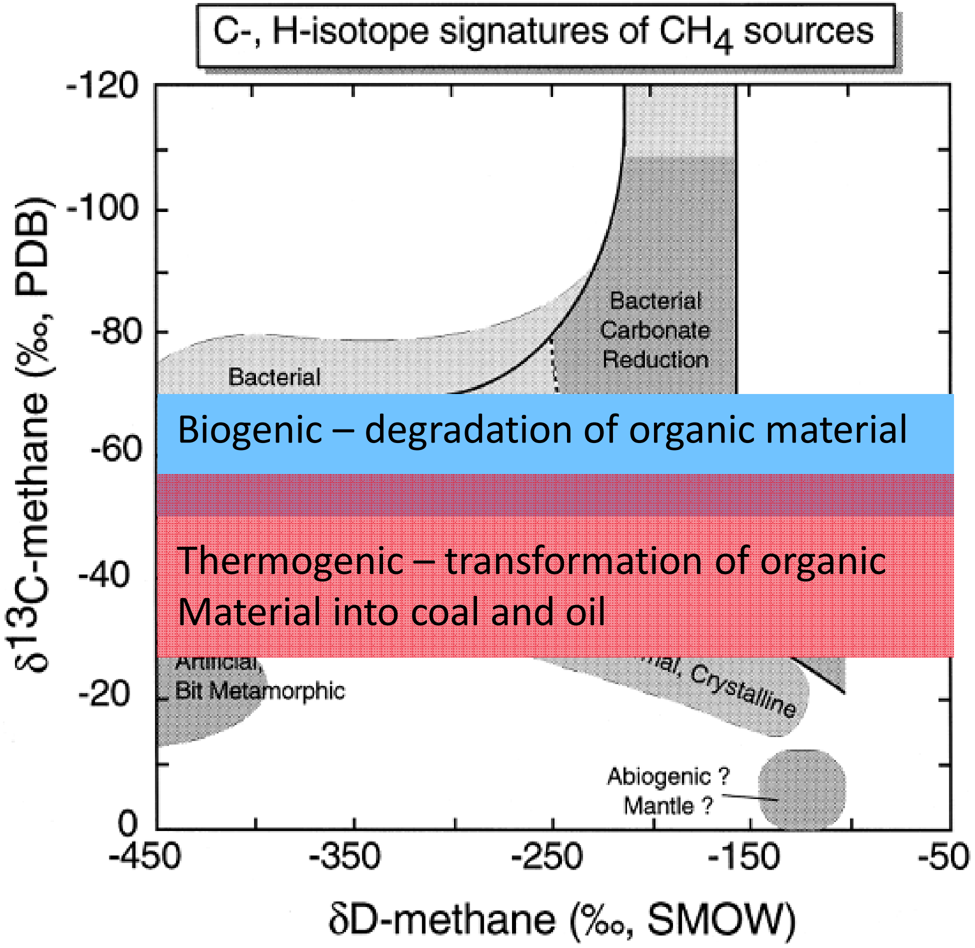
from Whiticar (1999)

Technology: CRDS – measuring isotopes of carbon

The ability to measure carbon isotopic ratios has the potential to allow discrimination of the source of the CH4 (or CO2) that is being measured at a given location.

Values are given in units called "delta" - normalised ratios of ^{14}C (99% of C) and ^{13}C (remaining ~1%).

$$\delta^{13}C = \left(\frac{\text{measured ratio}}{\text{standard ratio}} - 1 \right) \times 1000$$



from Whiticar (1999)

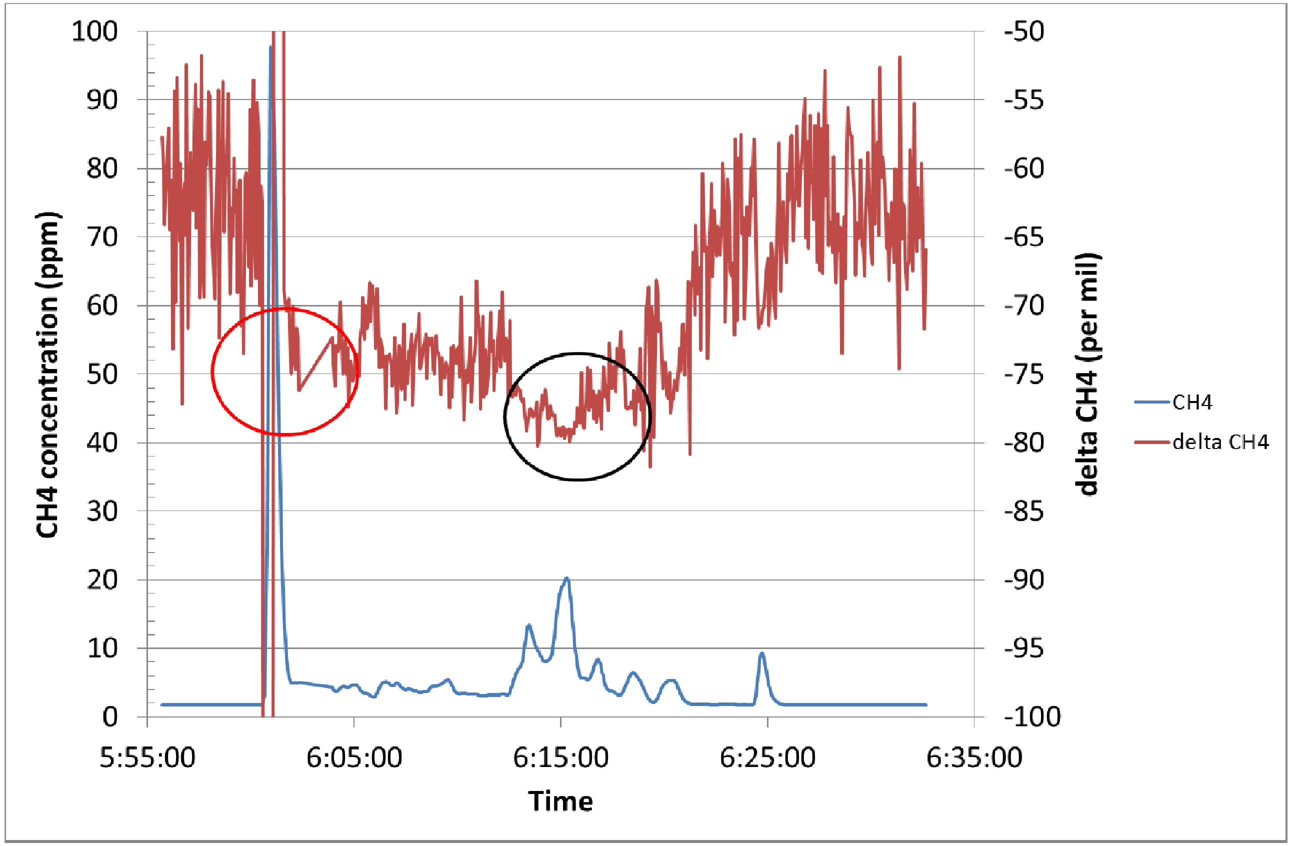
Technology: CRDS – measuring isotopes of carbon

Further complicating: much of the CH4 sourced from CSG in eastern Australia has a biogenic isotopic signature, rather than the expected thermogenic signature. Shows that shallow coals are affected by methanogenic bacterial action – hence biogenic signature.

Interestingly, our results are ambiguous as well – we have sampled from one deep CSG well and the results suggested a thermogenic source. As expected, gas sampled directly from wetlands was biogenic. Gas sampled from GAB bores (i.e. deep bores in towns like Pilliga and Lightning Ridge) are both mixed biogenic to thermogenic.

Technology: CRDS – measuring isotopes of carbon

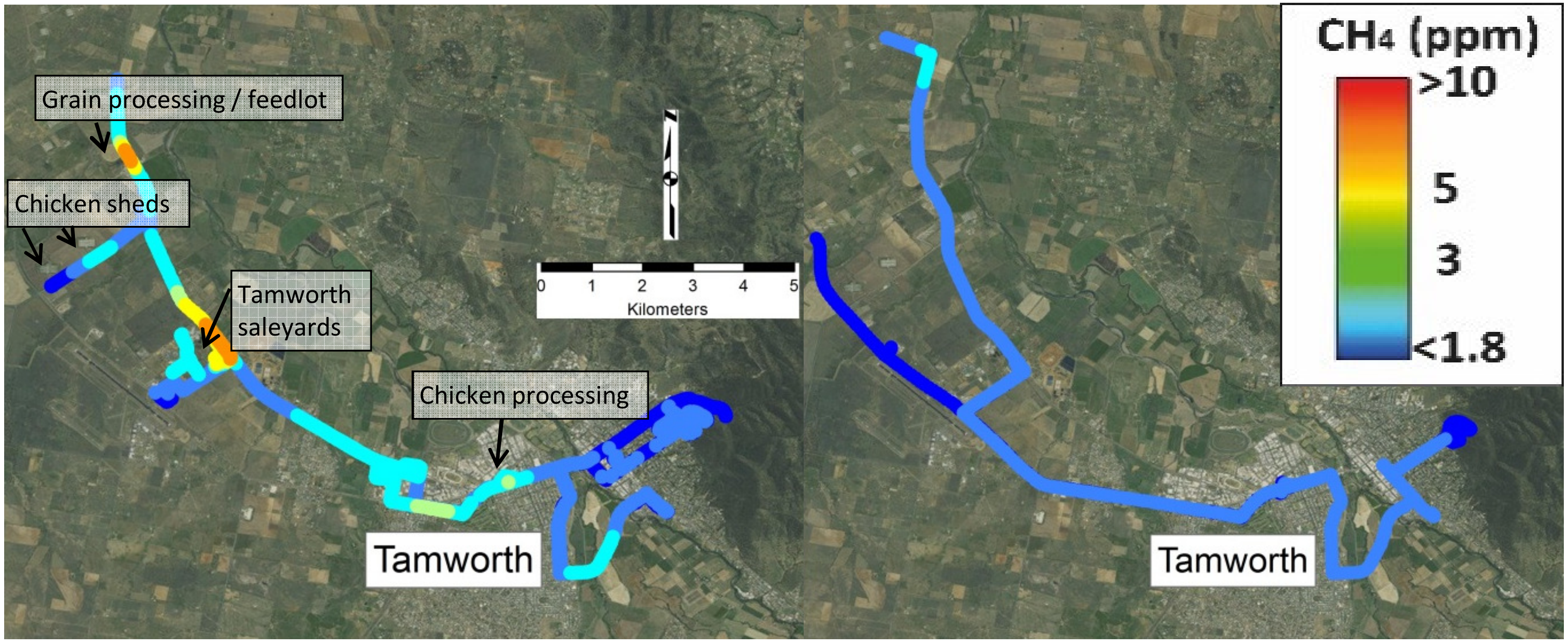
Time series showing CH_4 concentration and isotopic levels for Pilliga Bore (GAB). Data collected December 2013. Red circle shows initial response with very high CH4 concentrations – isotopic information is not usable here. Black circle is lower concentration. Suggests mixed thermogenic / biogenic signature.



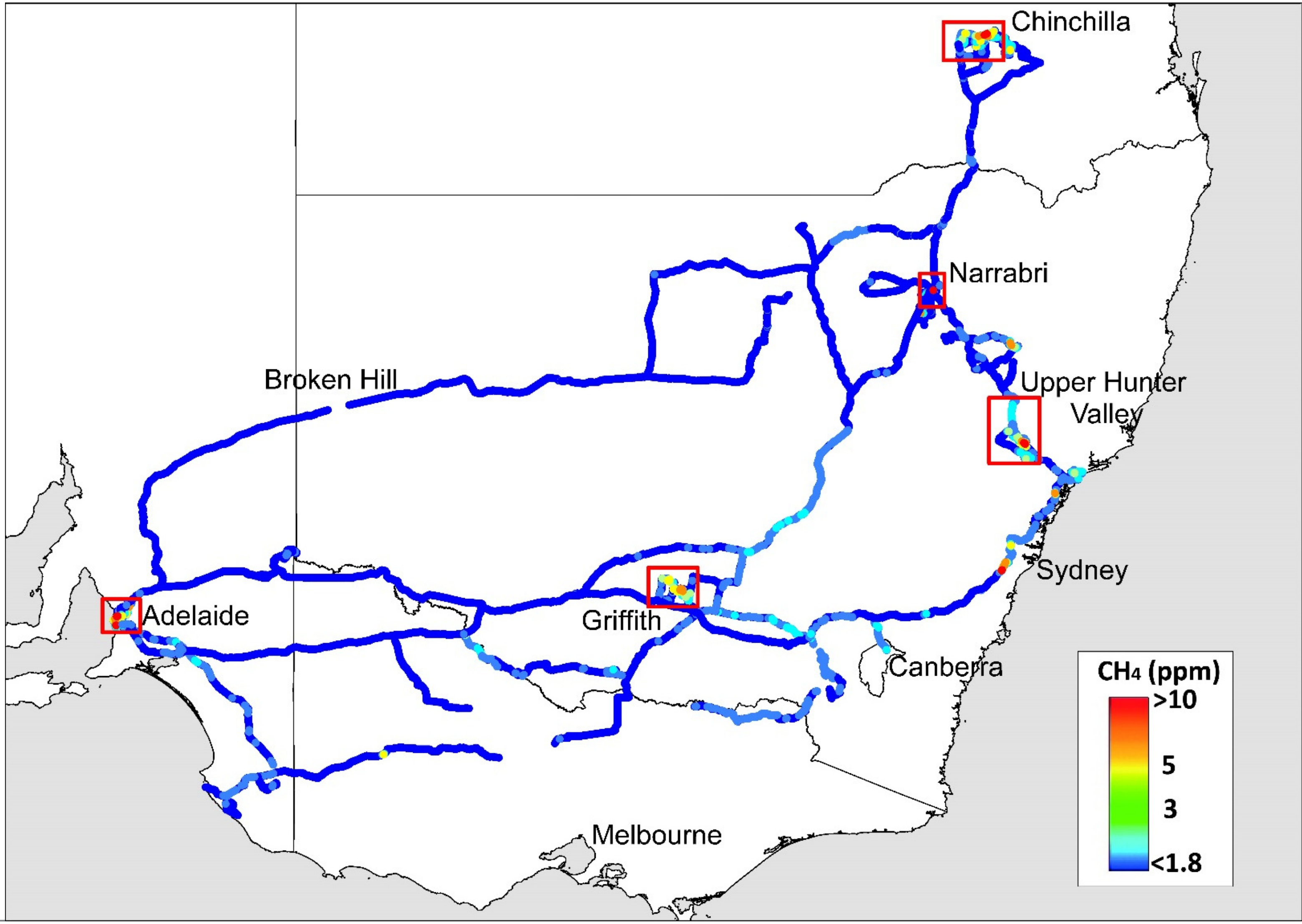
Technology: <u>when</u> you measure matters.

Daytime vs night time surveying

- Left collected in the evening of 29/4/13. Right collected early in the day on 30/4/13.
- Imagine if you had to collect this information using bottles and then take them back to the lab for analysis.



Overview of University work



Gas pre-development?
Surat Basin in QLD

CR#20298

Petrofocus
Geochemical exploration surveys for petroleum exploration

GSC026856CR

SOIL GAS ALKANE SURVEY

ATP 261P (D)

SURAT/BOWEN BASIN, QUEENSLAND

CONFIDENTIAL

For:

MOSAIC OIL N.L.

on behalf of the

ATP 261P (D) Joint Venture

March 1989

42-D-5

Petrofocus Pty Ltd
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CR#20298

CH_4

Table 1. Methane, ethane, propane and n-butane concentrations in soil gas samples ATP 261P (D).
Anomalous concentrations in **bold** typeface

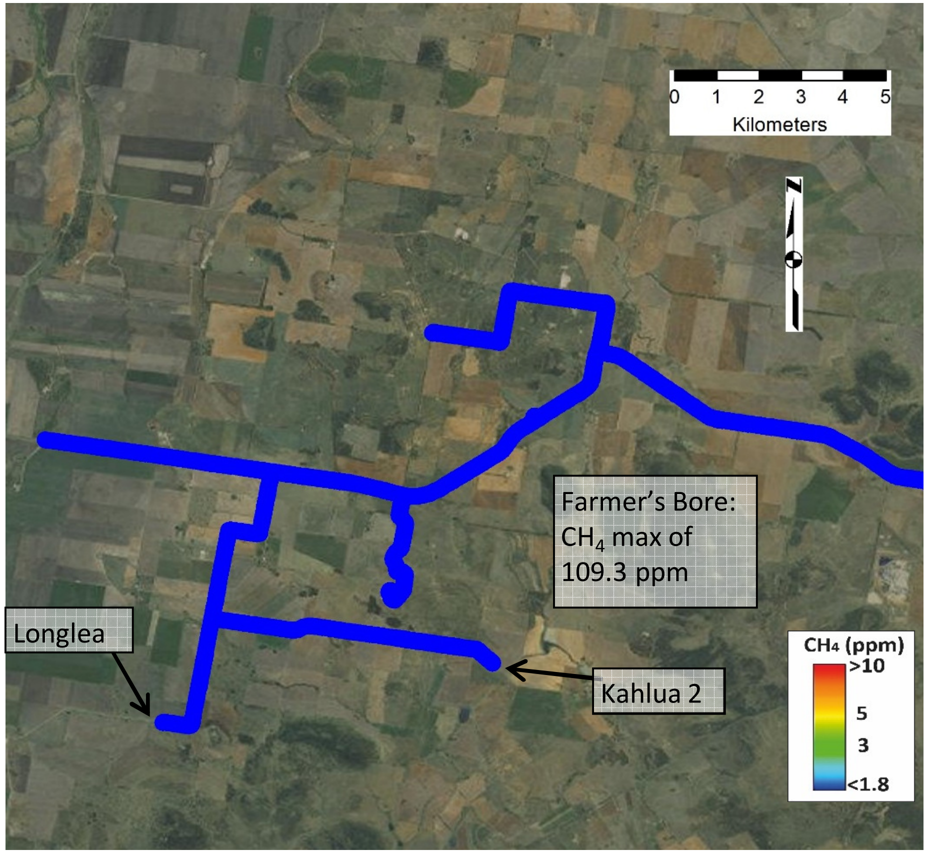
Sample No.	Label	C_1	C_2	C_3	$n\text{-}C_4$	$\frac{C_1}{C_1+C_2+C_3+C_4}$	$\frac{C_1}{C_2}$	% Wetness $\frac{C_2+C_3+C_4}{C_1+C_2+C_3+C_4}$
1		1.9	0.04	0.17	0.031	0.887	47.50	11.26
2		2.3	0.05	0.20	0.043	0.887	46.00	11.30
3		4.9	0.58	0.50	0.094	0.807	8.45	19.33
4		5.3	0.72	0.52	0.096	0.799	7.36	20.13
5		2.4	0.11	0.21	0.035	0.871	21.82	12.89
6		4.1	**1.18**	0.44	0.073	0.708	3.47	29.22
7		6.7	**1.38**	**0.65**	0.086	0.760	4.86	24.00
8		5.6	**1.24**	**0.67**	**0.108**	0.735	4.52	26.49
9		4.2	0.66	**0.60**	0.094	0.756	6.36	24.38
10		5.3	0.67	**0.58**	0.077	0.800	7.91	20.02
11		5.7	**1.27**	**0.70**	**0.120**	0.732	4.49	26.83
12		2.9	0.41	0.42	0.068	0.764	7.07	23.64
13		3.6	0.36	0.43	0.057	0.810	10.00	19.05
14		3.6	0.72	**0.55**	0.088	0.726	5.00	27.39
15		3.9	0.43	0.43	0.076	0.806	9.07	19.35
16		**20.0**	**1.02**	**0.58**	**0.129**	0.920	19.61	7.96
17		8.2	0.32	0.13	0.031	0.945	25.63	5.54
18		**14.3**	0.58	0.35	0.088	0.934	24.66	6.65
19		**14.1**	0.81	0.38	0.081	0.917	17.41	8.27
20		**22.1**	**1.45**	**0.71**	**0.172**	0.905	15.24	9.54
21		**16.4**	**0.99**	0.46	**0.106**	0.913	16.57	8.67
22		[illegible]	**1.58**	**0.62**	0.102	0.891	11.96	10.86
23		**20.2**	**1.86**	**0.85**	**0.205**	0.874	10.86	12.61
24		[illegible]	0.44	0.16	0.047	0.937	21.82	6.31
25		5.7	0.55	0.22	0.052	0.874	10.36	12.60
26		3.7	0.05	0.06	0.011	0.968	74.00	3.17
27		6.7	0.54	0.21	0.049	0.893	12.41	10.65
28		7.8	0.74	0.34	0.064	0.872	10.54	12.79
29		8.0	0.71	0.39	0.086	0.871	11.27	12.91
30		**10.8**	**1.25**	**0.55**	**0.116**	0.849	8.64	15.07
31		9.6	**1.02**	0.46	0.096	0.859	9.41	14.10
32		6.3	0.57	0.34	0.072	0.865	11.05	13.49

14

More than 20 ppm

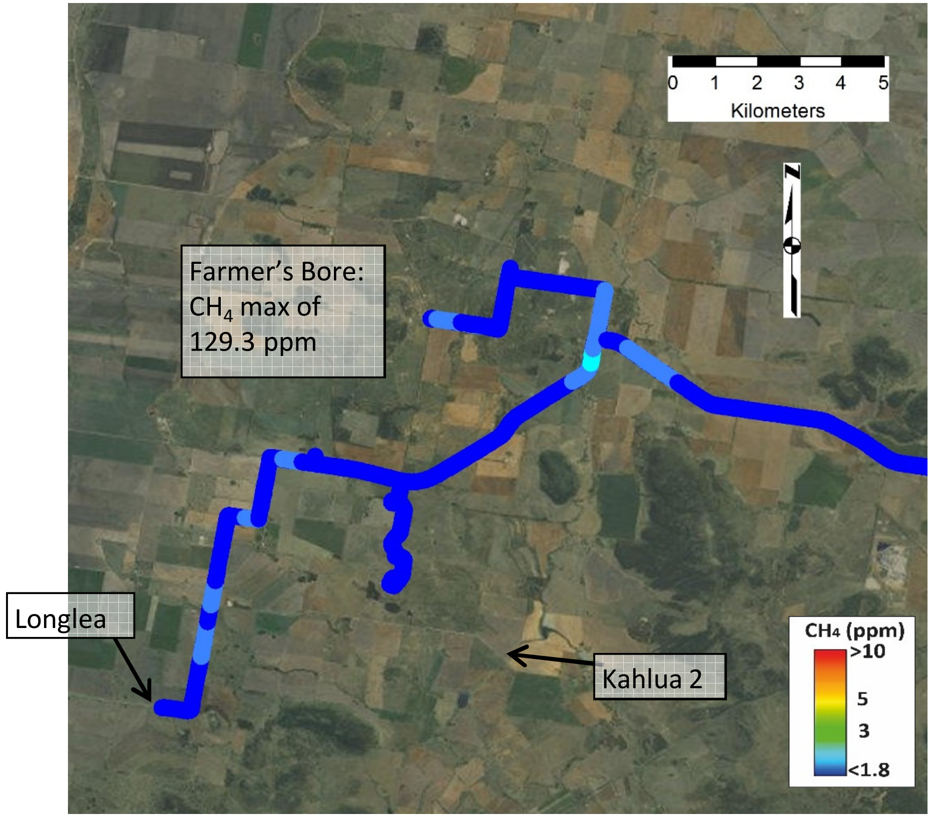
Gunnedah CSG 1st survey

- Data collected on Santos leases: daytime April 2013. CSG wells were shut in.
- CSG at baseline
- Elevated levels at farmer's bore
- No access to farmer's bore known to catch fire



Gunnedah CSG 2nd survey

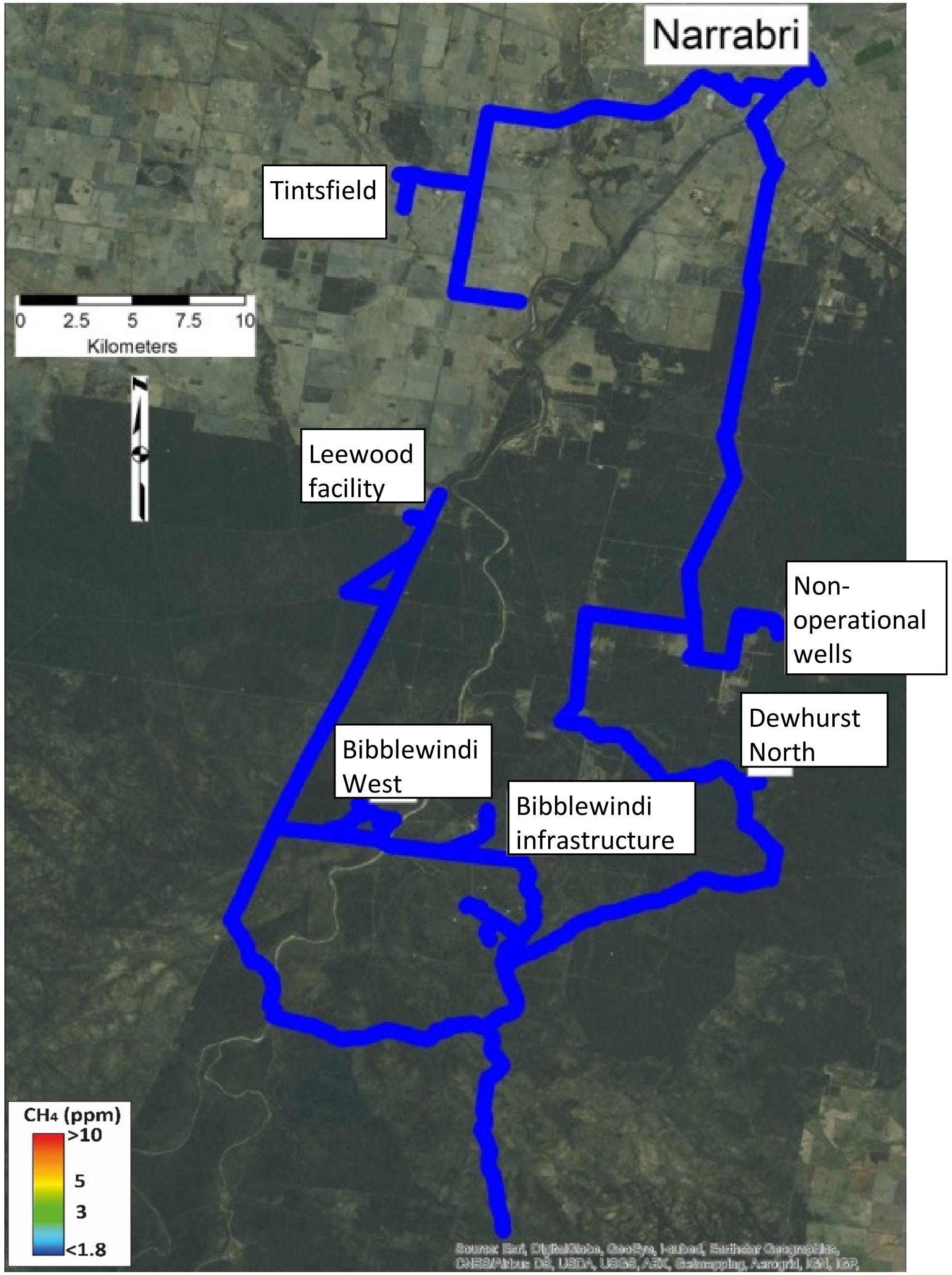
- Data collected on Santos leases: evening August 2013. CSG wells were shut in.
- CSG at baseline
- Elevated levels at farmer's bores



Pilliga overview: Pre-production baseline

Data collected during the day in May 2013.

Highest concentration: 1.78 ppm.

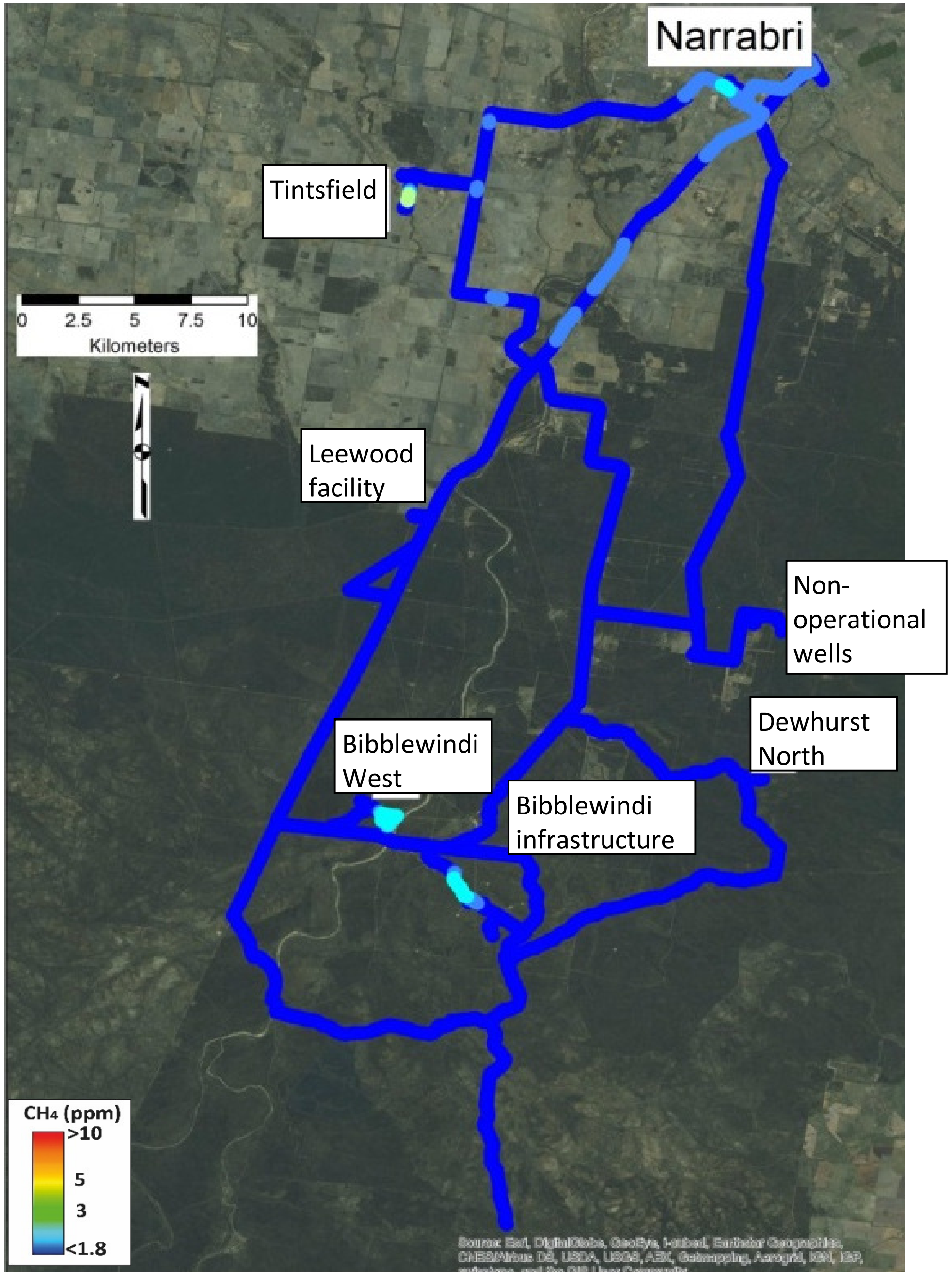


Pilliga overview: Pre-production baseline

Data collected during the evening in August 2013.

Highest concentration:

2.56 ppm.

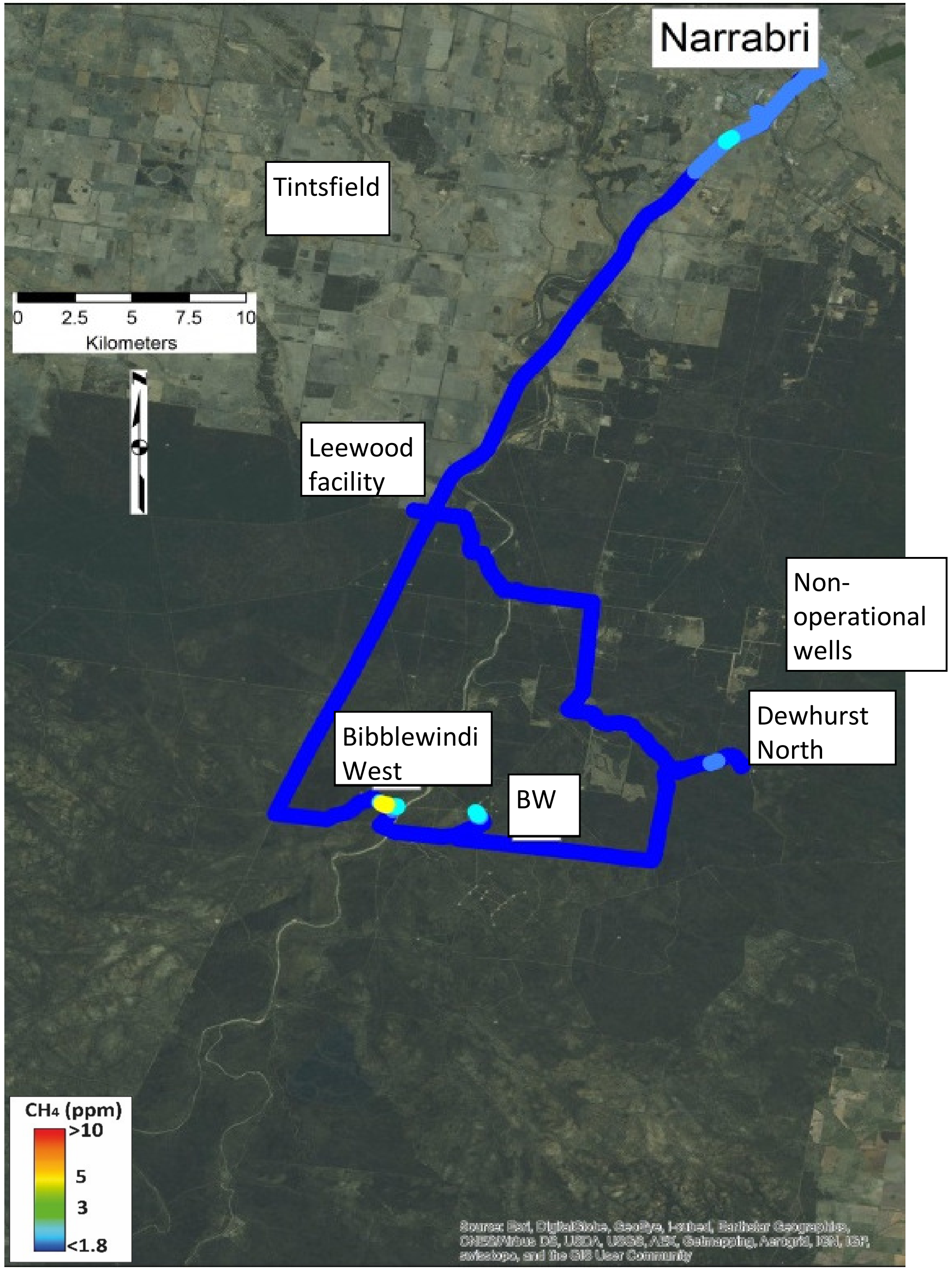


Pilliga overview: Pre-production baseline

Data collected during the evening August 2014.

Highest concentration:

7.78 ppm (see additional slides on this survey)

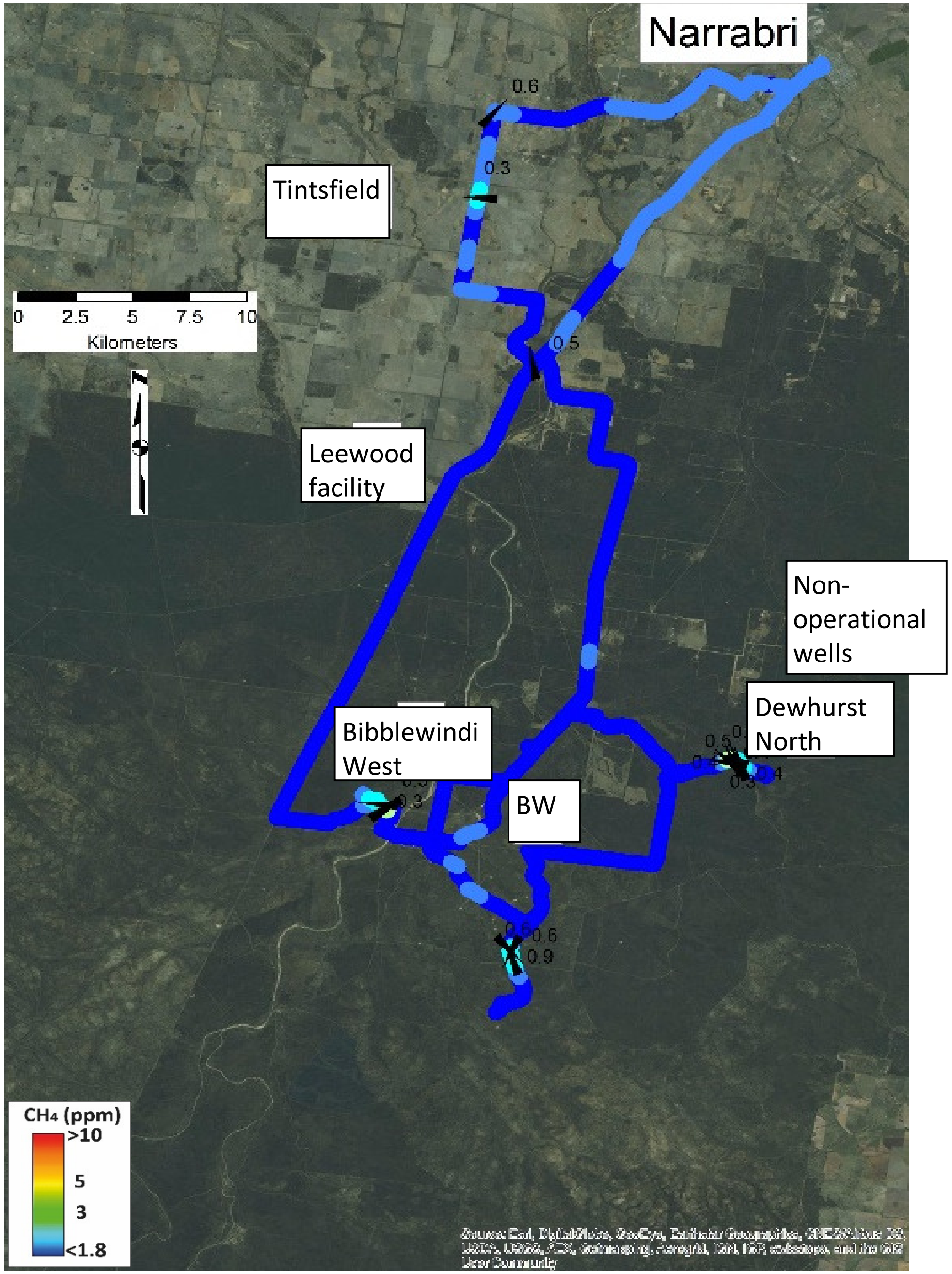


Pilliga overview: Pre-production baseline

Data collected during the evening in September 2015.

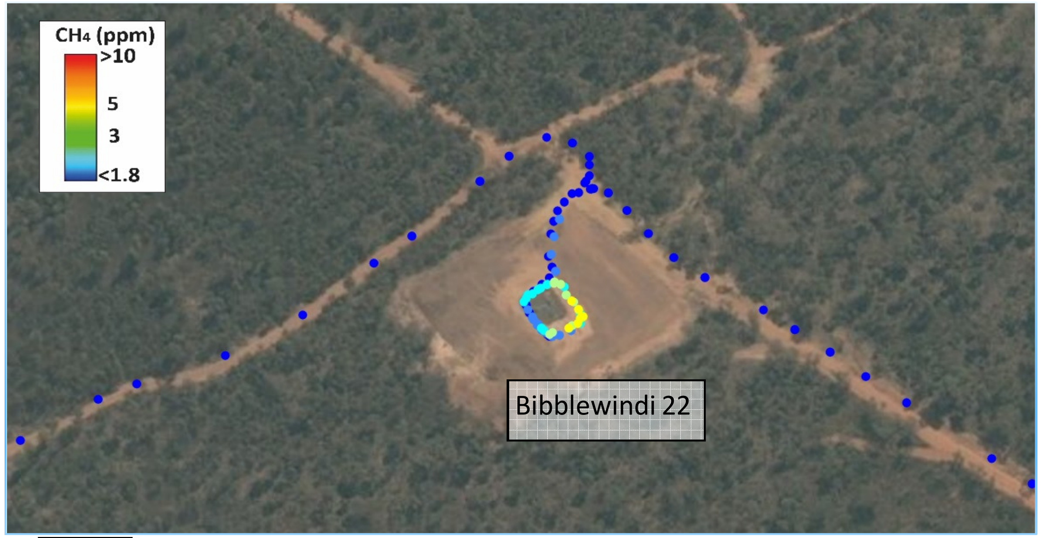
Highest concentration:

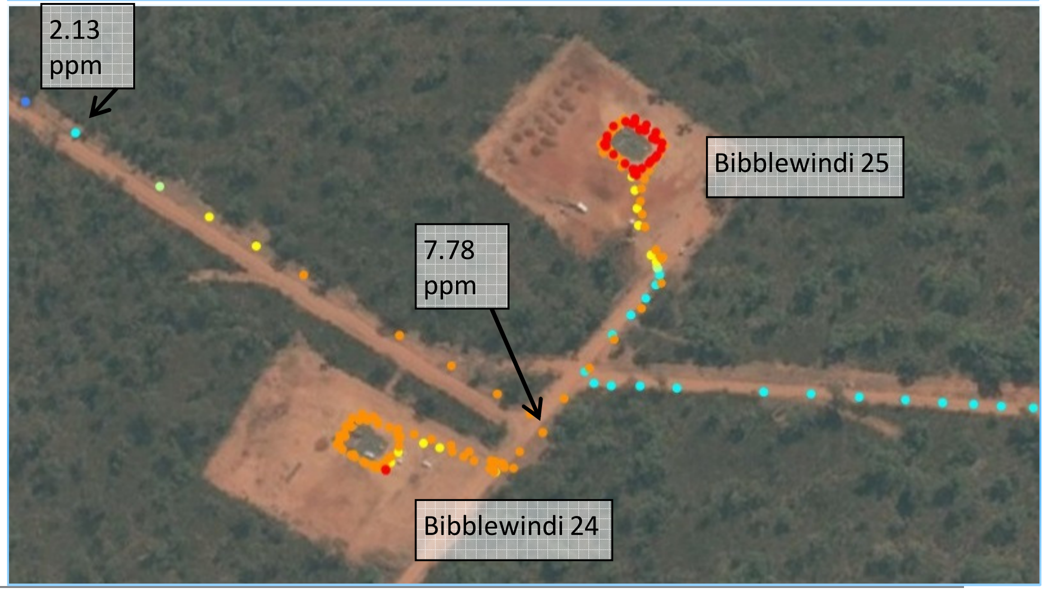
2.64 ppm.



Pilliga: August 2014 testing FLIR CH4 camera

- Data not from public roads
- Bibblewindi 22: 3.42 ppm inside fence.
- Bibblewindi 24: 10.5 ppm and Bibblewindi 25: 59.8 ppm. Both numbers collected inside fenced off area.





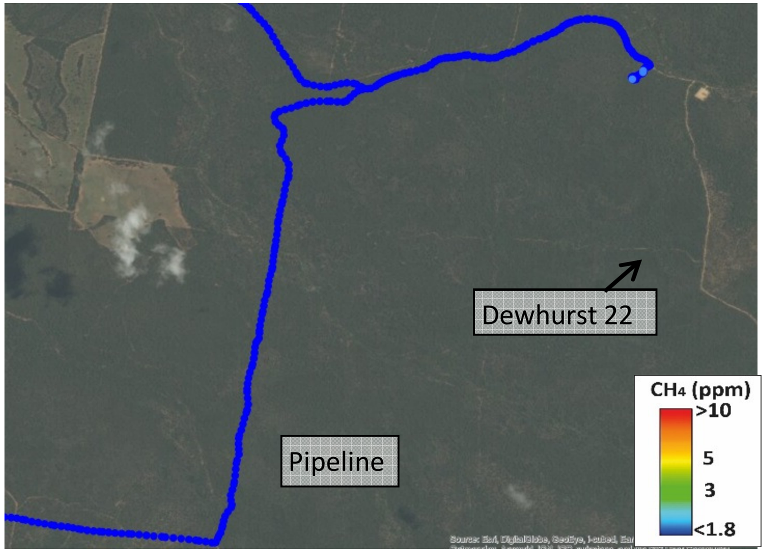
Pilliga Forest background and development

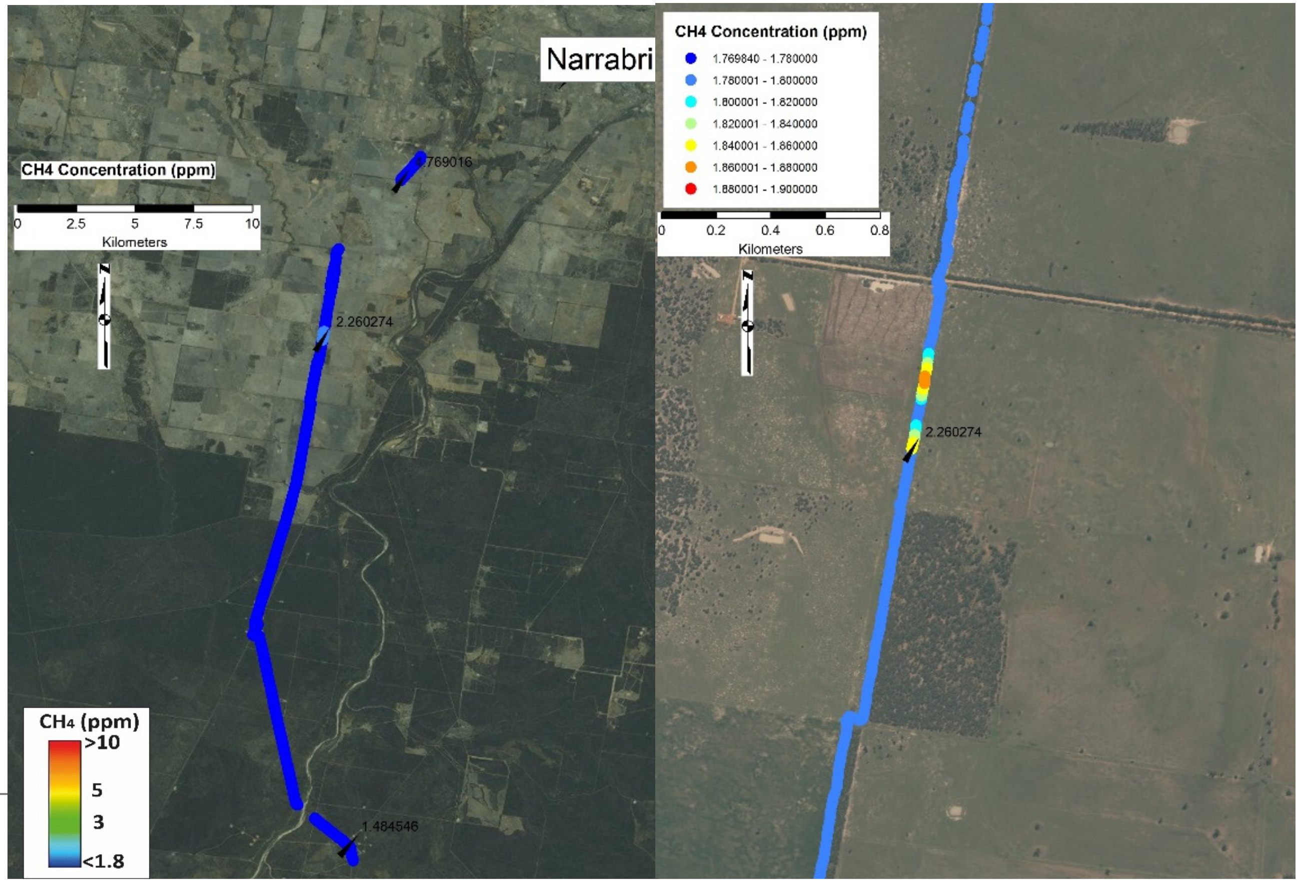
Survey of planned location for Leewood facilities

- Highest value in August 2014 was 1.81 ppm

Pipeline surveys

- Top : eastern Pilliga pipeline – August 2014. Highest value was 1.81 ppm.
- Bottom: Power station to Bibblewindi – September 2015. Highest value was 1.87 ppm (cows present).

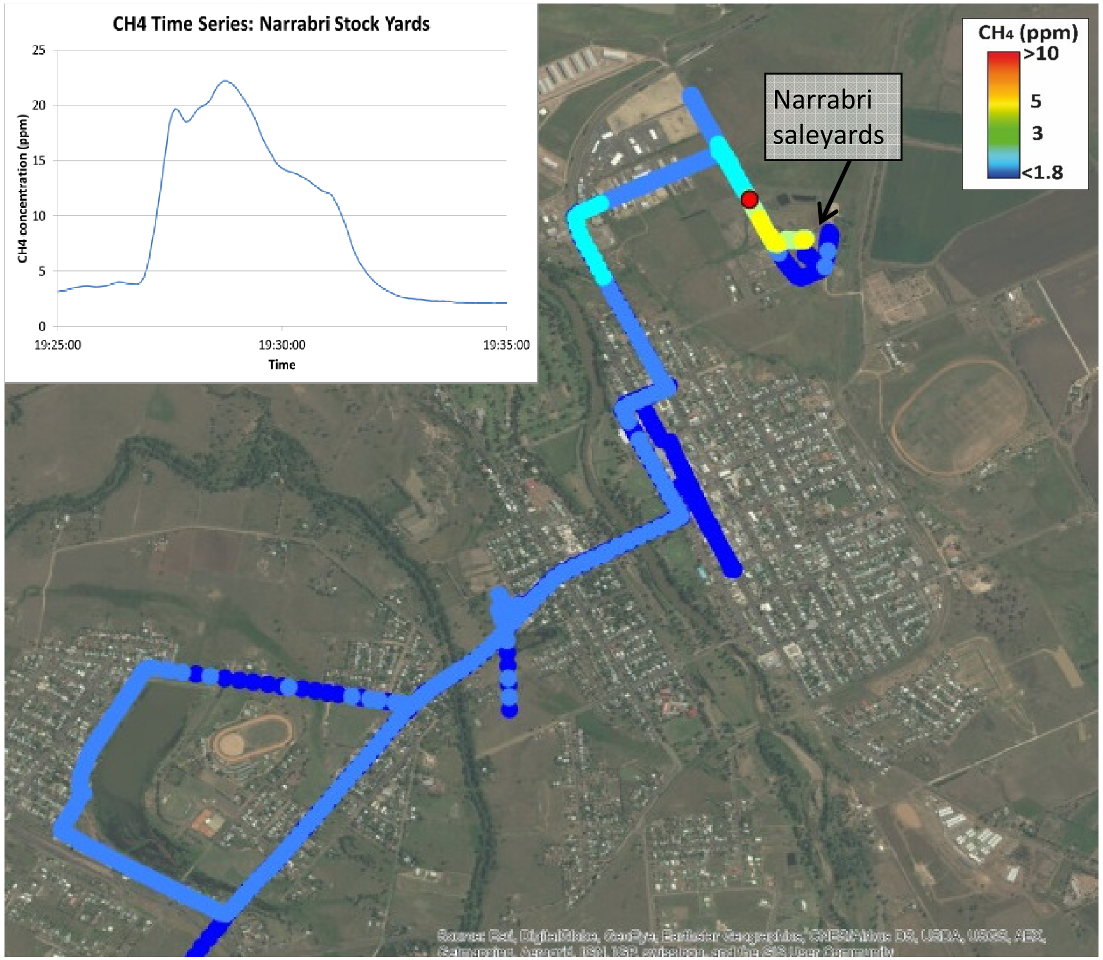




Non-CSG: Livestock as a CH4 source

Narrabri saleyards.

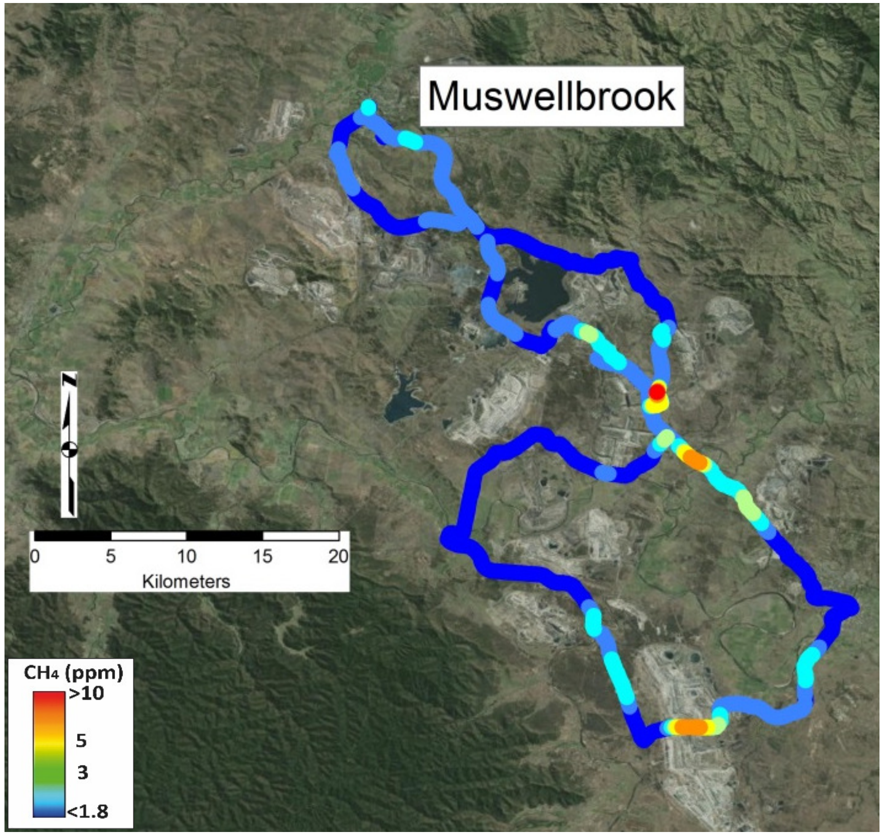
Data collected on the evening of 30/4/13.



Non-CSG: Upper Hunter Valley Coal

Afternoon and evening of 22/8/13

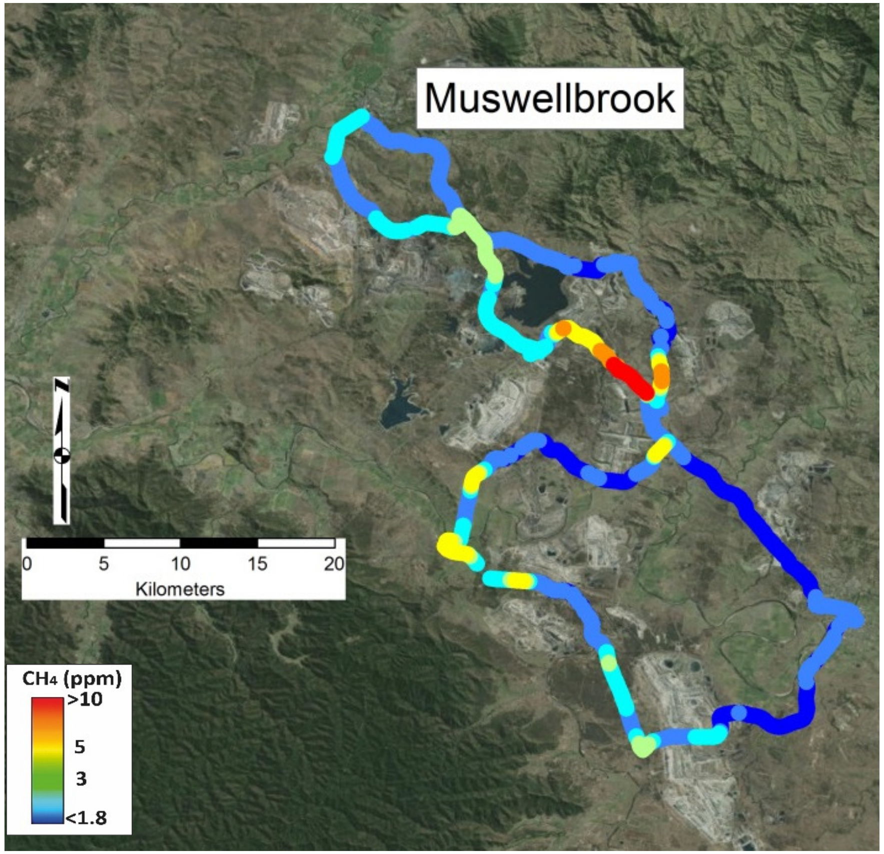
Highest concentration: 10.73 ppm



Non-CSG: Upper Hunter Valley Coal

Afternoon and evening of 15/8/14

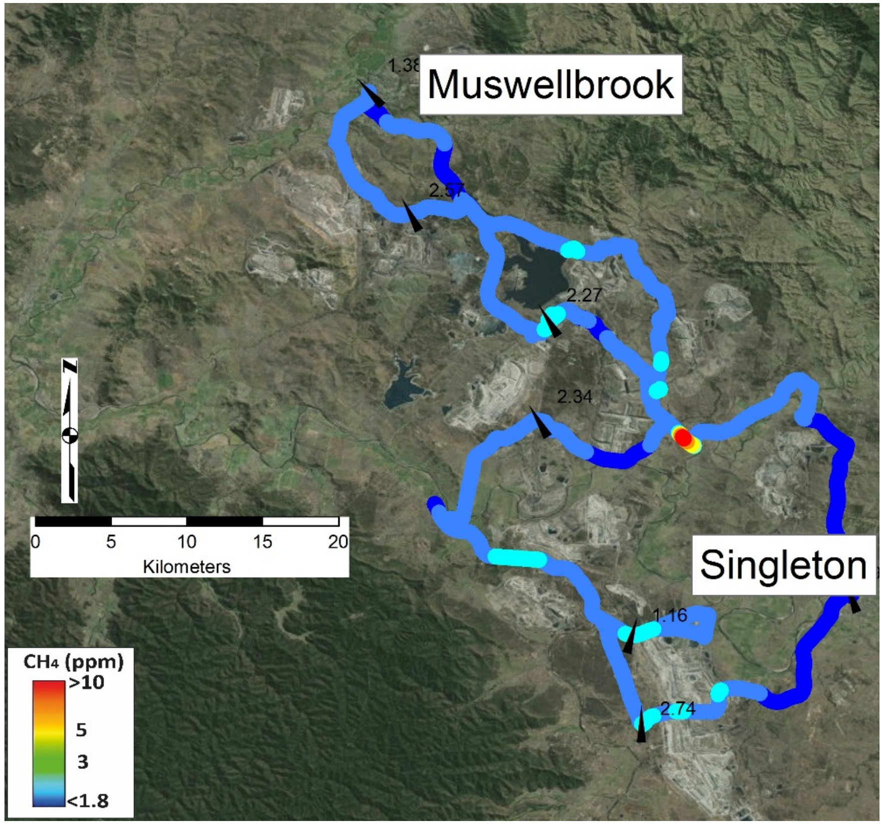
Highest concentration: 34.28 ppm



Non-CSG: Upper Hunter Valley Coal

Afternoon of 24/9/15

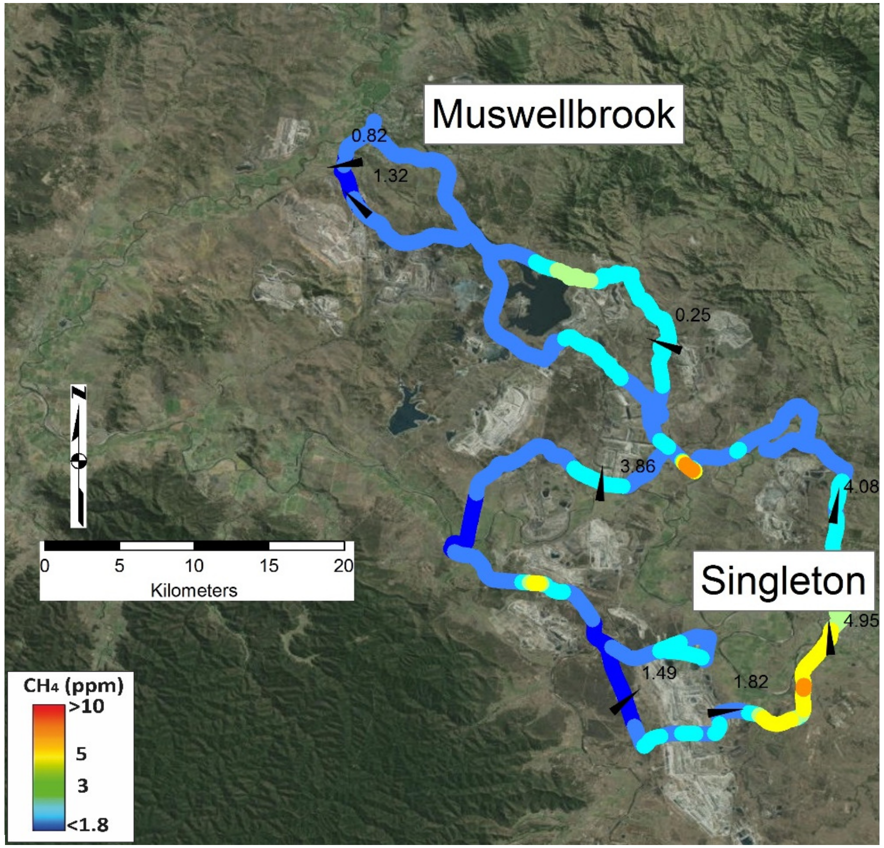
Highest concentration: 10.88 ppm



Non-CSG: Upper Hunter Valley Coal

Evening of 24/9/15

Highest concentration: 7.36 ppm



Non CSG land use summary – all varied from background 1.8 ppm to:

- Cattle (saleyards, feedlots, abattoirs): Tamworth 8.19 ppm, Narrabri 22.22 ppm
- GAB Bore: Pilliga 97.70 ppm
- Farmers' bores: Gunnedah 129.34 ppm
- Hunter Valley Coal: 34.28 ppm
- Landfills: Narrabri waste facility >24,000 ppm (when Picarro failed), 78.74 as we were driving through.
- Wetland / dam: 5 ppm, > 600 ppm when mud was scratched.

Summary

- The technology used for these studies is very new. These studies were not possible a few years ago.
- The data presented here are concentration snapshots. Many factors influence gas concentration (weather conditions, time of day…). We have collected data over a range of conditions; ultimately we have endeavoured to collect data so as to maximise the CH4 concentrations that we see to better identify CH4 sources.
- Baseline data were collected over Santos' CSG properties. There appears to be little or no naturally occurring CH4 in the Pilliga area.

Summary

- We detected CH_4 during later surveys in areas where "appraisal" had begun. Interestingly 2015 production was higher than 2014, yet 2014 concentrations were higher. Is this due to slightly different conditions or was the system running better in 2015? These data are snapshots.
- It is important to examine CH_4 distribution across CSG against other land uses that produce CH_4.

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Methane and Volatile Organic Compound Emissions in New South Wales

Report for the New South Wales Environment Protection Authority

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Citation

Day, S., Tibbett, A., Sestak, S., Knight, C., Marvig, P., McGarry, S., Weir, S., White, S., Armand, S., van Holst, J., Fry, R., Dell'Amico, M., Halliburton, B., Azzi, M. (2016). Methane and Volatile Organic Compound Emissions in New South Wales. CSIRO, Australia.

Copyright and disclaimer

Important disclaimer

EPA disclaimer

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Executive Summary

In order to investigate and better understand atmospheric methane (CH_4) emission sources, particularly from the coal seam gas industry, the NSW EPA commissioned CSIRO Energy to undertake a study to develop methods for characterising CH_4 and other gaseous emissions from different area sources in NSW. While there are internationally recognised methods for estimating (rather than measuring) CH_4 and other greenhouse gas emissions from many sectors of the economy for national inventory reporting, some of these methods do not provide sufficient accuracy for baseline monitoring in sensitive areas. Hence, methods for directly measuring emissions at the facility level are necessary for assessing the impacts of certain activities on greenhouse gas emissions, and assessing the effectiveness of mitigation measures.

The specific aims of the project were to firstly develop and trial methods that can be used to locate, identify and quantify CH_4 emissions from the CSG industry in particular but also other industries such as wastewater treatment, municipal solid waste disposal, coal mining, agriculture and natural sources. Secondly, investigations were undertaken to examine the possibility of attributing sources by measuring the chemical composition of the emissions and isotopic ratios of carbon and hydrogen in CH_4 and carbon in carbon dioxide (CO_2). Finally, ambient concentrations of volatile organic compounds were measured at various sites to gain an understanding of source related impacts on ambient air quality and to identify the prevalence of compounds that may specifically characterise a source.

Measurements were made between June 2014 and May 2016 at 16 sites across NSW that included:

- coal seam gas operations,
- landfills,
- wastewater treatment plants,
- agriculture (a rice farm and cattle feedlot),
- coal mining and
- natural sources.

In addition to the on site measurements, ambient CH_4 concentration was measured across NSW throughout the course of the project.

Methane Emissions

A variety of methods for detecting and quantifying CH_4 emissions were examined. Mobile surveys using a cavity ringdown spectrometer mounted in a 4WD vehicle was effective at locating CH_4 sources even while being driven at highway speeds. More than 25,000 km of surveys were driven during the project and a wide variety of CH_4 sources were detected. The surveys indicated that CH_4 concentrations across the state are generally consistent with normal background levels expected in continental locations, with somewhat higher concentrations in urban areas compared to rural regions. There was also often variation in ambient concentrations due to atmospheric mixing conditions – higher concentrations were often observed during the early morning. However, there were many locations in both rural and urban areas where significantly elevated CH_4 concentrations were detected. In some cases, the source of the CH_4 could be identified (e.g. landfills, agriculture, coal mining etc.); however in other instances, the source of the elevated CH_4 concentrations was not apparent. Some of the unidentified sources were located in urban centres where there was no obvious source of CH_4; it is hypothesised that some of these sources may be due natural gas reticulation emissions. Further work is required to confirm this.

Several methods for quantifying CH_4 emission rates were examined. Continuous techniques which include eddy covariance or inverse methods can provide temporal information on emissions over extended periods but they require fixed monitoring installations and because of the number of sites where measurements were required for this project, these techniques were not considered to be feasible. Instead, periodic measurements were made at most sites at least four times (often many more times) using ground level plume traversing and surface flux chamber methods. Later in the project, a tracer gas method was also applied at a number of sites.

The plume traversing method has been used successfully in previous monitoring of CSG wells and elsewhere, and this technique was deployed throughout the current project. The method does, however, require suitable wind conditions and access to the plume so that the CH_4 analyser can transect the plume. Unsuitable topography or the presence of buildings or other obstructions can reduce the effectiveness of the method. Consequently, this approach could only be used successfully at suitable test sites. Despite the limitations of this method, under favourable conditions, it is considered a useful method that has the advantages of simplicity, is rapid and can be applied at a range of scales.

Another approach involved surface flux chambers. These were deployed at a wide range of sites including natural areas, a rice farm, a feedlot, coal mines, a CSG water treatment facility, wastewater treatment plants and landfills. Some sites required the construction of special chambers to suit the particular application – for instance, a floating chamber was used at the wastewater and CSG water treatment facilities.

Overall, flux chambers provide accurate flux results for the area covered by the chamber and the method is simple to use. The main disadvantage is that because the chamber can usually only cover a small area, many measurements are necessary to characterise a given site. Consequently, the technique is relatively slow and labour intensive if used for estimating emissions from large areas. Moreover, for some sites with high levels of emission variation across the surface (e.g. landfills), it can be very difficult to achieve a representative sample hence any site-wide estimate will have a high level of uncertainty. For other sites with less heterogeneity, surface flux chambers can provide good results. The method is well suited to investigate emissions from wastewater treatment plants since it can provide detailed information on emission routes from various parts of the process. However, suitable access to emission sources must be available and this proved to be a limitation at some sites.

During the project, the use of a tracer gas for quantifying emission rates was examined. In this method, a tracer gas (acetylene was used in this project) is released at known rate from the CH_4 source and the concentration of both CH_4 and the tracer is measured downwind. The ratio of the two gases together with the tracer flow rate enable the CH_4 emission to be calculated. A significant advantage of the tracer method over other atmospheric plume dispersion methods is that it is not necessary to have detailed measurements of the plume dispersion characteristics or even the wind speed to calculate emission fluxes. Initial trials of the method using controlled releases of CH_4 at known rates yielded CH_4 flux estimates that were within 10 % of the actual emission rate. The tracer method was used at several locations during the project. Excellent results were obtained at the Narrabri CSG field where other methods could not be readily deployed. There are challenges associated with using the tracer method at large area sources, but encouraging results were obtained at one of the landfill sites. Of all the methods, this technique has considerable promise because of its high level of accuracy, relative simplicity and ability to be deployed at many different sites under widely varying atmospheric conditions.

Methane flux estimates were made at most of the sites examined including selected locations within four CSG fields. No emissions were found from the plugged, abandoned, and suspended wells in the Casino gas field. Emissions from production wells examined in the Camden and Gloucester gas fields were also very low, although in a few instances slightly elevated CH_4 concentrations above background levels were detected in the immediate vicinity of some well pads. The maximum emission rate detected from these wells was 0.03 g CH_4 min^{-1}; most of those examined showed no emissions. However, there were areas within the Camden gas field where significantly elevated CH_4 concentrations compared to background levels were detected on some occasions. In the Narrabri field, two of the six wells examined showed emissions that appeared to be mainly related to the operation of gas-powered pneumatic equipment on the pads. The emission rates measured at these wells ranged between 2.9 and 22.7 g CH_4 min^{-1} (4.2 and 32.7 kg day^{-1}), which are within the range of emissions measured previously on Australian CSG wells. While the uncertainy associated with the individual emission rates determined for these wells is relatively low, extrapolating the few results reported here to the entire industry would introduce a much higher level of uncertainty.

Emissions measured from a produced water treatment facility in the Narrabri field were low and were calculated to be between about 18 and 32 kg CH_4 day^{-1}. However, it is likely that most of the CH_4 contained in the produced water is emitted soon after being pumped to the surface so these estimates are probably an underestimate of the actual emissions associated with water production.

Except for the natural areas and the rice farm, seasonal variation was not detected in the results from these measurements. To some extent, this was because of the relative infrequency of the measurements, which did not provide sufficient temporal resolution. More commonly, however, other factors at each site (e.g. the different operations at landfills, coal mines, etc.) obscured more subtle seasonal variability. Short-term meteorological influences such as changing air pressure is also known to affect emission rates at some sites.

Implications for a NSW Methane Emission Inventory

Estimates of CH_4 emission rates were made at most of the sites visited during the project. However, due to various reasons, we were unable to generate flux estimates that could be considered representative; rather they represent snapshots at that moment in time. All of the estimates made must be considered within the limitations of the measurements made on each site, which often resulted in substantial uncertainty. The uncertainty of the emission flux estimates is derived not only from the measurements but also from the representativeness of the sample. For example, the uncertainty of the flux estimates made for individual CSG well pads is relatively low, especially when the tracer gas method was used. However, we only examined a small number of wells that represent only a few percent of the total number of wells in NSW; the CH_4 emission behaviour of the remaining wells is as yet unknown. In addition, the results obtained here may not be representative of normal average emissions due to diffecences in operation and management practices. Similarly, individual surface fluxes measured using the chamber method have low uncertainty but the heterogeneity of many sites may lead to large uncertainties if the individual measurements are extrapolated to estimate total emissions from large areas.

There was never any intention within the current project to develop an inventory of methane emissions for NSW; however, the results of study suggest that developing an accurate CH_4 emissions inventory for the state will be a major and challenging undertaking. There are numerous CH_4 sources across NSW and while some of these are reported to the federal Clean Energy Regulator under the current National Greenhouse and Energy Reporting legislation, emissions estimates are often subject to significant uncertainties. Moreover, some sources such as agriculture and natural sources are not reported while others may be below the current reporting thresholds. However, when considering the uncertainty of emissions estimates, it is also important to understand the relative contribution of each emission source to the total inventory. Small emission sources, even with very high uncertainty, contribute little to the overall uncertainty of an inventory. Conversely, large sources with high uncertainties (e.g. agriculture) will dominate the uncertainty of the inventory. If attempting to better define a statewide emission inventory, it is therefore worthwhile targeting in the first instance the larger sources.

During this project, several methodologies were examined and tested as to their applicability for directly measuring CH_4 emissions from various sources. The results have also yielded some preliminary flux estimates but these are still a long way from inclusion in a robust inventory for NSW as a whole or even for individual industry sectors. Some of the methods trialled show considerable promise for measuring emissions from some sources on a routine basis; however, other sources may require further development. In yet other cases, current practices or emission factors may yield sufficiently accurate data to develop an inventory, provided the necessary data can be obtained. A summary of the main sources investigated in this project is provided in Table ES.1. The relative size of the emission sources shown in Table ES.1 is a subjective estimate based on current national inventory data and the authors' knowledge of emissions and it is hence acknowlegeded that these magnitude estimates are at best a rough guide. Also shown in Table ES.1 are some methods for measuring or estimating emissions from these sources. It is noted that other sources of CH_4 exist in NSW (such as biomass burning) but these are not included in Table ES.1.

Table ES.1. Summary of the main sources of CH_4 emissions in NSW. Note that the relative magnitude of the emission sources is a rough guide only.

Source	Relative Emission Source Size	Uncertainty	Notes
Coal Mining	Large	Low to moderate	Fugitive emissions estimated and reported under NGERS. Underground mines measure emissions and have low uncertainty. Open-cut operations use gas content data from coring ahead of mining; moderate uncertainty.
CSG	Currently small in NSW	Moderate to high	Potential emissions from wells, processing plants, water treatment facilities, pipelines etc. Emissions reported under NGERS but some estimates have high uncertainty (although others may have lower uncertainty e.g. some venting and flaring operations). The tracer gas method has application for measuring emissions from well sites and some other infrastructure.
Agriculture	Large	High	Mostly from ruminant animals and liquid manure management. Feasible but difficult to measure; published emission factors for cattle more practical. Rice farming is a small source overall in NSW.
Landfills	Moderate	High	Difficult to measure but methods exist. The tracer gas method shows promise.
Wastewater Treatment	Probably small	High	Feasible to measure with chambers and tracer; most emissions from biosolids storage.
Wetlands	Small	High	Likely to be a small component of NSW inventory. Difficult to measure directly but chambers or methods (e.g. eddy covariance) are feasible.

Volatile Organic Compound Emissions

Volatile organic compounds (VOCs) that are potentially associated with methane emissions sources have been investigated in this project to gain an understanding of source related impacts on ambient air quality and to study the prevalence of compounds which may specifically characterise a land-use activity. As such, it was important to evaluate a large suite of organic compounds and to move to minimum levels of detection beyond that normally required under guidelines for air quality assessment. A suite of compounds that represent VOC emissions from anthropogenic sources was targeted and further, methodologies were implemented to isolate non-standard compounds of both biogenic and anthropogenic origin to provide added insight into source specific emissions that are detectable in ambient air.

The VOC evaluations were based on a substantial site monitoring programme of repeated campaigns to provide indicative information on emissions variability at a particular location as well as those inherent to the activities and processes that dictate source intensity. Ambient monitoring was undertaken for the source categories that were monitored for methane i.e. natural sources, the Camden region of CSG activity, animal feedlot, coal mining, CSG production facilities, landfills and wastewater treatment plants. Rice farming was excluded from VOC monitoring as this source was specifically selected for the purposes of its biogenic methane emissions and as such, ambient VOC determinations were not considered pertinent to this category. Monitoring campaigns for the Camden region encompassed ten sites across suburban and semi-rural areas where CSG operations were active and these sites were also monitored for seasonal variability in their emissions.

This work has reported the ambient concentrations for over 120 volatile organic compounds that are designated as priority pollutants in air quality assessment by Australian and International agencies. The suite of compounds comprised the hydrocarbon VOCs which are prioritised for photochemical assessment but which were targeted in this work as markers for urban transport and off-road vehicle emissions, liquid and gaseous fuels, and other combustion derived emissions. The priority air toxic VOCs were also evaluated as these characterise the emissions from various waste processing and industrial activities and are of importance in air quality assessment for human and environmental health purposes.

Further VOC characterisation studies were undertaken to include non-standard compounds of importance in source recognition. Mass spectral interpretation of the chromatographic output from VOC analyses was used to find and identify new compounds and a sorbent tube collection methodology was also investigated to extend the range of compounds that could be captured and isolated. The classes of compounds that were targeted included sulphur, oxygen and nitrogen containing species that are present as either volatile or semi-volatile compounds in ambient air, and which arise from biogenic as well as anthropogenic processes. These classes of compounds tend to have different chemical and physical characteristics to the priority VOCs and hence are more difficult to capture and isolate. Over 45 compounds, additional to the priority VOCs, were identified in this manner.

The determination of hydrocarbon VOCs in CSG sourced well gases was also undertaken. The focus was on the minor hydrocarbon compounds, i.e. those above C_5 and aromatic compounds, which are not generally measured in these gases. This determination was made on a selection of raw gas samples collected from producing CSG wells, and the analytical methodology was optimised for this specific application. The work was not a requisite of this project however, it was considered that this determination might be informative in the recognition of the CSG methane source impact to ambient air and with respect to human and environmental health.

A portfolio of instrumentation was implemented and methodologies were optimised and validated for priority VOCs, characterisation studies and the well gas hydrocarbons in order to cater for the differences in site sampling techniques and the associated modes of sample introduction, differences in sample matrix, instrumental detection requirements and the various classes of compounds targeted. Instrumental analysis was undertaken using gas chromatography with mass spectrometry and flame ionisation detection (GCMS and GCFID) for determination of priority hydrocarbon and air toxics VOCs, and using GCMS with thermal desorption capability for sorbent tube based characterisation studies; the latter incorporating both electron impact and chemical ionisation modes of mass spectrometry for the elucidation of compound identity.

The results from this work have been evaluated from the perspective of ambient concentration and relevance to source impact on air quality, and compound type and relevance to source characterisation. The reader is referred to Section 7 for a fully referenced discussion of the observations and findings.

General findings from the ambient study are summarised in the following points and findings specific to each source category are summarised subsequently.

- A number of the Freon™ group and other halocarbons (specifically dichlorodifluoromethane, trichlorofluoromethane, 1,1,2-trichloro-1,2,2-trifluoroethane and carbon tetrachloride) and certain sulphur containing species (carbonyl sulphide and, tentatively, dimethyl sulphone) were observed at relatively consistent concentration at all sites. They are found at trace concentration (< 0.5ppbv) and are considered compounds which are ubiquitous in the atmosphere.
- The presence, or lack of, a hydrocarbon profile indicative of vehicle exhaust was informative in evaluating contributing sources to the ambient air at a particular site and petrol versus diesel hydrocarbon profiles could also be distinguished. Minor vehicular related impacts were apparent at semi-rural and suburban locations in the Camden region and the impact of on-site vehicles was apparent at a number of operational sites.
- Measurement of VOCs at the Cuba State Forest found minimal impact from anthropogenic activity and as such, this natural source established a baseline for biogenically derived compounds. This enabled land-use source emissions to be effectively allocated for compounds that were common to anthropogenic and biogenic sources (such as ethanol, acetone and other oxygenates).

- From an air quality perspective, ambient concentrations of priority hydrocarbon and air toxic VOCs were generally low (mixing ratios of low ppbv) and, with certain exceptions, in the range expected for the particular source and the location or processes within that environment. Measurements at natural and rural environments, and remote locations associated with mining or CSG activities, were in the trace to low ppbv concentration range and many of the priority VOCs could not be detected in these environments.
- Obvious impacts on ambient VOC concentrations were seen from more intensive sources such as those resulting from animal feeding, municipal solid waste disposal and wastewater treatment, where compounds specific to the activity were apparent, such as biologically derived oxygenates and nitrogenous compounds, solvent residues and chlorinated compounds.
- Source characterisation studies for non-standard VOCs revealed additional compounds and organic classes of compounds to those from the priority VOC suites. The sorbent tube collection methodology was found to extend the range of compounds that could be captured and isolated compared to those from VOC collection by the canister technique. Compounds with strong links to vegetation and biological processes, such as monoterpenes and more complex oxygenated compounds, were apparent at many sites. At higher intensity land-use sites these were overlain with compounds whose attributes were more specific to the source, such as odorous sulphur and nitrogen containing compounds for example.
- Within each source category, site-specific operations and processes also dictated the intensity of the emissions and excursions from more typical measured levels were seen for particular operations at the feedlot, landfill and wastewater treatment sites.
- The effect of the seasons on ambient VOC concentrations was investigated from four monitoring campaigns over a twelve-month period for ten sites across the Camden region. This evaluation showed a link to seasonal variability in the emissions of biogenic compounds and possibly, vehicle related emissions. However, these observations must be tempered by the many other factors, such as source intensity, emissions transport and atmospheric fate, which are well known to affect ambient concentrations of VOCs and other air pollutants.
- The analysis of non-methane hydrocarbon VOCs in CSG sourced well gas was effective in providing quantitative results for minor hydrocarbon compounds which are not commonly measured in these gases, i.e. those above C_5 and aromatic compounds; benzene, toluene and xylenes. Compounds at a concentration down to 0.007ppmv were measurable. The determination was informative in the recognition of a CSG source impact to ambient air and with respect to human and environmental health.

Specific findings for VOC emissions associated with each source category are summarised in the following points:

- *Natural Sources* (Yaegl Nature Reserve, Cuba State Forest)
  Compounds with strong links to vegetation and biological processes (such as isoprene and monoterpenes) and the oxygenated species (such as ethanol, acetone, isopropanol and more complex oxygenates) were observed. The Yaegl site showed a minor traffic related impact from nearby roadways. There was no detectable impact from anthropogenic sources in the ambient air collected from Cuba State Forest. The monitoring of this natural source was used for allocation of biogenic versus anthropogenic activity to the emissions from other land-use sources.
- *Camden Region*
  The overall consistency in the results from ambient monitoring of the Camden sites establishes a database of expected concentrations of priority hydrocarbon and air toxics VOCs for the morning period at rural and semi-rural locations in the Camden region.

  A clear impact from traffic related emissions was seen in the hydrocarbon VOC profile observed in the ambient air for all ten sites monitored in Camden region. However, ambient concentrations of the hydrocarbon VOCs were in the low ppbv range and consistent with levels expected for semi-rural and suburban environments.

Biogenic compounds were apparent in the VOC profile and their emissions are indicative of the semi-rural atmosphere of the Camden regional sites. Compounds associated with biological processes included small oxygenates (ethanol, acetone and isopropanol) which were present at concentrations broadly similar to those observed in the natural environments. 2-butanone and more complex C_4-C_9 aldehydes, ketones and alcohols were also identified in samples from the summer campaign and emissions of isoprene and monoterpenes from vegetation were observed in the VOC profile at many sites.

Hydrocarbon and air toxics VOC profiles were not suggestive of a major industrial source of emissions in the vicinity of the Camden sites.

- *CSG impact on ambient VOCs* – VOC monitoring in the Camden region encompassed a geographical area where CSG production was active. Ethane and propane were present in the ambient air in this region and these compounds are components of CSG sourced well gas. An evaluation was therefore made as to the likely impact of CSG as a source of these emissions to ambient air. Based on measured methane concentrations for the region and ethane and propane concentrations in the CSG sourced well gas, a predicted ambient concentration for these compounds was compared to measured ambient concentrations. This evaluation concluded that ethane and propane emissions from CSG were negligible and their presence in ambient air in the Camden region was derived from other sources. Aromatic compounds were present in the well gas at extremely low concentrations and hence were not a measurable source of aromatic compounds to ambient air in the region (refer later point regarding well gas hydrocarbons).
- *Seasonal variability* – seasonal monitoring of VOCs across the Camden sites showed a general trend towards higher levels of biogenic compounds (such as oxygenated compounds, isoprene and monoterpenes) in the spring and summer campaigns which is consistent with warmer temperatures and a higher intensity of photosynthetically active radiation. Vehicle related hydrocarbon VOCs were generally lower in summer than the levels measured in winter and a reduction in the relative concentration of alkenes compared to alkanes is consistent with the effect of higher rates of photolysis on the more reactive species. Isobutane dominated the hydrocarbon emission profile in the warmer months, which may be indicative of higher evaporative losses from petrol-fuelled vehicles. These results indicate a possible link to seasonal variation particularly in the change in emissions of the biogenic compounds and, tentatively, the vehicle related emissions.

- *Cattle Feedlot* (Jindalee Cattle Feedlot).
The ambient air at this site was rich in an array of oxygenated, nitrogenous and sulphur-containing compounds commonly associated with animal by-products and odour. Ethanol, acetone and 2-butanone were found at higher concentrations than typically observed in vegetated environments and an excursion in ethanol (253ppbv) was measured on one occasion at the feedlot site. Odorous compounds related to animal by-products such as dimethyl sulphide and dimethyl disulphide, and to other biological processes; C_4 to C_8 aldehydes, ketones and alcohols were apparent in the emissions from this source. There were minimal emissions indicative of a vehicular or other source impacting the site indicating that the compounds found were directly attributable to the feedlot.

  With the exception of an excursion in ethanol, the overall ambient concentration of the priority VOCs associated with this source was lower than other more intensive land-use activities; i.e. landfill and wastewater treatment.

- *Coal mining* (Rix's Creek Coal Mine, Gunnedah Basin mining region).
Ambient concentrations at the Rix's Creek mine site were generally low in most VOCs compared to semi-rural and the higher intensity land-use sites. Those hydrocarbons that were identified inferred a diesel emissions profile, which is likely to be consistent with the machinery operating at the mine

site. In the case of the Gunnedah Basin mine, it is possible that fugitive emissions of ethane from seam gas contributed to the hydrocarbon profile.

The ambient air in the vicinity of the mine in the Gunnedah Basin showed low levels of compounds associated with vehicle exhaust and vegetation, which may be consistent with on-site mining activities, and the roadside location of the monitoring site.

- *CSG facilities* (Camden, Gloucester, Narrabri).
  The CSG production sites at Camden and Gloucester were characterised by a hydrocarbon profile that was dominated by C_2-C_4 alkane species, an absence in C_2 and larger alkenes and the presence of aromatics. The dominance of alkanes in the hydrocarbon profile is consistent with that measured in CSG sourced well gases, however, these and the aromatics were disproportionately represented in the ambient samples compared to their profile in the well gases. Hydrocarbon concentrations were also not correlated with measured methane in the ambient air at the well pads. Hence, the hydrocarbon profile and concentrations found in the ambient air cannot be interpreted to be linked to CSG production at the Camden and Gloucester sites and an alternative source of VOCs is considered likely. The overall ambient concentration of VOCs measured at the Camden and Gloucester facilities was low compared with semi-rural sites, for example.

  The VOCs present in ambient air samples collected within the Narrabri CSG field and their concentrations were consistent with those found in a natural environment.

- *Landfills* (Summerhill Waste Management Centre, Parkes Waste Facility).
  Compounds associated with household and chemical disposal were elevated in the ambient air at the landfill sites. An excursion in the ambient concentration of acetone (200ppbv), accompanied by 2-butanone (18.0ppbv), were measured on one occasion at the Summerhill Centre. Chlorinated compounds such as trichloroethylene and tetrachloroethylene that are commonly used as markers for landfill emissions were identified at the Parkes Facility albeit at low (< 1ppbv) ambient concentrations. Other chlorinated solvent residues included dichloromethane, chloroform and benzyl chloride. The monoterpenes, limonene and a-pinene, which are used as fragrances in household products, were identified.

  Compounds derived from biological decomposition were also identified. C_4 to C_{12} oxygenates as aldehydes, ketones, alcohols, phenol and esters are associated with biological processes more generally but are likely enhanced due to soil decomposition in landfills. These compounds contribute to the characteristic odour associated with landfills.

  The impact of allied sources such as exhaust emissions from on-site diesel trucks and those from a methane generation system were identified at the Summerhill site.

- *Wastewater treatment* (Singleton Wastewater Treatment Works, Wagga Wagga Wastewater Treatment Plant, Picton Wastewater Treatment Plant).
  In certain aspects of the wastewater treatment process at the Singleton plant, VOCs were measured at ambient levels that were at the high end, or exceeded, those measured at other high intensity land-use sources, such as the landfill and the cattle feedlot. At the sewage inlet to the plant, emissions of acetone (93ppbv) accompanied by 2-butanone, were higher than other land-use sources, with the exception of an excursion in these compounds on one occasion at a landfill site. The Singleton WWTP was significantly higher than other sources in chlorinated compounds at the settling ponds; cis-1,2-dichloroethene (up to 13.5ppbv), trichloroethylene (up to 4.4ppbv) and tetrachloroethylene (up to 58.3ppbv). Compounds associated with odour, such as aldehydes, ketones, alcohols and nitrogenous compounds were apparent in the emissions profile at the Singleton site.

  Source identification and quantification is affected by the proximity of the sampling point, amount and type of emissions, meteorological variables and a range of other factors. However, it is evident that emissions from the Singleton wastewater treatment site were captured at a level that would allow certain oxygenated and halogenated VOCs to be used to characterise the operations at that site at that time. The high levels found at the Singleton site are also of importance when considering and assessing air toxics along with odorous emissions from this source.

In contrast, ambient VOC concentrations at the Wagga and Picton plants were broadly in the range measured at other intensive land-use sources, apart from an excursion in ethanol (40.9ppbv) on one occasion at the inlet location of the Wagga Wagga wastewater treatment plant.

- *CSG sourced well gas* (Camden, Gloucester).
  Hydrocarbon VOCs were characteristically present as the alkane class and straight chain, cyclic and branched alkanes through to C_8 were measured. Alkenes were not present in the hydrocarbon profile of the well gases. Aromatic compounds were detected at low concentration; the highest aromatic content was measured in samples from AGL operations at the Gloucester gas field (around 0.5ppmv benzene, 0.2ppmv toluene, 0.02ppmv xylenes). The detection of the larger alkanes and aromatics correlated with those gases with higher non-methane hydrocarbon concentration. The aromatics are considered consistent with components originating from gas formation processes.

  The ambient air equivalent concentration for the aromatic compounds, based on a worst-case emissions scenario in close proximity to a producing well, was estimated to be low pptv (parts per trillion by volume). This compares favourably with low ppbv (parts per billion by volume) concentrations measured in the ambient air of semi-rural regions that are impacted by low-volume traffic.

In meeting the objectives of the VOC component of the project, this work has brought together a volume of information on the levels of source related organic compounds in the ambient air in the vicinity of land-use activities in regional NSW and provides an ambient VOC database for the Camden region. A basis for future studies into the qualitative and quantitative impacts of various emission sources on air quality has now been established.

Isotopic Analyses

Laboratory analyses of molecular composition and stable isotopes were conducted on source gas samples containing between 0.1 and 100 % CH_4 and/or CO_2. Molecular composition using gas chromatography based natural gas analysers gave very reliable bulk composition results. A GC-IRMS was used to analyse carbon and hydrogen isotopes on CSG and microbial source gases from landfill and wastewater treatment plants. Plots of stable isotope data allowed seemingly similar gas samples to be differentiated into different categories and contributing source characteristics identified. Contributions from thermogenic, CO_2 reduction and acetoclastic/methylotrophic generation were able to be made for samples with mixed origins.

Some gas sampling techniques were found to be unsuited for isotopic analyses because they tended to fractionate the isotopic signature of the gas yielding unreliable results. Extended periods of sample storage may also affect isotopic analyses and consideration must be given to the type of storage containers used for sample collection and storage.

Analyses of ambient CH_4 for carbon and hydrogen isotopes were not possible using the GC-IRMS system directly because of the low concentration of CH_4. A prototype device designed to cryogenically concentrate ambient CH_4 was trialled; however it was adversely affected by significant co-trapping of ambient oxygen and nitrogen from the air. Further development of this system is required. The rationale for developing the prototype system was that it would be able to measure both the carbon and hydrogen isotopes of CH_4; whereas the single commercially available system only measures the carbon isotopes of CH_4 with limitations.

An alternative method using cavity ringdown spectroscopy for measuring isotopic ratios of $^{13}C/^{12}C$ in ambient CH_4 was trialled. Although this technique is now in widespread use, there are some limitations with respect to using these data for source apportionment. With the instruments used in this project, it was apparent that significantly elevated CH_4 concentrations above ambient were required to achieve a satisfactory signal to noise ratio. Best results were achieved when the CH_4 concentration was above about 5 ppm. At this point in time, the cavity ring down spectroscopic technique cannot measure the hydrogen isotopes of CH_4 at atmospheric concentrations, limiting the resolving power for source gas identification using stable isotopes.

1 Introduction

Methane is present in the atmosphere at relatively low concentrations (approximately 1.8 ppmv); however, because of its high global warming potential relative to CO_2, it has a significant effect on the balance of incoming and outgoing energy from the atmosphere (i.e. radiative forcing). Moreover, CH_4 has been increasing in concentration in the atmosphere since pre-industrial times and is the second largest contributor to global warming after CO_2 (IPCC, 2007).

Atmospheric CH_4 is derived from a wide range of natural and anthropogenic sources. Natural sources include wetlands, lakes and rivers, termites, bushfires, oceans, permafrost, and geological sources. Human activities that result in CH_4 emissions are largely associated with agriculture (e.g. ruminant animals, rice production), waste (e.g. landfills, sewage), biomass burning and fossil fuel production and utilisation. On a global scale, it has been estimated that roughly 60 % of CH_4 emissions originate from anthropogenic sources (Kirschke et al., 2013); however, these estimates are subject to very high uncertainty. In addition, there are significant regional variations in emission fluxes of CH_4 (Fraser et al., 2013).

Over the last few years, CH_4 emissions have been the focus of considerable scientific interest, especially in relation to unconventional gas production (shale gas, tight gas, coal seam gas). Although natural gas utilisation may produce lower direct greenhouse gas emissions from combustion compared to other fossil fuels, some recent studies have found high levels of fugitive CH_4 emissions from shale and tight gas production in the United States. The results of these studies, however, have been variable and often have high levels of uncertainties associated with the reported emission estimates (Pétron et al., 2012; Allen et al., 2013; Karion et al., 2013; Caulton et al., 2014a; Schneising et al., 2014; Kort et al., 2014).

At present, almost all unconventional gas production in Australia is derived from coal seam gas (CSG). Most production is currently in Queensland where several export liquefied natural gas plants are in varying stages of production, with the first commencing operation in late 2014. Despite major differences between the U.S. and Australian unconventional gas industries, it has been suggested that Australian CSG production may also result in high levels of fugitive emissions (Grudnoff, 2012). However, a recent study of emissions from a sample of CSG well pads in Queensland and NSW found that CH_4 emissions were generally very low compared to most of the results that have been reported for U.S. shale and tight gas operations (Day et al., 2014). That study, however, only considered well pads – other infrastructure was not examined – and the sample size was small compared to the total number of production wells in Australia. Further investigations into methane emissions in the Surat Basin in Queensland are currently underway (Day et al., 2013; Day et al., 2015).

Coal seam gas production in New South Wales is currently much less than in Queensland but there are several CSG projects in NSW at various stages of development. At present, there is relatively little publicly available information on CH_4 emissions from NSW CSG operations – only six wells included in the Day et al. (2014) study were in NSW. To address this, the New South Wales Environment Protection Authority (NSWEPA) commissioned a study to investigate emissions across NSW. While this study was largely motivated by concern over the NSW CSG industry and to inform future regulatory programmes in relation to air emissions associated with CSG activities in NSW, the study brief also required measurements to be made at other CH_4 sources such as waste management operations (landfills and wastewater treatment plants), agriculture (e.g. intensive cattle feedlots and rice farming), natural sources (e.g. wetlands) and coal mining.

Methods for estimating greenhouse gas emissions from many of these activities already exist, mainly for the purposes of compiling national greenhouse gas inventories. In Australia, for instance, the National Greenhouse and Energy Reporting legislation requires operators of many facilities to estimate and report emissions according to specified methodologies. However, CH_4 emissions are usually estimated rather than actually measured (the notable exception being underground coal mining where fugitive emissions are measured) and consequently may not have sufficient accuracy to be used for baseline monitoring or for assessing the effects of industrial activity within a region on local greenhouse emissions (e.g. increased CSG production), or mitigation measures.

One of the key objectives of the study therefore, was to develop reliable methodologies that can be applied for measuring CH_4 emissions at the facility level from not only CSG operations but also other relevant land-use sectors throughout NSW. The second objective of the study was to investigate the possibility of characterising emissions from various CH_4 sources and using chemical 'fingerprints' to assist in attributing sources. This involved determining isotopic ratios of $^{13}C/^{12}C$ and $^{2}H/^{1}H$ in CH_4 and CO_2 samples collected from various sites, the determination of chemical composition on a wide range of samples, and the determination of ambient concentrations of a suite of volatile organic compounds in the vicinity of each source. Volatile organic compounds were investigated to gain an understanding of source related impacts on ambient air and to study the prevalence of compounds that may specifically characterise a source.

In this report, we present the results of this project, which was conducted between June 2014 and May 2016.

2 Methane Emissions

Atmospheric CH_4 concentrations have increased from about 720 ppb (0.72 ppm) during the mid-18th century to more than 1800 ppb (1.80 ppm) during 2011 (Hartmann et al., 2013). These values represent global averages but there are significant regional and seasonal variations in concentration. Baseline atmospheric monitoring of clean air at the CSIRO Cape Grim station in Tasmania shows that current southern hemisphere clean air concentrations of CH_4 vary between about 1.75 to 1.79 ppm, with the higher concentrations occurring during the winter months (CSIRO, 2015).

According to the most recent IPCC Assessment Report, global CH_4 emissions during 2011 were estimated to be 556 $\pm$ 56 Tg CH_4 y^{-1} with 354 $\pm$ 45 Tg CH_4 y^{-1} (64 %) attributed to anthropogenic activities and 202 $\pm$ 35 Tg CH_4 y^{-1} (36 %) from natural sources (Hartmann et al., 2013). These estimates, however, are subject to considerable uncertainty due in some cases to limited data and also differences in the methodology used to develop the inventories. For instance, Kirschke et al. (2013) estimated the global CH_4 budget for several decades using top-down and bottom-up methods. For the period between 2000 to 2009, top-down methods yielded total emissions of between 526 and 569 Tg CH_4 y^{-1} (mean 548 CH_4 y^{-1}) while the bottom-up approach gave an estimate of 542 to 852 Tg CH_4 y^{-1} (mean 678 Tg CH_4 y^{-1}). Emissions are not evenly spread across the globe and substantial regional variation is apparent (Fraser et al., 2013). While the sources of most of the global CH_4 budget are well understood, improving estimates of emission fluxes is an area of active research.

In Australia, anthropogenic CH_4 emissions from energy use, agriculture, waste management and other sectors are estimated and reported in the annual National Greenhouse Gas Inventory. Table 2.1 summarises the emission estimates reported for Australia during 2013 (AGEIS, 2015). Total emissions were estimated to be 111.8 Mt CO_2-e (~5.3 Tg CH_4) with agriculture (principally from ruminant animals) comprising about 60 % of CH_4 emissions. Fugitive emissions from coal mining and oil and gas production were the next largest source (26 %) followed by waste disposal activities (12 %). Much smaller amounts were emitted through certain land-use activities and industrial processes. Natural sources of CH_4 are not accounted for in the National Inventory. While it has been suggested that up to a third of Australia's methane emissions are derived from natural sources, there is as yet very little quantitative information on the magnitude of these emissions (Dalal et al., 2008).

Table 2.1. CH_4 emissions in Australia and NSW as estimated in the 2013 National Greenhouse Gas Inventory.

Category	2013 CH_4 Emissions (Gg)	
	Australia	NSW
Energy	**1,483**	**677**
Fuel Combustion	86	27
Fugitive Emissions From Fuels	1,397	650
Industrial Processes	**3.3**	**1.7**
Chemical Industry	0.7	
Metal Industry	2.6	
Agriculture	**3,165**	**709**
Enteric Fermentation	2,685	656
Manure Management	115	20
Rice Cultivation	26	26
Prescribed Burning of Savannas	327	0.1
Field Burning of Agricultural Residues	11	6.2
Land-use, Land-Use Change and Forestry KP	**59**	**19**
Afforestation and reforestation	1.3	0.1
Deforestation	43	15
Forest management	10	1.3
Cropland Management	0.6	0.5
Grazing land management	2.8	1.4
Waste	**615**	**203**
Solid Waste Disposal	495	163
Biological treatment of solid waste	4.9	1.6
Wastewater treatment and discharge	115	38
Total	***5,324***	***1609***

Table 2.1 also shows the CH_4 emission data for NSW during the 2013 reporting year. Here, agriculture is still the dominant emission source but represents only 44 % of total CH_4 emissions compared to about 60 % across the country as a whole. Fugitive emissions from fuels, on the other hand, account for approximately 40 % of NSW's CH_4 emissions, which are due mainly to the state's large coal industry. NSW currently has a very small oil and gas industry so less than 5 % of the state's fugitive emissions are attributed to this sector.

National greenhouse gas inventories are usually compiled according to the general methods described in the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. For the purposes of compiling national inventories, it is usually not practical to measure emissions directly. Consequently, most of the methodologies provided in the 2006 Guidelines rely on using emission factors derived for given processes. In this approach, a measure of the activity of the process is multiplied by the appropriate emission factor to yield the emission rate for that process. While this approach has the advantage of simplicity, significant uncertainty may be introduced if (a) the activity data are incomplete or inaccurate or (b) the emission factor is not well defined.

Although the use of emission factors provides a relatively simple approach for estimating greenhouse gas emissions, the emission factors themselves are based on measurements reported in the open scientific and technical literature. In the following section, we briefly examine methodology that has been applied to measure emissions from some of the main sources of CH_4 in Australia.

2.1 Detection of Methane

There are currently many instrumental methods available to detect and analyse CH_4. In the simplest form, inexpensive handheld gas detection sensors are frequently used in potentially hazardous environments to alert personnel to dangerous levels (i.e. explosive) of CH_4 in certain workplaces such as underground coal mines or gas processing facilities. These instruments generally have limited sensitivity and typically display in units of percentage of lower explosive limit (LEL, i.e. ~5% CH_4 in air v/v).

The next level of complexity includes portable gas detection systems that are usually used for leak detection in industrial applications. Leak detection instruments have higher sensitivity than gas sensors used for general workplace safety applications, often being capable of measuring concentrations of a few ppm above ambient levels. These instruments often have a wand with a sample inlet that can be placed near a potential leak point such as a valve or pipe fitting. Remote sensing instruments are also used for leak detection; these are typically hand held instruments that can be used to quickly scan complex facilities such as gas processing plants for leaks. Remote instruments include open-path laser and infrared imaging cameras.

Mobile open-path laser instruments have often been used to detect leaks in gas infrastructure. One such system, the ALMA G2 instrument which is mounted on a helicopter, was used in Queensland recently to detect CH_4 sources in a CSG production region (Day et al., 2015). Other vehicle mounted laser systems are also now commercially available.

While gas detectors and leak detection systems are critical for safety and routine maintenance at many industrial facilities, these systems are less frequently used in research into CH_4 emissions, particularly at the near ambient levels encountered more distant from the source under investigation. There are many instruments available with sufficient sensitivity to accurately measure low levels of CH_4 in ambient air e.g. FTIR, tuneable lasers, gas chromatography, etc. Some of these systems can be deployed in the field but usually only in fixed installations. Alternatively, samples can be collected and later analysed in a laboratory. However, for detection of CH_4 sources, it is usually more convenient to use a mobile system where a real-time instrument is mounted in a vehicle or aircraft.

The commercial development of cavity ringdown and off-axis integrated cavity output spectroscopy over the last decade has provided instruments with resolution of 1 ppb or less for CH_4. Some of these instruments are also capable of measuring isotopic ratios of ^{12}C and ^{13}C in CH_4, which may provide some information on the source of the CH_4. As a result, these instruments are now commonly in use for measuring CH_4 (and other gasses) in ambient air and there have been numerous studies reported where these instrument were used. In two recent examples, Karion et al. (2013) and Caulton et al. (2014a) used aircraft mounted cavity ringdown instruments to detect and quantify CH_4 emission fluxes from unconventional gas fields in the United States. Vehicle mounted cavity ringdown instruments have also been used successfully for locating CH_4 from a range of sources both in Australia (Maher et al., 2014; Iverach et al., 2015; Day et al., 2015) and overseas (Phillips et al., 2013; Zazzeri et al., 2015).

2.2 Coal Mines

Coal seams usually contain CH_4 and sometimes CO_2 that is stored within the pores of the coal. When the coal is mined, this gas is released to the atmosphere as fugitive emissions. During 2013, fugitive emissions from coal mining in Australia were estimated to be 26.2 Mt CO_2-e, which represents about 5 % of Australia's total greenhouse gas inventory (Department of the Environment, 2015a).

All Australian coal mine operators are required under the National Greenhouse and Energy Reporting (NGER) legislation to report their annual fugitive emissions according to methodology prescribed in the Determination. In the case underground mines, emissions must be determined according to Method 4, i.e. they must be directly measured rather than estimated. Most emissions from underground coal mines are associated with the ventilation air and can be quantified by applying Equation 2.1.

$$Q = V \times (C - C_a) \qquad (2.1)$$

Where Q is the emissions rate, V is the volumetric air flow out of the mine and C is the concentration of methane in the air stream and C_a is the methane concentration in ambient air. Any methane that is drained is also measured and included in the total annual emissions. While there may be some uncertainties involved in this approach (Day and McPhee, 2008; Day et al., 2011) in general it yields accurate emission data.

Emissions from open-cut mining, on the other hand, are much more difficult to estimate because gas escapes over the entire mine site, which may be very large in area, so that volumetric flows and concentrations are not readily measured. In an open-cut mine, some of the fugitive emissions are from seam gas released as the coal is excavated. Additional emissions may occur from gas released from strata that are disturbed but not actually excavated, and exposed by the mining process. These emissions are particularly difficult to estimate since they depend on the gas content and composition as well as the nature of the disturbance of the pit floor and highwall and the rate of leakage of the gases. As a result of the technical challenges associated with defining fugitive emissions from open-cut coal mining, research into methodology has been conducted in Australia and elsewhere for more than 20 years (Williams et al., 1993; Kirchgessner et al., 2000; Saghafi et al., 2003; Saghafi, 2005; Saghafi et al., 2008; Saghafi et al., 2012).

Despite the level of research, direct measurement of emissions from individual open-cut is not yet practical for routine reporting, although research is underway to investigate the use of atmospheric methods for this purpose (ACARP Project C24017, http://www.acarp.com.au/Media/ACARPCurrentProjectsReport.pdf). At present, emissions from Australian open-cut coal mines are estimated for the purposes of NGER reporting using either Method 1, which is based on the use of state based emissions factors, or Methods 2 and 3, which use gas content data from strata measured for the reporting mine.

Method 1 was developed from research conducted during the early 1990s where methane concentrations across plumes of methane emanating from a number of mines in NSW and Queensland were measured at ground level (Williams et al., 1993). The concentration data, combined with local wind speed measurements were used in conjunction with a plume model to infer the methane flux from the mines. The results of that study yielded average emission estimates of 3.2 m^3 per tonne of run-of-mine (ROM) for NSW and 1.2 $m^3\ t^{-1}$ for Queensland mines. While these results represented the first quantitative estimates of fugitive emissions from open-cut coal mining in Australia, there are a number of limitations with the methodology that restrict its general applicability, which include:

- Measurements can only be made under suitable atmospheric conditions.
- Ground level plume tracking requires vehicle access to the plume, which is often not possible.
- Separating individual mines can be difficult or impossible if mines are closely spaced.
- The method requires specialised personnel and equipment.
- At the time the Williams study was conducted, limitations in the sensitivity of contemporary instrumentation meant that discriminating low level CH_4 perturbations from background concentrations introduced relatively large errors. However, recent developments in ambient monitoring equipment (e.g. cavity ringdown spectroscopy) have largely overcome this problem and modern commercially available instruments now provide the ability to measure small

concentration differences with much higher precision than older flame ionisation detector instruments.

Because of these issues, and the high uncertainties associated with applying average emission factors to all mines, subsequent research focussed on developing a more manageable alternative method for estimating fugitive emissions.

Initial work in this regard in Australia examined the feasibility of using surface flux chambers for measuring gas emissions (Saghafi et al., 2003). While this work provided important information on the gas release routes within open-cut mines, the methodology required many individual measurements to build up an accurate estimate of emissions. There were also a number of practical and safety limitations involved with personnel operating in some parts of the mining operation. Moreover, because gas release from coal and other strata varies with time, the time of measurement was an important factor in measuring emissions using this method.

Later research investigated using the gas reservoir properties of coal and other strata to determine fugitive emissions of CH_4 and CO_2, which would overcome many of the practical problems of in-pit measurements while potentially providing mine-specific data (Saghafi et al., 2003; Saghafi et al., 2005; Saghafi et al., 2008). The work undertaken by Saghafi et al. (2003, 2005, 2008) now forms the basis for NGER Methods 2 and 3, which both use gas content data measured at the reporting mine to estimate fugitive emissions. Note that Methods 2 and 3 are identical except in the case of Method 3, samples must be obtained in accordance with appropriate Australian standards.

The general methodology of this reservoir approach involves measuring the in situ gas content of core samples from the target coal seams and other strata collected ahead of mining. A model of a ‘gas release zone’ is then developed for the mine to estimate annual emissions taking into account the gas released from the coal, other non-coal strata, and that from the highwall and pit floor. Although the methodology is complex and requires a detailed programme of coring and gas content testing (refer to Chapter 3 of the Technical guidelines for the estimation of greenhouse gas emissions by facilities in Australia - July 2014 http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/nger-technical-guidelines-2014), it produces mine-specific emission factors which yield emission estimates with much lower uncertainties than those based on the Method 1 approach. Most Australian open-cut coal mine operators now use Method 2 or 3 for reporting their fugitive emissions to the Regulator.

Emissions generated from extracting coal are the largest component of coal mining fugitive emissions, in some cases accounting for more than 70 % of a mine’s total greenhouse gas emissions (Day et al., 2006) but there are several other sources of fugitive emissions associated with mining:

- Post Mining Emissions – Post mining emissions are those that continue during the time the coal leaves the mine and it reaches the end user. These emissions are currently poorly defined and are estimated for NGER reporting by applying an emission factor of 0.014 t CO_2-e per tonne of ROM coal (~0.67 kg CH_4 t^{-1}). At present, only post mining emissions from gassy underground mines are estimated and reported.
- Abandoned Mines – Most mines continue to release fugitive emissions after they have ceased operation. While both underground and open-cut decommissioned mines may emit greenhouse gases, only underground mines are considered for NGER reporting. The method used for estimating these emissions assumes that emissions from abandoned mines reduce over time according to an ‘emissions decay curve’. Emissions at a particular point after the mine has closed, E_{dm}, are calculated by the expression:

$$E_{dm} = E_{tdm} \times EF_{dm} \times (1 - F_{dm}) \tag{2.2}$$

where E_{tdm} is the annual emission rate of the mine at closure, E_{dm} is the emission factor for a mine at a point in time since decommissioning (calculated from the decay formula) and F_{dm} is a factor to account for emissions reduced by the inflow of water into the mine. The term EF_{dm} is given by Equation 2.3:

$$EF_{dm} = (1 + At)^b \tag{2.3}$$

where *t* is the time elapsed since mine closure and *A* and *b* are mine specific constants.

- Spontaneous Combustion and Low Temperature Oxidation – Waste material from open-cut coal mining often contains some carbonaceous material that may undergo low temperature oxidation. In some cases, spoil piles may undergo self-heating which if unchecked can lead to spontaneous combustion. These processes lead to emissions of greenhouse gases (Carras et al., 2009; Lilley et al., 2012). In some mines, these emissions may be significant but most mines now effectively manage spoil and waste placement to avoid spontaneous combustion (Day et al., 2010). Emissions from spontaneous combustion and low temperature oxidation of coal are not included in national greenhouse gas inventories and are not reported for NGER purposes.

Estimates of fugitive emissions from post mining, abandoned mines and spontaneous combustion are generally subject to very large uncertainties. However, it is likely that the total contribution from these sources represent only a small proportion of greenhouse gas emissions from the coal mining industry.

In NSW, fugitive emissions from coal mining during 2013 were estimated to be 14,381 Gg CO_2-e which is a reduction of about 20 % compared to 2000 levels (Department of the Environment, 2015a). Although coal production has increased by about 70 % over this period (Australian Energy Statistics, 2015), emissions have decreased partially as a result of a shift in production from underground to open-cut mining as well as the implementation of mitigation schemes at many mines, such as flaring and gas capture systems. It is also likely that some of the apparent decrease is due to the implementation of the more accurate Method 2 now used throughout the industry.

2.3 CSG Production

Coal seam gas is one of several types of so-called unconventional gas. Other types of unconventional gas include shale and tight gas. Shale and tight gas occur in source strata with permeability that is much lower than conventional reservoirs and consequently require horizontal drilling and hydraulic fracturing stimulation for economic extraction. Most of the gas in shale and tight gas reservoirs is stored within the pores as compressed gas (i.e. free gas) although some may also be present as adsorbed gas in organic material in shale source rocks. Coal seam gas in contrast, is mainly stored as adsorbed gas within the microporous structure of coal with relatively little free gas. Hydraulic fracturing stimulation may be used on CSG wells but at present is not widely practised in Australian CSG operations, although its application may increase in the future as less permeable seams are developed.

The methods of gas production from the various types of reservoir differ substantially, which may in turn affect CH_4 emissions. Some of the main points of difference between CSG, shale and tight gas are summarised in Table 2.2.

Table 2.2. Key differences between CSG, shale gas and tight gas (from Day et al., 2012)

Property	CSG	Shale Gas	Tight Gas
Source Rock	Coal seams	Low permeability fine grained sedimentary rocks	Various source rocks have generated gas that has migrated into low permeability sandstone and limestone reservoirs.
Depth	300-1000 m	1000-2000+ m	> 1000 m
Gas Occurrence	Physically adsorbed on coal organic matter	Stored within pores and fractures but may also be adsorbed on organic matter.	Within pores and fractures.

Property	CSG	Shale Gas	Tight Gas
Gas Composition	Usually > 95 % methane. Small amounts of CO_2 and other gases may be present.	Mostly methane but may also contain significant quantities of higher hydrocarbons (condensate).	Mostly methane.
Extraction Technology	Vertical and horizontal drilling employed. Hydraulic fracturing is sometimes required. Currently less than 10 % of wells in Australia require this treatment but this may increase as lower permeability seams are targeted.	Hydraulic fracturing and horizontal wells are usually necessary.	Large hydraulic fracturing treatments and/or horizontal drilling are required.
Water Usage	Water must be pumped from seams to reduce reservoir pressure and allow gas to flow. If hydraulic fracturing is necessary, water is required for the fracturing process.	Water is required for hydraulic fracturing	Water is required for hydraulic fracturing.
Extraction Challenges	Removal of seam water and its subsequent disposal.	Overcoming low permeability. Minimising the amount of water required for hydraulic fracturing. Reducing infrastructure footprint.	Reducing infrastructure footprint.

Although CSG production methods are quite different to shale and tight gas, one common feature of all unconventional gas is that many more wells are required for production compared to unconventional gas fields. In unconventional gas fields, wells are drilled progressively over the life of the reservoir; as production declines in old wells and are eventually abandoned, new wells are drilled to maintain the required production rate from the field.

Methane emissions from gas production can occur at all stages of production – exploration, field production, processing, transmission and storage, and distribution. These emissions may be unintentional such as leaking valves and other equipment or accidental events like equipment failures and pipe ruptures that result in gas escaping to the atmosphere. However, some emissions are deliberate and include venting and flaring or the operation of certain types of gas powered pneumatic devices.

In Australia, almost all unconventional gas production is CSG. All gas producers (both unconventional and conventional) are required to estimate their greenhouse gas emissions under the NGER legislation requirements although at present there is no distinction between conventional and unconventional production. Although much of the processing and distribution infrastructure is similar across conventional and unconventional operations, the large number of wells, water extraction and processing facilities, etc. associated with CSG production may provide additional routes for gas loss compared to conventional production methods.

Fugitive emissions from gas operations are estimated by so called 'bottom up' methods which are based on estimating emissions from certain processes or even individual items of equipment then aggregating the results to obtain an estimate for the entire industry. Most of the estimates of fugitive emissions made by the Australian CSG industry for the purposes of NGER reporting are based on the use of emission factors that are provided in either the NGER Determination or the American Petroleum Institute (API) Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry (API, 2009). While the API Compendium is extremely comprehensive, much of the data upon which the emission factors were derived are relatively old and often limited. Consequently, some of the methods have very high uncertainties. Moreover, these methods were developed based on North American experience rather than current Australian practices.

Given the rapid growth of unconventional gas production in recent years and the high uncertainties surrounding greenhouse gas emissions, there has been strong interest in fugitive emissions from the sector. Since about 2012, there have been a number of studies, mostly in the U.S. that have attempted to measure fugitive emissions from unconventional gas production, although it should be noted that all of these related to shale or tight gas rather than CSG.

Most of the recent U.S. studies have used 'top-down' methods to estimate emissions for gas producing regions. These methods are based on measuring atmospheric concentrations of CH_4 and other gases and using information on atmospheric transport phenomena to calculate emissions rates for the area under investigation. Some researchers have used ground based methods where measurements were made either from vehicles or fixed monitoring towers (e.g. Pétron et al., 2012). Others have used airborne measurements (e.g. Karion et al., 2013; Caulton et al., 2014a) or satellite data (Kort et al., 2014; Schneising et al., 2014) to estimate emissions from gas production regions.

Top-down methods have the advantage of measuring all emissions over the study area, thus unlike bottom-up approaches, avoid the risk of missing emission sources. However, because all sources are included in the measurements if other unrelated emissions sources are present, complex data analysis and interpreation is required to properly attribute and quantify emission rates. A top-down system using a network of fixed ground stations is currently being developed to provide long term monitoring of CH_4 from CSG and other sources in the Surat Basin in Queensland (Day et al., 2015).

Although top-down methods have certain advantages for measuring emissions, depending on the scale at which they are applied, they usually give little detail on the routes of emissions. Some bottom-up methods, on the other hand, are suitable to measure emissions from individual items of equipment. In a very comprehensive study of fugitive emission from the U.S. gas industry during the 1990s, a number of methods were used to measure emission rates (Kirchgessner et al., 1997). One approach was 'bagging' where the leaking component is enclosed in a flexible enclosure to trap the gas. A carrier gas is then passed through the bag and the emissions rate E, is calculated from the total flow through the bag, f_b, and CH_4 concentration in the gas stream, C, according to Equation 2.4.

$$E = f_b \times C \qquad (2.4)$$

Because this method is very time consuming, an alternative method known as the 'Hi-Flow' method was developed. This is similar to the bagging method except that the air around the leaking component is entrained in an airstream generated by a blower and the CH_4 concentration in the entrained airstream is measured with a suitable gas analyser. The emission rate is thus calculated using the same method as given in Equation 2.4. The Hi-Flow system has since been developed into a commercially available portable instrument designed for routine leak rate quantification. However, there been a recent report suggesting that on one type of commercial Hi-Flow instrument, the range switching operation of the gas analyser may cause underestimation of leak rates (Howard et al., 2015).

With properly operating and calibrated instrument, however, the Hi-Flow (and bagging) methods provide accurate emission rates and have been used successfully for measuring emissions rates from unconventional gas infrastructure. In the U.S., Allen et al. (2013) used the Hi-Flow method to measure emissions from leaks, pneumatic devices etc. on well pads while in Australia, Day et al. (2014) used both bagging and a purpose built apparatus similar in principle to the Hi-Flow method to measure emissions from CSG well pads in NSW and Queensland.

Both bagging and Hi-Flow techniques are usually only capable of measuring emissions from single items of equipment so many measurements are required to survey even relatively simple infrastructure like well pads. To reduce the time requirements, preliminary screening of plant is usually conducted using portable leak testing or imaging instruments to locate leaks, which are then quantified using a suitable technique. An alternative method for quantifying emissions from infrastructure is to use atmospheric methods similar to the top-down techniques discussed above. One of the advantages of this approach is that it can also be used at a range of scales. For instance, Hirst et al. (2004) used an atmospheric dispersion method to measure hydrocarbon emissions from an oil and gas field several kilometres downwind. Others have used these methods to measure emissions at distances of less than 50 m from the source (Loh et al., 2009; Tsai et al., 2012). Day et al. (2014) used a ground based traversing method with a vehicle mounted CH_4 analyser to estimate emissions from Australian CSG well pads.

Most atmospheric methods require detailed knowledge of the plume transport characteristics to produce accurate results. In some cases, this information may be difficult to measure or estimate hence the uncertainty of the estimates is increased. Some of these problems are avoided by using a tracer gas that is released at a known rate from the same location as the source under investigation. Provided that the tracer is not reactive and is subject to the same dispersion behaviour as the target CH_4 source, the emission rate can be calculated by multiplying the tracer release rate by the ratio of the methane concentration enhancement (i.e. the measured CH_4 minus the background level) to the tracer enhancement. This method has been used to measure CH_4 emissions from natural gas operations in the U.S. (Lamb et al., 1995; Allen et al., 2013).

2.4 Wetlands

Wetlands have been estimated to account for around 25 % of naturally occurring CH_4 emissions globally (Waletzko and Mitsch, 2014) and hence have been the subject of intensive study over many years. In Australia, however, the contribution of wetlands to the overall CH_4 budget is poorly defined with only a handful of studies reported. In addition, the range of emission rates reported is very wide – Dalal et al. (2008) cite values for emission rates varying over four orders of magnitude between 3 μg CH_4 m^{-2} h^{-1} and 44 mg CH_4 m^{-2} h^{-1}.

Australian wetlands are very diverse and include marine and coastal environments, inland wetlands and some man-made regions (Department of the Environment, 2015b). There are many factors that affect CH_4 emissions from wetlands and soil more generally such as temperature, seasonal effects, compaction (i.e. the degree to which air can penetrate the soil), moisture content and vegetation type. Given the diversity of wetland types, the wide range of emission fluxes is unsurprising.

Measuring emission fluxes from wetlands is usually performed using either atmospheric methods or surface flux chambers. A comprehensive review of these methods, including their strengths and weaknesses, is provided in Denmead (2008). Remote sensing methods have also been used to estimate emissions from large areas such as the Amazon Basin (Melack et al., 2004) although because of the coarse spatial resolution of satellite imagery, this is not suitable for smaller areas.

Many of the methods mentioned above are complex requiring specialised instrumentation and sometimes infrastructure such as towers. Flux chambers, on the other hand are relatively simple to use in the field yet provide high sensitivity for measuring low emission fluxes accurately and consequently, this is the most common method used for measuring soil gas emissions.

There are numerous chamber designs available, including a number of commercial systems, but essentially, all operate by enclosing an area of soil by placing a chamber on the ground surface and measuring the concentration of CH_4 (or other gas) within the chamber over time. Typically, the area enclosed by the chamber is less than about 1 m^2. Flux chamber measurements are often made in the 'static' mode in which there is no exchange of air between the inside and outside of the chamber and the gas concentration within the chamber is measured over a period of time. The rate of change of CH_4 concentration in the closed chamber is a function of the gas flux. Analyses of the gas within the chamber may be achieved with an analyser connected to the chamber; alternatively, small gas samples may be taken throughout the experiment using a gas syringe for later analyses in a laboratory (by gas chromatography, for example).

Chambers can also be operated in a flow-through mode where a supply of clean air or other carrier gas is passed through the chamber at a constant rate. The flux is a function of the difference in concentration between the incoming and outgoing stream. However, the sensitivity of flow-through systems is less than static chambers so flow through systems are generally only used in areas with higher gas flux.

Despite the relative simplicity of chambers systems there are a number of factors that must be considered when interpreting the results. One of the most obvious is that the chambers only cover a very small area relative to the study region. Hence, many measurements are necessary to achieve a reasonable level of coverage of even small areas. Moreover, the inherent heterogeneity of soils mean that significant differences in flux may occur over small distances.

More subtle factors may also affect the results of flux chamber measurements. Small pressure differences between the inside and outside of the chambers may lead to large errors. Denmead (2008) cites results where a pressure differential of 100 Pa changed the measured flux by a factor of 10. Because of this, static chambers often have a small vent to allow the pressure to equilibrate, especially if an analyser with a flow return system is used to measure the gas concentration.

Because chambers enclose a section of ground, there is the potential to alter the microclimate above the soil, which in turn has the potential to affect gas emissions. Generally, this problem is mainly associated with chambers that are left in place for extended periods – shorter term experiments (of the order of a few minutes) are less likely to cause such changes.

Another point relates to some static chambers where an internal fan is used to ensure that the gas is well mixed within the chamber. It has been demonstrated that high levels of turbulence induced by this mixing may affect the apparent emission flux (Denmead, 2008). It has also been suggested that static chambers may affect the flow of gas when high concentrations are reached in the chamber (Denmead, 2008) and for this reason, flow through chambers may be preferred when flux rates are high. Debate continues as to the optimum design of flux chambers (Pihlatie et al., 2013).

2.5 Cattle Production

Greenhouse gas emissions from livestock in Australia were estimated to be 59.7 Mt CO_2-e during 2013 (Department of the Environment, 2015a), which represents about 70 % of the nation's agricultural emissions. Most of the livestock emissions are due to CH_4 produced by enteric fermentation (56.4 Mt CO_2-e or 2,685 Gg CH_4), with manure management from intensive feedlots contributing a further 3.3 Mt CO_2-e. It has been estimated that about 52 % of enteric fermentation emissions in Australia are derived from cattle (Charmely et al., 2015).

Because agriculture is not included in the NGER legislation, emissions from cattle are estimated for the purposes of compiling the National Greenhouse Gas Inventory using Tier 2 methodology, which essentially relies on a linear relationship between CH_4 production in cattle and their feed intake. However, recent research has shown that some of the factors used for compiling the Australian national inventory may be overestimating emissions by as much as 24 % (Charmley et al., 2015).

Research into greenhouse gas emissions from cattle has been conducted over many years. Much of this work has been conducted using apparatus where individual cattle are enclosed in a flow-through chamber and provided with feed and water for the duration of the test, which may last for up to 24 hours (Tomkins et al., 2011). The temperature and humidity of the chamber are closely controlled while an air stream of perhaps 200-300 L min^{-1} is passed through the chamber. The air flow rate and concentration of CH_4 in the outlet air stream are continuously measured over the duration of the experiment and are used to calculate the daily CH_4 flux for the animal under test. A similar technique uses a hood that surrounds the test subject's head rather than the entire animal (Boadi et al., 2002). While chamber methods are potentially very accurate, they require highly specialised equipment and facilities, emissions are measured under laboratory conditions rather than in the field, and the procedures have a low throughput.

Other methods that allow measurements to be made while cattle forage normally include various atmospheric techniques. One approach uses SF_6 as an inert tracer gas. Here, a permeation tube that releases SF_6 at a known rate is inserted in the animal's rumen. A sampling system attached to the animal collects air from near the animal's nose and mouth, which is later analysed by gas chromatography (Johnson et al., 2007). The emission rate of CH_4 is calculated by multiplying the release rate of SF_6 by the ratio of CH_4 to SF_6 concentrations in the sample. A similar tracer technique has also been used where instead of SF_6, radioactive CH_4 that has been labelled with either ^{14}C or ^{3}H is infused into the rumen (Hegarty et al., 2007).

There have been a number of studies made to validate the tracer method against the chamber method and agreement between the two methods is generally within about 5 % (Grainger et al., 2007; McGinn et al., 2006).

Chamber and tracer methods are designed to measure emissions from individual cattle, however, there have also been numerous studies aimed at measuring emissions from entire herds or intensive feedlot facilities. These studies often used an atmospheric dispersion method where CH_4 concentration is measured downwind of the source and inverted to provide an emission flux using a backward Lagrangian stochastic model (Tomkins et al., 2011; McGinn et al., 2011). This method was used by McGinn et al. (2008) to measure emissions from cattle feedlots in Queensland and Canada.

As well as enteric fermentation, cattle manure may also be a significant source of CH_4 and in some cases N_2O, which is also a potent greenhouse gas. For the purposes of compiling national greenhouse gas inventories, the IPCC CH_4 emission factor for manure management of non-dairy cattle in Oceania is 5 kg CH_4 head^{-1} y^{-1}, which assumes that all manure management is by dispersal on pastures and ranges (IPCC, 1996). However, the amount of CH_4 produced varies substantially depending on the type of management. For most beef cattle in Australia, manure is dispersed throughout the rangelands, which results in mainly aerobic decomposition with low emissions of CH_4. Intensive agricultural facilities like feedlots, on the other hand, tend to use liquid management practices where the manure is held in lagoons. In this situation, decomposition is by anaerobic activity that produces much larger quantities of CH_4. The IPCC emission factor for liquid manure management (such as in a feedlot) in a warm climate with an annual average temperature above 25 °C is 38 kg CH_4 head^{-1} y^{-1}.

Methane emissions from manure lagoons are generally made using some form of floating flux chamber (e.g. Husted, 1993; Kebread et al., 2006) or micrometeorological method (e.g. Kebread et al., 2006; Ro et al., 2013). However, it should be noted that there are obvious health and safety implications associated with direct contact methods such as flux chambers.

2.6 Rice Cultivation

Globally, rice cultivation is one of the main agricultural sources of CH_4 and contributes about 10 % of atmospheric CH_4 emissions (Dalal et al., 2008). In Australia, rice production is only a relatively small component of the local agricultural industry so the proportion of CH_4 emissions from rice cultivation relative to overall agricultural production is much lower than the global average. Current annual CH_4 emissions from Australian rice cultivation are estimated to be 556 Gg CO_2-e (~26.5 Gg CH_4), which represents less than 0.7 % of emissions from the agricultural sector as a whole (Department of the Environment, 2015a). Almost all Australian rice is grown in NSW but even here, the contribution of rice emissions is less than 3 % of all NSW agriculture greenhouse gas emissions (Department of the Environment 2015b).

Specific emission data for Australian rice emissions is very sparse and for the purposes of compiling the National Greenhouse Gas Inventory, emission estimates are made using a Tier 1 method with an IPCC default emission factor of 10 g m^{-2} y^{-1} (Department of the environment, 2015c). Consequently, the uncertainty on these estimates is high (although given the small size of the rice contribution to total greenhouse gas emissions in Australia, this is largely immaterial).

Methane is emitted from rice paddies by several routes: transport through the vascular system within the plants, ebullition and diffusion through water to the atmosphere. It has been estimated that plant transport is the main mechanism (Jain et al., 2004) while ebullition accounts for perhaps 20 % of the flux. Diffusion contributes only a minor component of gas emissions. The rate at which CH_4 is emitted is strongly affected by a wide range of factors. Perhaps the single largest influence on emissions is water management. For instance, mid-season drainage or intermittent flooding, which are practised in some rice growing regions, can significantly reduce CH_4 emissions. The increased aeration of the soil promoted by these management regimes may also lead to increased CH_4 oxidation further reducing emissions (Uprety et al., 2011). Other factors that affect CH_4 emissions are seasonal and diurnal responses, temperature, pH of the water, type of cultivar, fertiliser application and others (Uprety et al., 2011; Dalal, 2008; Jain et al., 2004; Neue, 1997).

Like wetlands, CH_4 emissions from rice fields are most commonly measured using surface flux chambers. Often, these are purpose built for the task and may be deployed manually during field measurement campaigns (e.g. Cicerone et al., 1983; Khalil et al., 1991; Keerthisinghe et al., 1993). Alternatively, automated chambers may be installed in the field for long term monitoring (e.g. Schütz et al., 1989). If permanent fixed chambers are to be used it is important to ensure that they do not affect the growing cycle of the rice. Hence, these chambers have lids that can be automatically opened after each measurement to allow normal airflow to the plants. The chambers are also normally constructed from clear plastic so as not to block sunlight to the plants. Another feature of chambers used for rice emissions is that they must be high enough to accommodate the plants throughout the growing season. Accordingly, chambers are often relatively tall and require internal mixing with a fan to avoid concentration stratification during measurements.

As well as chamber methods, micrometeorological methods such as eddy covariance may also be used for measuring emissions from rice paddies (Uprety et al., 2011).

2.7 Landfills

Emissions from landfills are currently estimated to comprise about 10 % of NSW total greenhouse gas emissions (Table 2.1). Often emissions from landfills that are required to be reported (i.e. those from sites that generate more than 10,000 t CO_2-e per annum) are estimated using Method 1, which is based on estimates of the amount of material within the landfill and that received at the facility during the reporting year, and a first order decay model. Higher order methods are also permitted in which emissions from the site that are not captured are estimated using a series of flux chamber measurements made over a representative area.

Many studies that have examined landfill emissions have used surface flux chambers because of the simplicity and versatility of the method (e.g. Bogner et al., 1995; Mosher et al., 1999; Stern et al., 2007). However, flux chambers only measure a small surface area during each measurement and thus many individual measurements are required to estimate emissions from a large site such as landfills. Moreover, landfills are often particularly inhomogeneous so that large differences in flux may occur over short distances. In one study, emission rates were found to vary over seven orders of magnitude from less than 0.0004 g m^{-2} day^{-1} to more than 4000 g m^{-2} day^{-1}, which introduces potentially very large uncertainties into estimates based on inadequate numbers of flux chamber measurements (Bogner et al., 1997).

As a result of the sampling difficulties posed by chamber methods, other techniques have been investigated to measure emissions from landfills. Most of these methods overcome the sampling problems associated with flux chambers but often require more elaborate equipment and higher levels of data analyses and interpretation. The majority of useful methods are atmospheric techniques and include eddy covariance (Hovde et al., 1995; Tuomas et al., 2007), tracer gases (Czepiel et al., 1996; Mosher et al., 1999; Czepiel et al., 2003; Spokas et al., 2006) and plume mapping (USEPA, 2012; Amini et al., 2013). The latter method may use open path laser instruments to measure the integrated CH_4 concentration between the plume and a series of fixed reflectors (sometimes at elevated locations to measure the vertical component) then combining with local wind speed data to calculate an emission flux from the site. The general methodology of this approach is now the basis of USEPA method OTM 10 – Optical Remote Sensing for Emission Characterisation from Non-Point Sources.

A description of the tracer and flux chamber methods are described in Section 5.2.3 and 5.2.4 of this report, respectively.

2.8 Wastewater Treatment

For the purposes of national greenhouse gas reporting under the current NGER legislation, wastewater treatment plants estimate emissions based on the population of the region they serve. Method 1 use the population and default emission factors to estimate emissions while higher methods (Methods 2 and 3) also use measurements of the chemical oxygen demand (COD) of the effluent. At present, there is no provision for direct measurement of CH_4 emissions from wastewater treatment plants. As a result, estimates for many plants probably have a relatively high degree of uncertainty. However, the contribution of wastewater treatment plants to overall CH_4 emissions is fairly low and based on current estimates (notwithstanding the uncertainty of these estimates), represent less than 3 % of NSW's CH_4 inventory (Table 2.1).

Most wastewater treatment facilities in Australia and elsewhere comprise a number of processes (primary, secondary and sometimes tertiary) with varying levels of CH_4 emissions. A range of techniques has been applied at facilities to measure emissions throughout the treatment process.

Toprak (1995) measured CH_4 and CO_2 emissions rates from an anaerobic waste pond using a fixed system to collect gas evolved from the plant. The apparatus comprised an inverted plastic funnel with a diameter of 365 mm that was fixed below the surface. Gas bubbles were collected in the funnel and the gas flow rate measured directly using a flow meter connected to the funnel. The average gas flow rate measured during the study was approximately 19.6 m^3 day^{-1} (combined CH_4 and CO_2) although there was a significant level of diurnal variation in the rate. Moreover, the volume of gas produced was also found to increase with increasing ambient air temperature.

One of the advantages of such a system is that it can be left in place for an extended period and with a simple logging system can yield continuous emission data, which is not feasible with infrequent periodic measurements. However, this methodology samples over a single, very small area (~ 0.1 m^2) so the representativeness or otherwise introduces a level of uncertainty to the results.

More commonly, flux chambers of some design are used for measuring emission fluxes from wastewater facilities. Czepiel et al. (1993) used a floating metal flux chamber to measure gaseous emissions from the non-aerated parts of the treatment process. For aerated operations, they used a modification of the flux chamber where a collapsible plastic bag supported on a wooden frame was placed in actively aerated ponds.

3 Volatile Organic Compounds

Air quality concerns regarding unconventional gas production has gained momentum in the United States due primarily to the rapid expansion of the onshore gas industry and the associated use of hydraulic fracturing. Methane along with volatile organic compounds (VOCs) and other pollutants have been studied with respect to air quality and health impacts related to the unconventional oil and gas industry (Field et al., 2014). The CSG sector is somewhat different in Australia to that in the United States, as has been discussed in the previous sections, but nevertheless emissions inventories are important in quantifying the contribution of air emissions from a particular source category to ambient air quality.

This study expands the understanding of source emissions with the inclusion of volatile organic compounds for the various methane emissions sources. The VOC emissions have been addressed from an ambient air quality perspective, not as an emissions inventory as such, to provide information on ambient concentrations across a region or close to a particular source and to investigate whether it is possible to ascertain certain characteristics of that source.

The contribution of a source to ambient VOC concentrations at a particular location is dependent on a number of factors, such as the source strength, source proximity, transport mechanisms (dispersion, dilution and mixing), and atmospheric chemical transformation. Meteorology will produce variability in the ambient concentrations observed and photochemistry will reduce the concentration of reactive hydrocarbons in the atmosphere. Emissions may show diurnal variation where the pattern of the measured compounds follows the intensity of the activity. Long term averaging techniques and large data sets are required to allow the seasonal variation of VOC emissions to be detected over shorter term variation arising from the many factors that control emissions flux and fate. While statistical techniques such as positive matrix factorisation are used to identify a source and its relative contribution, this technique requires large sample sizes to generate the data set required for statistical analysis and the identification of factors that may be assigned to specific sources or source groups.

The work conducted for this project focuses on the trace level detection of a large suite of volatile organic compounds in order to gain an understanding of source related impacts on ambient air and to study the prevalence of compounds that may specifically characterise a source. As far as we are aware, a VOC study as comprehensive as this one has not been undertaken in Australian gas fields, nor for the number of source categories examined in regional New South Wales.

4 Isotopic Ratios

The isotopic ratio of carbon in CH_4 ($\delta^{13}C$ CH_4) is a measure of the stable isotopes of carbon ($^{13}C/^{12}C$) within the CH_4 gas molecule being analysed. The units for $\delta^{13}C$ are reported in parts per thousand (‰) against the international standard Vienna Pee Dee Belemnite (VPDB). Similarly the isotopic ratio of hydrogen in methane (δ^2H CH_4) is a measure of the stable isotopes of hydrogen ($^2H/^1H$) within the methane gas molecule. The units for δ^2H are reported in parts per thousand (‰) against the international standard Vienna Mean Standard Ocean Water (VSMOW). The same system of nomenclature can also be used for other hydrocarbons and carbon dioxide.

Often referred to as the isotopic signature or fingerprint of a molecule, this parameter is relevant since different sources and sinks of CH_4 have a different affinity for the ^{12}C and ^{13}C isotopes and similarly for the ^2H and ^1H isotopes. By analysing $\delta^{13}C$ CH_4 and δ^2H CH_4, different sources (of CH_4 in the atmosphere or in the ground) may be distinguished.

4.1 Bulk Gas Composition

The bulk molecular composition of gas is widely used to differentiate the origin of the sample. Biogas derived samples are characterised by high CH_4 and significant carbon dioxide levels (anaerobic methanogenesis) and almost no heavier hydrocarbons. Hydrocarbon derived natural gases are influenced by biogenic versus thermogenic formation (e.g. Strapoc et al., 2011; Scott et al., 1994; Golding et al., 2013), the maturity of their source rocks (e.g. Rezniko, 1969; Stahl, 1974; Connan and Cassou, 1980) and elemental composition of the organic matter in coal or shale source rock, especially hydrogen/carbon ratio (Rice et al., 1989; Boreham et al., 2001). Coal seam gas consists of mainly light hydrocarbons (C_1-C_5) in various proportions and CO_2 (Papendick et al., 2011), and in some cases small amounts of nitrogen (N_2) (Smith et al., 1985; Smith and Pallasser, 1996; Hamilton et al., 2014), hydrogen (H_2), helium (He) (Clayton, 1998) and hydrogen sulphide (H_2S) (Clayton, 1998). The presence of 'wetter' components such as propane, butane, etc. tends to be a reflection of coal or other organic matter rank and pure microbial gases are characterised by exceptionally low concentrations of ethane and heavier hydrocarbons (Li et al., 2008; Faiz and Hendry, 2006). Gas derived from petroleum oil and shale oil/gas accumulations is characterised by a significant greater proportion of heavier hydrocarbons (C_2-C_{5+}) in addition to the CH_4, much more so than in coal seam gas (Golding et al., 2013).

The schematic in Figure 4.1 shows pictorally some of the most common sources of methane release into the environment from natural and anthropogenic sources (NASA, GISS, 2013). The primary removal mechanism of methane from the atmosphere is through chemical reactions with the hydroxyl radical ($OH^•$) forming CO_2. The $OH^•$ reacts with a number of gases in the atmosphere and is commonly referred to as a chemical species that 'cleans' the atmosphere.

Figure 4.2 is a schematic cross section of the Earth's crust, showing origin, migration and accumulation of CH_4. Origins of CH_4 include conversion of organic material by micro-organisms (biogenesis), thermal decomposition of buried organic matter (thermogenesis) and deep crustal processes (abiogenesis). Buoyant CH_4 migrates upward through rock pores and fractures and either accumulates under impermeable layers or eventually reaches the surface and dissipates into the atmosphere.

Abiogenic CH_4 is the least understood system but its documented discovery at an East Pacific Rise hydrothermal vent and in other crustal fluids supports the occurrence of an abiogenic source of hydrocarbons (Lollar et al., 2006; Horita and Berndt, 1999). This methane is generally formed by the reduction of CO_2, a process which is thought to occur during magma cooling, in hydrothermal systems during rock-water interactions and the serpentinisation of ultramafic rocks. In the context of global hydrocarbon reservoirs, abiogenic contribution is only a minor fraction based on isotopic signatures (Lollar et al., 2002).

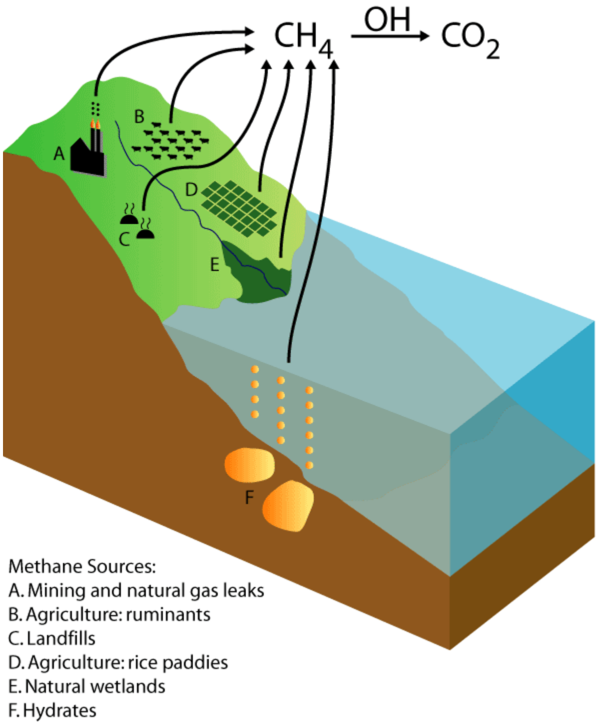

Figure 4.1. Schematic of sources of methane in the environment (NASA, GISS, 2013)

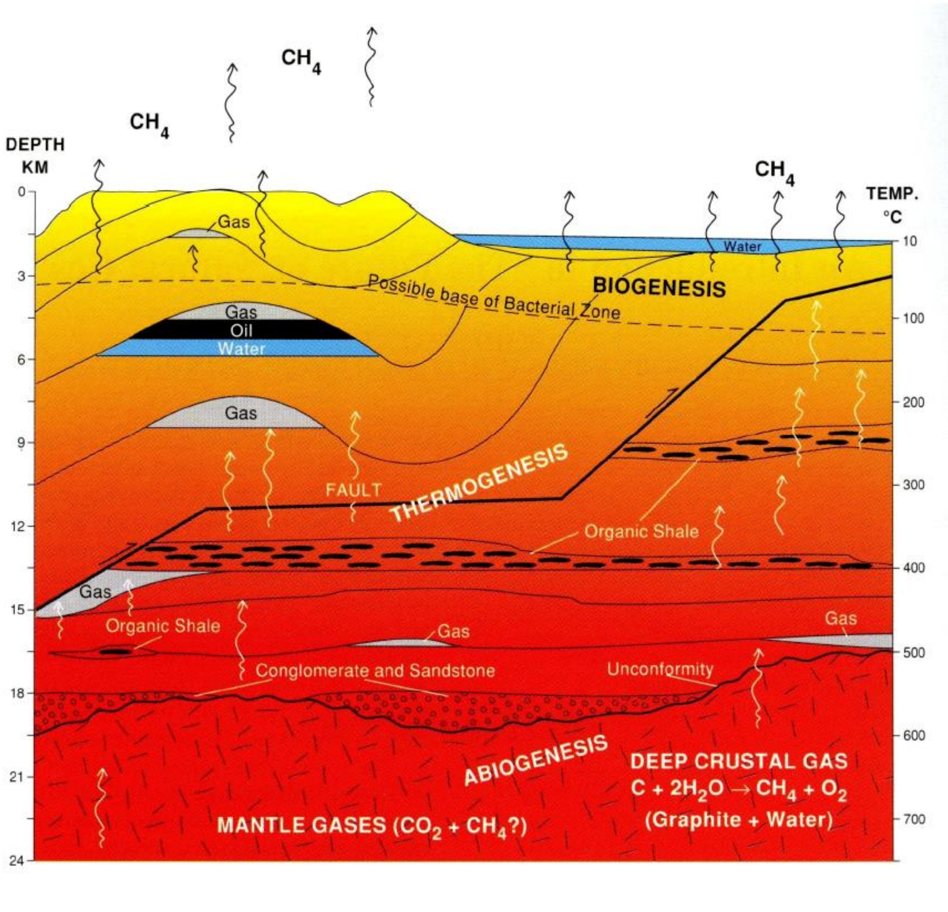

Figure 4.2 Schematic cross section of sub-surface methane generation pathways (Howell et al., 1993)

4.2 Carbon and Hydrogen Isotopes of Gases

The isotopic compositions of natural gases has long been used to help identify its origins (e.g. Golding et al., 2013, Stahl, 1977; Schoell, 1980; Rice et al., 1989; Whiticar, 1994), and the thermal maturities of their source rocks (e.g. Boreham et al., 2001, Stahl and Carey, 1975; Dai and Qi, 1989; Berner and Faber, 1996). Thermogenic gases are generated from organic matter and oil by cracking at high temperature. Methane also forms as a product of anaerobic microbial metabolism. Methane carbon isotope values between -20 to -50 ‰ VPDB typically indicate thermogenic gas and values lower than -50 ‰ are indicative of biogenic influences (Schoell 1980, 1988). Intermediate values (-50 to -60 ‰) may be the result of mixing of thermogenic and secondary biogenic gases. Because variable contributions of the end members can result in a wide variety of carbon isotope values, distinguishing between thermogenic and biogenic contributions can be problematic on the basis of $\delta^{13}C$ signatures alone. Table 4.1 summarises commom natural and anthropogenic methane sources.

Isotopic values for atmospheric CO_2 tend to range from -8 to -12 ‰ depending on air pollution levels (Longinelli et al., 2005, Clark-Thorne and Yapp, 2003) and values for carbon isotopes of CO_2 in coal seams worldwide range between -28 ‰ and +19 ‰ (Smith et al., 1985; Rice, 1993; Kotarba and Rice, 1995; Clayton, 1998). Bacterial reduction of CO_2 leads to isotopically heavier C isotopes in the residual gas, in severe cases positive values (Emery and Robinson, 1993). Carbon isotopic values of CO_2 between -5 to -28 ‰ are indicative of thermogenic sources (Irwin et al., 1977; Chung and Sacket, 1979; Clayton, 1998; Golding et al, 2013). Isotopic values of endogenic CO_2 are close to the main value for elemental C in the upper mantle and vary from -10 to -5‰ (Smith et al., 1985; Javoy et al., 1986; Hoefs, 1987; Jenden et al., 1993).

The hydrogen isotopic composition of CH_4 generated from the biogenic samples utilising anaerobic digestion of organic material generally ranges from -300 ‰ to -350 ‰ VSMOW. Taken together with carbon isotope values of CH_4, these values are generally consistent with bacterial origins and methyl type fermentation. During bacterial CO_2 reduction, the formation water supplies the hydrogen, whereas during fermentation, up to three quarters of the hydrogen comes directly from methyl groups in the coal or other organic precursors, which is already depleted in the heavier deuterium atoms, hence explaining the very depleted hydrogen isotope signature. In contrast, most coal samples (Surat, Bowen, Sydney, Gloucester Basin, etc.) have typical hydrogen isotope values -200 to -260 ‰ VSMOW, depending upon coal thermal maturity and mixing inputs from secondary microbial CH_4 (Golding et al., 2013) which tend to be dominated by bacterial carbonate reduction.

The combination of the $\delta^{13}C$ and $\delta^{2}H$ data for CH_4 in a cross-plot generally provide insights into their origins (see Whiticar, 1999). In Figure 4.3, some differentiation of CH_4 sources is possible but one needs to bear in mind that there are always exceptions to this broad classification due to the intrinsic nature of gases (i.e. multiple sources can rapidly mix, gas samples easily leak and suffer fractionation effects, etc.).

In the present study, analysis of the bulk composition and isotopic compositions of carbon and hydrogen for CO_2 and CH_4 were used to give insights into the origin of gases.

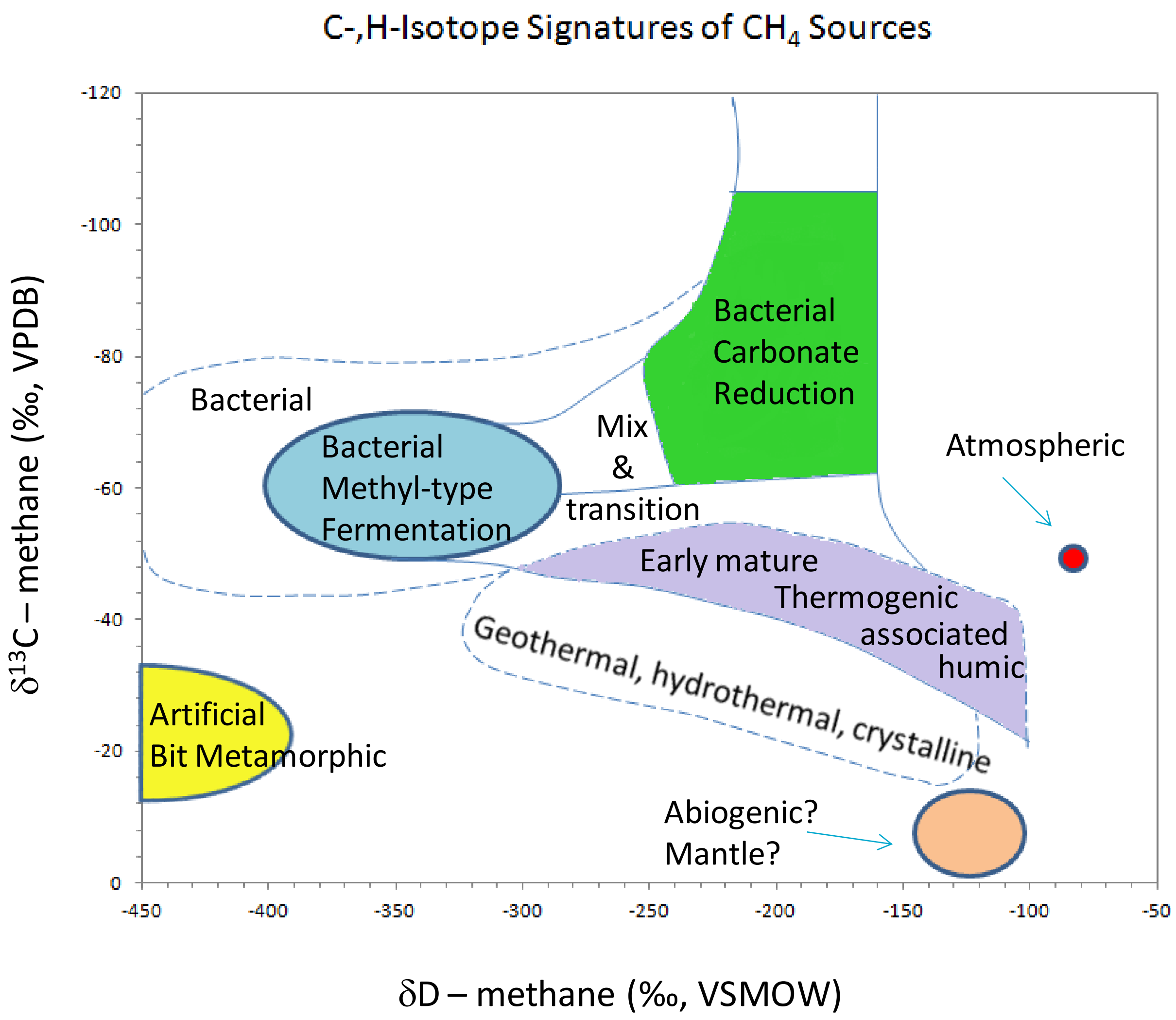

Figure 4.3 Stable isotope cross-plot of carbon and hydrogen isotopes of CH_4 (Whiticar, 1999)

Table 4.1 Carbon and hydrogen isotopes of common natural and anthropogenic CH_4 and CO_2 sources

Methane Source	$\delta^{13}C$ CH_4 (‰ VPDB)	Upper	Lower	$\delta^{2}H$ CH_4 (‰ VSMOW)	Upper	Lower	$\delta^{13}C$ CO_2 (‰ VPDB)	Upper	Lower
Natural Sources									
Wetlands (swamps)	-55	-50	-58	-258	-229	-314	10	18	2
Wetlands (bogs and Tundra)	-65	-52	-70						
Oceans	-59								
Mud Volcanoes	-40								
Termites	-57	-52	-76				-22	-8	-28
Wild Animals	-62								
Atmospheric Methane	-47	-46	-48	-86	-83	-89			
Methane Hydrates	-55	-50	-60						
Permafrost (Siberian Thaw Lakes)	-65	-50	-80	-300	-290	-320			
Anthropogenic Sources									
Biomass burning (C4 vegetation) Savanah Grassland	-17	-14	-20	-200					
Biomass burning (C3 vegetation) Boreal Forest	-26	-23	-30	-200					
Enteric fermentation (C4 vegetation) Ruminants	-50	-45	-55	-340					
Enteric fermentation (C3 vegetation) Ruminants	-63	-60	-76	-350					
Landfill	-56	-51	-62	-254	-230	-310	15	24	5
Food Digester (anaerobic)	-49	-47	-56	-326	-305	-340	10	17	3
Domestic Sewage	-57	-46	-60	-300	-298	-330	8	12	2
Feedlot Manure	-58	-47	-61	-341	-280	-350	4	6	-20
Rice Farms	-62	-59	-67	-323	-305	-365	16	18	-29

Methane Source	$\delta^{13}C$ CH_4 (‰ VPDB)	Upper	Lower	$\delta^{2}H$ CH_4 (‰ VSMOW)	Upper	Lower	$\delta^{13}C$ CO_2 (‰ VPDB)	Upper	Lower
Coal extraction	-35	-14	-77	-223	-219	-230	-17	-12	-25
Coal Seam Gas (Sydney Basin)	-49	-23	-72	-251	-200	-273	15	25	-21
Coal Seam Gas (Surat Basin) production	-56	-50	-60	-212	-205	-217	9	15	-27
Coal Seam Gas (Surat Basin) desorbed	-51	-45	-59	-221	-202	-238	4	8	-3
Coal Seam Gas (Bowen Basin)	-60	-23	-78	-215	-200	-220	19	20	-13
Natural Gas (North Sea)	-35	-25	-37	-180	-178	-213			
Natural Gas (Siberia)	-50	-47	-53	-190	-183	-221			
Natural Gas (Australia)	-38	-27	-50						
Natural Gas (commercial, Eastern Australia)	-39	-35	-41	-214	-200	-220	-2	-1	-9
Traffic Exhaust (California, USA)	-46	-30	-49	-110	-100	-130			

References: (Anthony et al., 2012; Boreham et al., 2001; Burra et al., 2014; Craig et al., 1988; Dlugokencky et al., 2011; Draper and Boreham, 2006; Faiz and Hendry, 2006; Golding et al., 2013; Hamilton et al., 2014; Keeling, C. D., 1960; Kinnon et al., 2010; Li et al., 2008; Lowe et al., 1991; Montiel et al., 2011; Pacific Environment, 2014; Quay et al., 1999; Rust, F. E., 1981; Schaefer et al., 2016; Schoell, M., 1988; Smith et al., 1982; Stevens, C. M., 1988; Stevens and Rust, 1982; Strapoc et al., 2011; Townsend-Small et al., 2012; Umezawa et al, 2012; Zimmerman et al., 1982).

5 Experimental

5.1 Sampling Sites

The original project brief specified that measurements were to be made at 15 sites across NSW covering a range of CH_4 sources:

- Four main CSG regions i.e. Camden, Narrabri, Gloucester and Casino
- One landfill site at a country location
- One landfill site in major city
- One rice farm
- One coal mine in the Hunter region
- One coal mine in the Narrabri/Gunnedah region
- Four wastewater treatment plant , i.e. sewage treatment plants (STP); three in country NSW; one in the Sydney metropolitan or major regional centre
- One intensive agriculture site such as a feed lot or a pig farm
- One natural source of methane such as natural seep, forest or drainage line.

Sites for field measurements and sampling were selected from each of the categories listed above by the NSWEPA (except the rice farm, which was selected by CSIRO after consultation with CSIRO Agriculture officers). An initial selection was made in consultation with the EPA regional offices, after which facility operators were then invited to participate in the project. A number of the operators of the some of the invited facilities declined to participate, so alternatives were then sought by the EPA. A consequence of this was that none of the coal mines in the Narrabri/Gunnedah region were available to participate in the project so two Hunter Valley mines were included instead.

In the case of CSG operations, the negotiations to gain access to some facilities were somewhat protracted and hence detailed on-pad measurements did not commence at these sites until about the middle of 2015.

In general, sites were selected to be spread across NSW but because in most cases participation in the project was voluntary, the final selection of sites was largely dependent upon the operators agreeing to provide access to their sites. In addition to this, some consideration was given to the proximity of the CSIRO base in Newcastle to some sample sites to assist in the logistics of visits to the sites over the course of the project (for example, the Summerhill Waste Management Centre in Newcastle was selected to represent the city landfill site, and the Singleton Wastewater Treatment Works was chosen as one of the country sewage treatment plants).

A brief description of each site are provided in Table 5.1. Approximate locations of each site are also shown in Figure 6.1 in the Results section.

Table 5.1. Details of the sampling sites investigated during the study

Site	Owner	Category	Approximate Location	Notes
Camden Gas Project	AGL Energy	CSG production	-34.12°, 150.77°	144 wells, with 96 producing. One gas processing plant. The Camden gas project is currently the only CSG producer in NSW selling gas commercially.
Gloucester Gas Project	AGL Energy	CSG production	-32.05°, 151.97°	Four pilot wells producing gas. Produced gas is flared. The project was cancelled in February 2016, and since then all wells have been suspended with no gas production.
Narrabri Gas Project	Santos Limited	CSG production	-30.63°, 149.65°	About 50 pilot wells with gas and water treatment facilities. Some of the gas produced is used in the Wilga Park Power Station; the remainder is flared.
West Casino Gas Project	Metgasco Limited	CSG production	-28.82°, 152.96°	This project is now cancelled. All wells are either suspended or plugged and abandoned.
Parkes Waste Facility	Parkes Shire Council	Country landfill	-33.13°, 148.14°	The largest of a number of landfills operated by Parkes Shire Council. The site has been operating since 1995 and is currently licensed to accept up to 20,000 t of solid waste per annum. Waste is periodically buried – there is no gas capture at this site.
Summerhill Waste Management Centre	Newcastle City Council	Metropolitan landfill	-32.89°, 151.64°	This is the primary waste management facility in Newcastle. It is licensed to accept up to 220,000 t of solid waste per annum. A gas collection system is installed which is used to generate up to 2 MW of electricity on site.
Yanco Agricultural Institute	NSW Department of Primary Industries	Rice farm	-34.62°, 146.42°	The Institute conducts research into sustainable agriculture, especially rice production and horticulture. Measurements were made in an experimental rice crop.
Rix's Creek Coal Mine	The Bloomfield Group	Hunter Valley coal mine (open-cut)	-32.53°, 151.12°	Open-cut operation producing approximately 2.5 Mt run-of-mine (ROM) coal per annum.
Wambo Coal Mine	Peabody Energy	Hunter Valley coal mine (open-cut and underground)	-32.57°, 150.99°	This mine is a combined open-cut and underground operation. Total production is about 7.5 Mt ROM coal per annum.

Site	Owner	Category	Approximate Location	Notes
Camden Gas Project	AGL Energy	CSG production	-34.12°, 150.77°	144 wells, with 96 producing. One gas processing plant. The Camden gas project is currently the only CSG producer in NSW selling gas commercially.
Gloucester Gas Project	AGL Energy	CSG production	-32.05°, 151.97°	Four pilot wells producing gas. Produced gas is flared. The project was cancelled in February 2016, and since then all wells have been suspended with no gas production.
Singleton Wastewater Treatment Plant	Singleton Council	Country STP	-32.60°, 151.18°	The facility located on Army Camp road receives all of the wastewater from Singleton for treatment. The capacity of the facility is about 20,000 equivalent persons (EP).
Dubbo Wastewater Treatment Plant	Dubbo City Council	Country STP	-32.20°, 148.63°	The Boothenba Road plant is the main sewage treatment facility for Dubbo. The plant is currently operating at the limit of its capacity (approx. 38,000 EP) and a new facility adjacent to the existing plant was under construction during this project. The new plant was commissioned during late 2015.
Wagga Wagga Narrung Street Wastewater Treatment Plant	Wagga Wagga City Council	Country STP	-35.09°, 147.36°	The Narrung Street plant is the largest of several wastewater treatment facilities operated by the Wagga Wagga City Council. It treats both domestic and industrial effluent.
Picton Wastewater Treatment Plant	Sydney Water	Metropolitan STP	-34.20°, 150.62°	The Picton plant is one of six treatment facilities in the Hawksbury-Nepean catchment operated by Sydney Water. It has a capacity of approximately 13,000 EP.
Jindalee Feedlot	Teys Australia	Intensive agriculture – cattle feedlot	-34.46°, 147.77°	Cattle are sourced from farms within about a 500 km radius for fattening. The facility has a capacity of around 17,000 head.
Yaegl Nature Reserve	NSW National Parks and Wildlife Service	Natural area	-29.46°, 153.23°	The reserve comprises a floodplain of mainly paperbark forest and some coastal saltmarsh. The total area of the reserve is 312 ha. Because it is a wetland there are no tracks through the reserve so vehicle access is limited.

In addition to these 15 sites, further measurements of ambient concentrations of CH_4 and volatile organic compounds (VOCs) were made within the Camden gas field south of Sydney and at site within the Cuba State Forest, approximately 30 km west of Leeton (approximate location -34.60°, 146.08°). Generally, during field trips, the vehicle-mounted methane analyser was operating for most of the time the vehicle was driven between sites. This provided a large database of ambient methane concentrations across NSW over almost a two-year period.

5.2 Methane Measurements

There are many choices available for measuring CH_4 fluxes as discussed in Section 2. However, this project required measurements to be made at many sites and at multiple times throughout the project period so it was not considered practical to use methods based on fixed installations (e.g. eddy covariance and inverse modelling) for all sites. While such systems have to the potential to yield continuous data, the cost of setting up 16 monitoring systems across NSW would have been prohibitive. Accordingly, we adopted methods that could be applied during periodic visits to each site.

Ambient CH_4 concentrations and in many cases, the emission flux, were measured at the sites listed in Table 5.1 using a range of methods, which are described in the following sections.

5.2.1 MOBILE SURVEYS

Ambient CH_4 concentration was usually measured using a Picarro Model G2301 CH_4, CO_2, H_2O cavity ring-down spectrometer, which was fitted into a four-wheel-drive vehicle. On some other occasions, CH_4 concentrations were measured using other Picarro or Los Gatos Research instruments (see following sections). A Picarro Mobile Kit provided power to the vehicle mounted gas analyser via an inverter that operated off the vehicle's 12 V power supply. An auxiliary battery fitted to the vehicle allowed the instrument to be operated for up to several hours without the engine running. The Mobile Kit also includes a GPS receiver (Hemisphere R330 GNSS receiver) and software so that concentration data can be processed and displayed in GIS software. Wind speed and direction at sampling sites were measured using a 2-dimensional sonic anemometer (Climatronics Sonimometer) mounted on the roof of the vehicle (measurements were made only while the vehicle was stationary).

The nominal operating range of the analyser is 0-20 ppm CH_4 with a resolution of about 1 ppb. However, we have previously found that the analyser can reliably measure concentrations of at least 300 ppm, provided that the instrument is calibrated against suitable standards (Day et al., 2014). The data acquisition rate of the Picarro instrument is typically 0.3 Hz when used to measure CH_4, CO_2 and H_2O concentrations simultaneously, however the acquisition rate decreases when operated above 20 ppm CH_4. Details of the instrument specifications can be found at
http://www.picarro.com/products_solutions/trace_gas_analyzers/co_co2_ch4_h2o.

The calibration of the analyser was regularly checked against several standard gas mixtures including a high precision reference air sample containing 1.732 ppm CH_4 and 383 ppm CO_2 prepared by the CSIRO Oceans and Atmosphere, GASLAB (Francey et al., 2003). The CH_4 concentration indicated by the Picarro instrument was always within about 0.2 % of the nominal concentration of the reference air (i.e. <4 ppb CH_4). Other standards were also used from time to time for higher concentrations. These less precise mixtures were commercially purchased calibration standards containing between 10.8 ppm and 103 ppm CH_4.

During mobile surveys, the spectrometer was operated continuously while the vehicle was travelling but also for extended periods when stationary. Air was sampled via a ¼" nylon tube attached to the front of the vehicle about 1 m above ground level. The normal flow rate of sample air to the spectrometer is approximately 100 mL min^{-1}; however, to minimise the lag time between air entering the inlet tube and reaching the analyser, an auxiliary pump in the Mobile Kit was used to increase the flow rate up to about 5 L min^{-1}. The residence time of the sample within the sample line was less than 0.5 s at this flow rate. When used for flux chamber measurements (Section 5.2.4), the auxiliary pump was bypassed using a three-way valve.

Surveys were made by driving the vehicle on public and sometimes private roads at speeds up to about 110 km h^{-1}. The rate of measurement of the instrument was such that relatively small methane anomalies could be detected at highway speed although the response time of the instrument, which was about 14 s, resulted in an offset of several hundred metres at this speed. However, when surveys were made on the selected sites, the vehicle speed was much lower (typically <20 km hr^{-1}) and often little more than walking pace so the offset yielded by the vehicle speed could usually be ignored.

Later in the project, we acquired a Los Gatos Research Ultra-Portable Methane/Acetylene Analyser. This instrument has an operating range of 0-1000 ppm CH_4, 0-1 % C_2H_2 and 0-7 % H_2O (full specifications can be found at http://www.lgrinc.com/documents/LGR_Portable_FAMA_Datasheet.pdf). A GPS receiver could also be connected to the analyser to provide spatial information if required. Calibrations were periodically made using the standard mixtures as for the Picarro; two additional standards containing 4.1 and 20.6 ppm C_2H_2, respectively, were also used.

5.2.2 PLUME TRAVERSES

In some circumstances, it is possible to estimate CH_4 emissions from sources using a plume dispersion method. In this method, the CH_4 concentration profile in a plume originating from the CH_4 emission source is measured at some distance downwind by performing traverses across the plume. This method, among others, was used by Day et al. (2014) to estimate CH_4 emissions from Australian CSG well pads. The technique is illustrated in Figure 5.1.

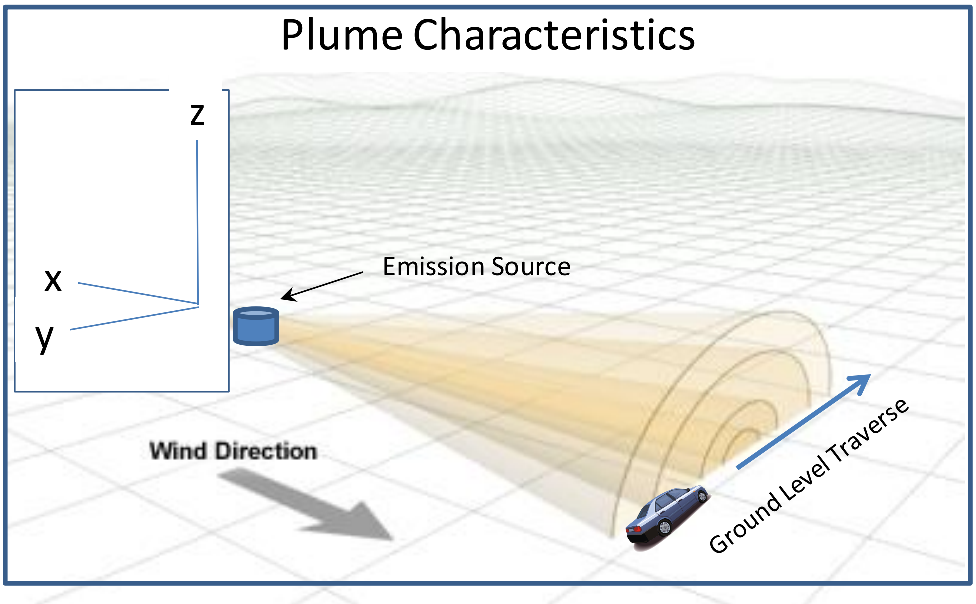

Figure 5.1. Schematic representation of the plume traversing experiments (from Day et al., 2014).

By traversing across a plume downwind of the source, the emission flux, *F*, may be estimated by integrating the CH_4 concentration enhancement, *C*, of the plume in the horizontal, *y*, and vertical, *z*, directions and multiplying by the average wind velocity, *u*.

$$F = u \int_{-y}^{y} \int_{0}^{z} C(y,z)dydz \qquad (5.1)$$

Because concentration measurements are made only at ground level, the vertical dispersion must be estimated by reference to plume dispersion models such as the Pasquill-Gifford curves of σ_z (i.e. the standard deviation of the distribution of CH_4 concentration in the vertical direction) as a function of downwind distance under given atmospheric turbulence conditions (Hanna et al., 1982). In this approach we assume that the maximum CH_4 concentration in the vertical column occurs at ground level; the vertical concentration profile of CH_4 within the plume is then assumed to decrease from the ground level concentration with height according to a Gaussian distribution. Because the maximum concentration must be at ground level, the source must also be at or near ground level. The method is therefore unsuitable for elevated sources, although other plume dispersion methods can often be applied in these cases.

Plumes that undergo significant rise from momentum or buoyancy effects would also be unsuited to these simple ground level traverses because the maximum plume concentration would most likely be well above ground level. While CH_4 is less dense than air and therefore is buoyant, most of the sources examined in this study emit CH_4 over diffuse areas so that any emissions are rapidly entrained in the prevailing air flow, which rapidly dilutes the CH_4. Consequently, the density difference between the plume and surrounding air mass is very small and buoyancy effects are negligible. Previous experiments using ground level traverses have confirmed this (Williams et al, 1993; Day et al., 2014).

Estimating the vertical extent of the plume introduces a significant source of uncertainty because the vertical concentration profile must be estimated from information on the spatial distribution of the source (i.e. an area or point source), downwind distance and prevailing atmospheric stability. Often these data are not well defined. In carefully designed experiments, ground based plume measurements can yield high levels of accuracy (e.g. Loh et al., 2009; Humphries et al., 2012). However, in less favourable conditions, such as short term measurements made during occasional site visits, higher uncertainties are expected. In the case of the CSG well measurements, Day et al. (2014) estimated that the uncertainty of their measurements, which were made within less than 50 m of relatively small point sources, was of the order of 30 % when sufficient traverses could be made to provide a reasonable average. Significantly higher uncertainties of up to 100 % resulted when estimates were based on only one or two traverses. Other researchers using this method have reported uncertainties of a factor of two or three when applied to large diffuse sources such as coal mines (Williams, et al., 1993; Lilley et al., 2012).

Notwithstanding the uncertainties associated with this method, plume traverses were attempted at some sites. Measurements were made using the vehicle-mounted Picarro analyser downwind of the source. Background CH_4 concentrations were measured by performing traverses upwind of the source.

5.2.3 TRACER GAS

Because of the uncertainties associated with ground level traverse methods and other problems associated with site topography, access and variable winds, we investigated an alternative approach to determine emission rates based on the use of a tracer gas. Here, a stable gas unrelated to the source, such as acetylene, is released at a known rate, F_{Tracer}, from the same location as the CH_4 source. Simultaneous downwind measurements of the concentration enhancement (i.e. concentration above background) of both the tracer, C_{Tracer}, and CH_4 C_{CH4}, are made and the emission rate of methane, F_{CH4}, calculated according to Equation 5.2.

$$F_{CH4} = F_{Tracer} \times {}^{C_{CH4}}/_{C_{Tracer}} \qquad (5.2)$$

The tracer method avoids the need to estimate the vertical CH_4 profile in the plume. In addition as shown in Equation 5.2, information on wind speed, direction or the width of the plume is not required to calculate the emission rate. The method, however, does require additional analytical capability to measure the tracer gas with sufficient accuracy and precision. It is also essential that the tracer experience the same plume transport phenomena as the target so it is important that the tracer is well mixed in the plume.

A series of experiments were conducted using controlled releases of CH_4 to validate the procedure. Methane was released from a cylinder in an open area at rates that were measured using a flow meter (Fisher and Porter Rotameter) that had been calibrated against a NIST traceable calibrator (Bios DryCal DR2). Acetylene was released from the same location at rates between about 1 and 2 L min^{-1}, which were also measured with the flow meter. Initially samples were collected from within the plume with evacuated stainless steel canisters and later analysed in the CSIRO North Ryde laboratories for CH_4 and C_2H_2 using Fourier transform infrared spectroscopy (FTIR). Although this approach yielded reasonable results, only a small number of plume samples could be analysed and there was a delay of days or even weeks between the time the sample was taken and the analyses.

Later measurements were made using the Los Gatos Research (LGR) Ultra-Portable Methane/Acetylene analyser, which provided real-time analyses of the plume and due to the rapid sampling rate (up to 1 Hz) yielded many data pairs of CH_4 and C_2H_2 concentrations, which improved the precision of the method.

The results of one of the validation experiments are shown in Figure 5.2 where the concentrations of CH_4 and acetylene are plotted as a function of time as the LGR instrument was moved through the plume at between about 20 and 50 m from the source. Unlike the plume traverse methods described in Section 5.2.2, there was no attempt in this experiment to make perpendicular transects across the plume – the instrument was simply moved to ensure that measurements were made within the plume. In this example, the actual CH_4 flow rate (measured by the calibrated flow meter) was 4.32 L min^{-1} and the acetylene flow was 1.95 L min^{-1}, both released from the same point.

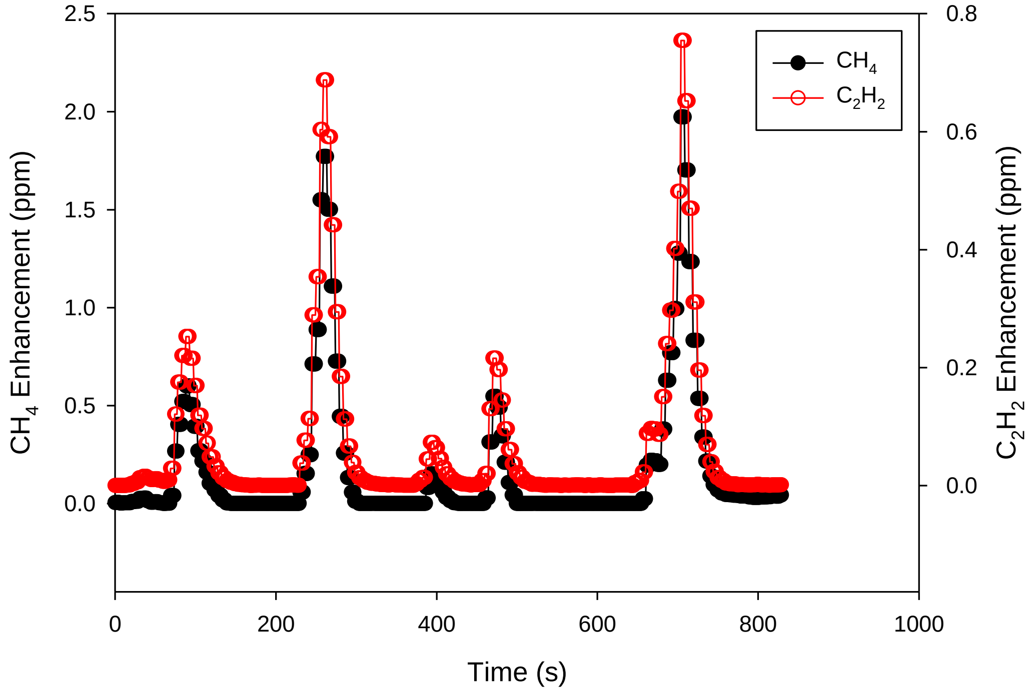

Figure 5.2. Methane and acetylene concentration enhancements measured as a function of time during a controlled release experiment.

There is an excellent correlation between the CH_4 and acetylene traces, which is illustrated even more clearly in Figure 5.3 where the acetylene enhancement is plotted as a function of the CH_4 enhancement.

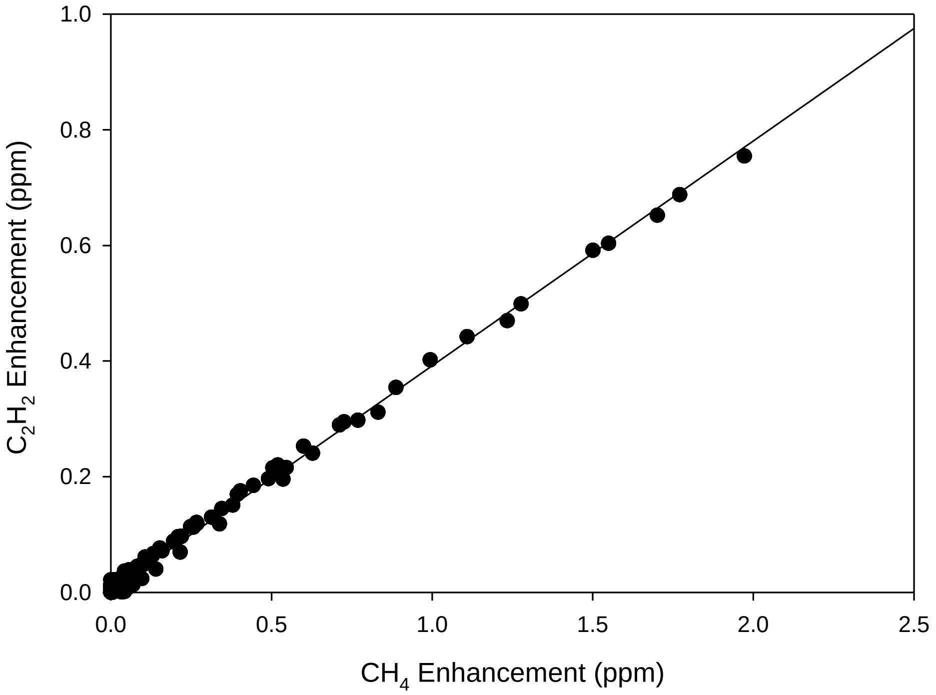

Figure 5.3. Correlation of the methane and acetylene enhancements shown in Figure 5.2.

The CH_4 emission flux calculated from this experiment using Equation 5.2 yielded a mean value of 4.68 L min^{-1}, a difference of about 8 % from the actual emission rate.

A number of other experiments were made using this method and the results of the measurements are summarised in Figure 5.4. These experiments were conducted over two days in light to moderate wind conditions (1-5 m s^{-1}). Measurements were up to about 50 m downwind of the point emission source. It is seen that the CH_4 emission rate determined from the tracer method was in each case well within 10 % of the true CH_4 release rate (indicated by the horizontal lines in Figure 5.4).

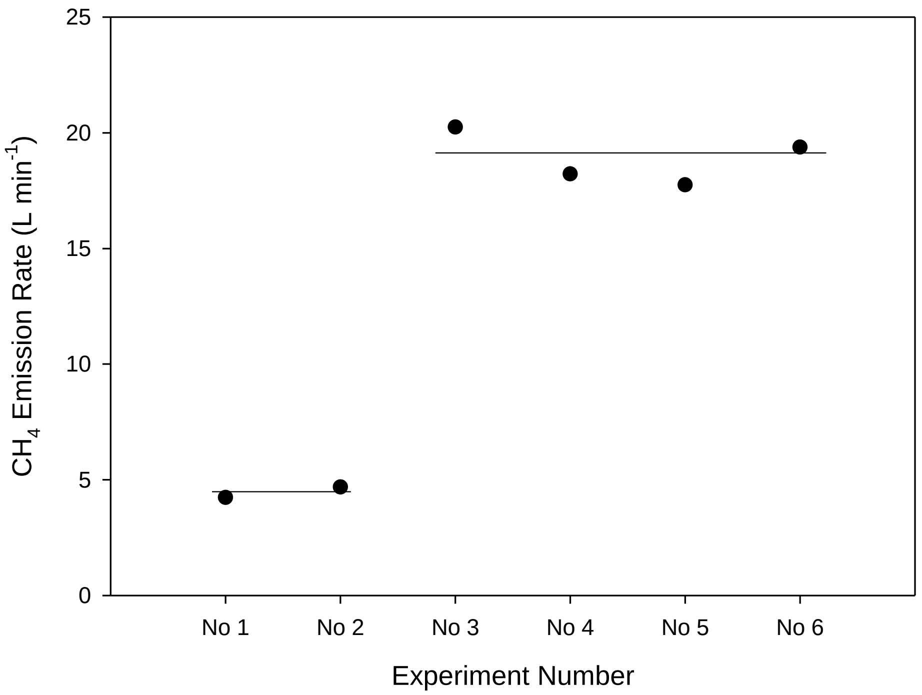

Figure 5.4. Summary of controlled release experiments where the methane emission rate was estimated using the tracer gas method. The horizontal lines show the actual methane release rate (Experiments 1 and 2: 4.32 L min^{-1}; Experiments 3-6: 19.2 L min^{-1}).

Although the use of a tracer is a powerful technique, there are some limitations that must be considered. Firstly, the tracer must be well mixed with the plume for optimum accuracy. This usually means that some level of wind and a reasonable downwind distance are needed to allow adequate mixing to occur. Secondly, the tracer should be released at the same location as the source gases. In some situations such as CSG wells, where CH_4 emissions are released from a relatively small area, it is often simple to release the tracer in approximately the same location as the target. Where the source is released over a larger area, co-release may not be possible. This may be compensated for by sampling further downwind so that the separation from the source and tracer is small relative to the downwind distance. However, for very large sources spread over larger areas (e.g. landfills or coal mines) the downwind distance required may be too large to be practical (e.g. the tracer becomes too dilute to accurately measure). For large sources such as these, alternative methods, perhaps requiring multiple sources of tracer are required. It may also be possible to use a hybrid method of tracer release and plume dispersion methods to estimate emissions from large sources (Lamb et al., 1995).

The tracer technique when available and determined to be suitable was deployed at several sites, including the CSG well sites visited as part of the project.

5.2.4 SURFACE FLUX CHAMBERS

Surface flux chambers were used at many of the selected sites to measure CH_4 and CO_2 emission rates for soil and liquid surfaces. In all cases, the chambers were operated in the static mode where there is no exchange of air with the outside atmosphere so that the CH_4 (and CO_2) concentration within the chamber usually increases with time. Some natural surfaces show a decrease in CH_4 concentration, which is due to microbial activity in the soil. The general principle of the operation of static flux chambers is illustrated in Figure 5.5.

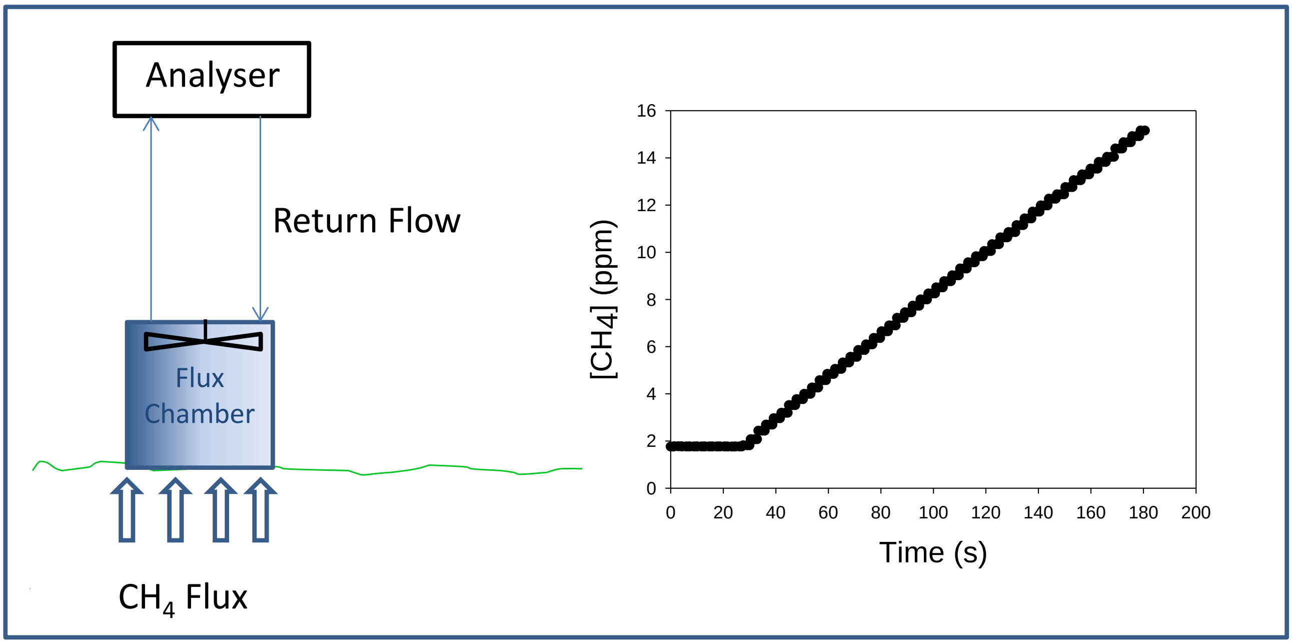

Figure 5.5. Schematic representation of a flux chamber operated in the static mode. The plot to the left shows the methane concentration within the chamber during a controlled release experiment as a function of time.

In this mode of operation the gas flux, *F*, is calculated from the rate of change in concentration inside the chamber, *dC/dt* (i.e. the slope of the plot shown in Figure 5.5) according to Equation 5.3

$$F = \frac{dC}{dt} \times \frac{V}{A} \qquad (5.3)$$

where *V* is the volume of the chamber and *A* is the area of surface covered by the chamber.

Chambers can be various sizes and shapes and made from various materials including plastic or metal.

During this project, emissions from ground and liquid surfaces were often measured using a variety of chamber designs. Initially we used a simple chamber comprising a plastic cylindrical chamber 37.5 cm in diameter and 40 cm high with a total volume of about 45 L and an area of coverage of 0.11 m^2. The chamber was connected to the inlet and return ports of Picarro analyser in the vehicle via 6 mm nylon tubing. After placing the chamber on the test surface, the concentration of CH_4 and CO_2 in the chamber was measured over a period of at least several minutes while a small electrically powered fan inside the chamber ensured that the air was well mixed during the experiment.

At some locations, especially where high fluxes were apparent (typically above 10 g CH_4 m^{-2} day^{-1}), a commercially manufactured battery powered portable flux system was used. This system (West Systems, Srl) used an aluminium chamber with a volume of 6 L and surface coverage of 0.03 m^2 (not that the chamber was smaller than other chamber so introduced a slight sampling disadvantage due to is smaller area of coverage). The analytical system was a tuneable laser diode CH_4 analyser and a non-dispersive infrared CO_2 analyser housed in a portable case.

While these two systems were suitable for most of the sites where surface flux measurements were made (e.g. natural surfaces, landfills, coal mines), there were some occasions when more specialised chambers were required. In particular, wastewater treatment plants and the rice farm required purpose built chambers to adequately measure emissions.

At one wastewater treatment plant, we fitted fixed chambers in two of the ponds and made measurements of flux during periodic visits to the site. One of the chambers is shown in Figure 5.6.

Figure 5.6. Fixed flux chamber in operation at the Singleton wastewater treatment plant

Each chamber was constructed from a 60 L polyethylene drum with the base removed and fixed to a walkway so that the open base of the chamber was submerged in the liquid. A length of 6 mm tubing allowed the chamber to be connected to the vehicle mounted analyser. A recirculating fan provided mixing within the chamber during each measurement. Because CH_4 and CO_2 accumulated in the chambers during intervening site visits, prior to flux measurements, each chamber was flushed with clean air for several minutes until the CH_4 and CO_2 concentrations within the chamber were close to ambient levels. The fixed chambers were only deployed at the Singleton wastewater treatment plant.

In addition to the fixed chambers, floating systems were built to enable the spatial distribution of emissions to be determined on water surfaces. The chambers were made from 60 L polyethylene drums cut in two and fitted with a circular float (Figure 5.7). Tubing was fitted so the unit could be attached to the Picarro analyser while a battery powered fan provided internal mixing. These chambers could be used up to about 20 m from the vehicle and were used at all four wastewater treatment sites. The floating chambers were also used to measure CH_4 flux from a CSG water treatment facility and occasionally on the wetland.

Figure 5.7. Floating flux chamber in use at a sewage treatment plant

Flux measurements at the rice farm also required specially designed and built chambers. Since measurements were made during the growing season, the chambers had to have sufficient height to accommodate the rice plants, which reached a maximum height of about 1.2 m before harvesting (Figure 5.8).

Figure 5.8. Purpose-built flux chamber used for measuring CH_4 emissions from rice

The photograph on the left of Figure 5.8 shows the chamber in position immediately after the rice crop was sown while the right hand image shows the chamber in use about two months into the growing cycle. During each measurement, the chamber was placed over the rice to seal onto a fixed polyethylene base, which was permanently set into the soil. The CH_4 concentration in the chamber was measured as for the other chambers by connecting a nylon tube (visible in left hand photo) to the Picarro instrument in the vehicle, which is parked at the side of the paddock. The chamber was also mixed continuously during each measurement using a small electrically powered fan visible on the top of the chamber. Six bases were installed in the rice field and left in position for the duration of the growing season. This allowed measurements to be made at various locations to assess the spatial variability of the emission profile. As well as measurements made on the fixed bases, other locations throughout the paddock were selected from time to time.

5.3 Volatile Organic Compound Determinations

5.3.1 PRIORITY VOCS

The volatile organic compounds (VOCs) targeted in this study are prioritised under Australian and International guidelines for air quality assessment. They comprise a comprehensive range of compounds that also allow the evaluation of source contribution and source recognition, of importance in this project. These compounds are incorporated into two VOC suites termed the 'PAMS hydrocarbon suite' and the 'TO-15 air toxics suite'.

The PAMS (Photochemical Assessment Monitoring Stations) suite is prioritised under United States Environmental Protection Agency (USEPA) and California Air Resources Board (CARB) protocols as the major organic precursors to the formation of ozone in the atmosphere. The suite comprises 57 aliphatic and cyclic hydrocarbons, including aromatic compounds, in the $C_2 – C_{12}$ hydrocarbon range which, by their nature, provide information on urban transport emissions, liquid and gaseous fuels and combustion derived emissions. Of importance to this project, these components assisted in attributing compounds to the primary source emissions as well as identifying possible contributing sources for each source category.

The TO-15 (Toxic Organics - Method 15) air toxics suite is prioritised under USEPA ambient air quality guidelines for human and environmental health. The TO-15 suite comprises 65 organic compounds that include halogenated and oxygenated species, along with certain hydrocarbons. These compounds characterise the emissions from various waste processing and industrial activities and aspects of emissions from natural processes.

Included in these suites are the aromatic compounds prioritised under the Australian National Environmental Protection (Air Toxics) Measure (Air Toxics NEPM), i.e. the BTX group; benzene, toluene and xylenes (NEPC, 2011). Note that formaldehyde and benzo[a]pyrene are also NEPM priority air toxics but these were not included in this study for a number of reasons. Formaldehyde is prioritised due to its toxicity as a primary emission (particularly from furnishings to indoor air and as a component in exhaust emissions to ambient air) and its role as a secondary pollutant of importance in the formation of atmospheric aerosol. These aspects were of lesser importance to the major aims of this work; the characterisation of VOCs from methane sources. Formaldehyde is also reactive and therefore requires a specific method of sampling and analysis that involves *in-situ* derivatisation as the mode of collection and liquid chromatography as the method of analysis. Benzo*[a]*pyrene is a particle-bound, semi-volatile compound that is primarily generated from combustion sources. This compound requires a filter-based method of collection and specific analytical and instrumental modes of analysis. Particles and semi-volatile organics were not the prime focus of this study.

The VOC suites are listed in Tables 5.2 and 5.3 for PAMS hydrocarbon and TO-15 air toxics VOCs respectively. The compounds are named according to IUPAC convention except where the alternative name is in common usage (such as toluene rather than methylbenzene) and in this case, both names are provided. The VOC tables of site results, presented in Appendix B, use the primary name as listed in Tables 5.2 and 5.3 and compounds common to both suites are reported in the PAMS listing only. The compounds are ordered by chromatographic retention time (down each column) as this provides a level of guidance as to their relative boiling point and volatility.

These compounds were determined using dedicated instrumentation that incorporated gas chromatography and detection using mass spectrometry and flame ionisation (GCMS and GCFID). These methodologies provided analysis at trace levels, below 0.1 part per billion by volume (ppbv) mixing ratios (also loosely termed concentration) in ambient air, for each of the priority air pollutants. The low detection limits enhanced the number of compounds identified in the VOC profile, which then assisted in emissions allocation to a particular source.

The sampling, analytical and instrumental methodologies implemented for the determination of priority VOCs are detailed in Section 5.3.4 together with the results of method validation and reporting protocols.

Table 5.2 USEPA/CARB PAMS Hydrocarbon VOC Suite

USEPA PAMS Hydrocarbon VOCs		
Ethene	2-Methylpentane	Ethylbenzene
Ethane	3-Methylpentane	*m*-Xylene (1,3-dimethylebnzene)
Acetylene (ethyne)	1-Hexene	*p*-Xylene (1,4-dimethylbenzene)
Propene	n-Hexane	Styrene (phenylethene)
Propane	Methylcyclopentane	*o*-Xylene (1,2-dimethylbenzene)
Isobutane (2-methylpropane)	2,4-Dimethylpentane	n-Nonane
1-Butene	Benzene	Isopropylbenzene
n-Butane	Cyclohexane	n-Propylbenzene
trans-2-Butene	2-Methylhexane	*m*-Ethyltoluene (1-ethyl-3-methylbenzene)
cis-2-Butene	2,3-Dimethylpentane	*p*-Ethyltoluene (1-ethyl-4-methylbenzene)
Isopentane (2-methylbutane)	3-Methylhexane	1,3,5-Trimethylbenzene
1-Pentene	Isooctane (2,2,4-trimethylpentane)	*o*-Ethyltoluene (1-ethyl-2-methylbenzene)
n-Pentane	n-Heptane	1,2,4-Trimethlybenzene
Isoprene (2-methyl-1,3-butadiene)	Methylcyclohexane	n-Decane
trans-2-Pentene	2,3,4-Trimethylpentane	1,2,3-Trimethylbenzene
cis-2-Pentene	Toluene (methylbenzene)	1,3-Diethylbenzene
2,2-Dimethylbutane	2-Methylheptane	1,4-Diethylbenzene
Cyclopentane	3-Methylheptane	n-Undecane
2,3-Dimethylbutane	n-Octane	n-Dodecane

Table 5.3 USEPA TO-15 Air Toxics VOC Suite

USEPA TO-15 Air Toxics VOCs		
Propene	*cis*-1,2-Dichloroethene	Dibromochloromethane
Dichlorodifluoromethane	n-Hexane	1,2-Dibromoethane
Chloromethane	Ethyl acetate	Tetrachloroethylene (tetrachloroethene)
1,1-Dichloro-1,1,2,2-tetrafluoroethane	Chloroform (trichloromethane)	Chlorobenzene
Chloroethene (vinyl chloride)	Tetrahydrofuran (oxolane)	Ethylbenzene
1,3-Butadiene	1,2-Dichloroethane	*m*-Xylene (1,3-dimethylebnzene)
Bromomethane (methyl bromide)	1,1,1-Trichloroethane	*p*-Xylene (1,4-dimethylbenzene)
Chloroethane (ethyl chloride)	Benzene	Bromoform (tribromomethane)
Ethanol	Carbon tetrachloride (tetrachloromethane)	Styrene (phenylethene)
Acrolein (prop-2-enal)	Cyclohexane	*o*-Xylene (1,2-dimethylbenzene)
Acetone (propanone)	1,2-Dichloropropane	1,1,2,2-Tetrachloroethane
Trichlorofluoromethane	Bromodichloromethane	*p*-Ethyltoluene (1-ethyl-4-methylbenzene)
Isopropanol (2-propanol)	Trichloroethylene (trichloroethene)	1,3,5-Trimethylbenzene
1,1-Dichloroethene	1,4-Dioxane (1,4-dioxacyclohexane)	1,2,4-Trimethylbenzene
Dichloromethane (methylene chloride)	Methyl methacrolate (methyl-2-methylpropenoate)	Benzyl chloride (chlorophenylmethane)
Carbon disulphide (methanedithione)	n-Heptane	1,3-Dichlorobenzene
1,1,2-Trichloro-1,2,2-trifluoroethane	*cis*-1,3-Dichloropropene	1,4-Dichlorobenzene
trans-1,2-Dichloroethene	Methyl isobutyl ketone (4-methyl-2-pentanone)	1,2-Dichlorobenzene
1,1-Dichloroethane	*trans*-1,3-Dichloropropene	1,2,4-Trichlorobenzene
Methyl *tert*-butyl ether (2-methoxy-2-methylpropane)	1,1,2-Trichloroethane	Napthalene (bicyclo[4.4.0]deca-1,3,5,7,9-pentene)
Ethenyl acetate (vinyl acetate)	Toluene (methylbenzene)	Hexachloro-1,3-butadiene
2-Butanone	Methyl n-butyl ketone (2-hexanone)	

5.3.2 DETERMINATION OF NON-STANDARD COMPOUNDS

Further characterisation of VOCs present in the ambient samples from each source category was undertaken for the determination of non-standard compounds. Non-standard compounds are additional to those measured as priority VOCs and their identification provides further information for source recognition purposes. This determination was achieved by re-examination of the chromatographic output from the VOC analysis for additional peaks that were not included in the priority compound suites. These signals were interpreted using their mass spectral output and, where signal intensity and clarity allowed, the compounds were identified. The results from the most informative VOC analysis for each source (those of higher concentration and tendency to compound diversity) were processed in this manner. Over 30 additional compounds were identified from examination of the VOC output, as listed in Table 5.4.

A sorbent collection and instrumental technique was also investigated to evaluate its power in organic characterisation of emissions from the various land-use sources. This technique has the potential to isolate more reactive species (such as nitrogen and sulphur containing compounds), more complex polar species (such as large oxygenated compounds) and those classed as semi-volatile organic compounds (SVOCs). These classes of compounds can be less amenable to canister collection due to these physical and chemical characteristics. The sorbent technique requires dedicated instrumentation comprising thermal desorption and GCMS (TD-GCMS) and both electron ionisation and chemical ionisation modes of mass spectrometry were utilised to extend capability in mass spectral elucidation and compound identification. Fourteen compounds additional to those identified by evaluation of the VOC output were identified using the sorbent technique. The sorbent methodology tended to preference compounds of greater polarity (e.g. esters) and lower volatility (e.g. C_{10} to C_{12} oxygenates) compared with those from the VOC output, as can be seen in Table 5.4.

The methodologies used for determination of non-standard compounds using the chromatographic output from VOC analysis and by sorbent tube techniques are detailed in Section 5.3.5.

Table 5.4 Non-standard compounds identified from characterisation studies of selected sources using evaluation of VOC output and by sorbent techniques

Non-standard Compounds	
Characterisation using VOC Output	Sorbent Technique
Carbonyl sulphide	Carbonyl sulphide
Sulphur containing; likely dimethyl sulfone	Sulphur containing; likely dimethyl sulfone
Dimethylsuphide	Alcohol; likely 2-butanol
Nitromethane	Butylester
Butanal	Ketone; likely 4-methyl-4-penten-2-one
Bromopropane	C_7 oxygenate; possibly alkylester
Nitrogenous	C_7 oxygenate; possibly alcohol
Oxygenated; likely alcohol	Benzaldehyde
C_4 aldehyde; likely 2-methylpropanal	a-Pinene
2-Pentanone	Phenol
Pentanal	C_8 ketone; possibly 6-methylheptanone
C_5 aldehyde; likely 3-methylbutanal	C_8 oxygenate
C_5 aldehyde; likely 2-methylbutanal	Monoterpene; possibly 3-carene
Nitroethane	C_8 aldehyde; likely octanal

Non-standard Compounds	
Characterisation using VOC Output	Sorbent Technique
Nitrogenous	Monoterpene; likely p-cymene
Dimethyldisulphide	Limonene (monoterpene)
Hexanal	Acetophenone
Furfural	C_9 oxygenate; likely nonanal or nonenol
3-Heptanone	C_{10} oxygenate; likely decanal or decenol
Heptanal	C_{11} oxygenate; likely undecanal
Oxygenate; possibly 2-ethylhexanal	C_{12} aldehyde
a-Pinene (monoterpene)	C_{12} ketone
Benzaldehyde	
a-Methylstyrene	
C_7 oxygenate; likely alcohol	
C_8 alcohol; possibly 2-ethyl-1-hexanol	
Monoterpene; likely p-cymene	
Limonene (monoterpene)	
Eucalyptol (1,8-cineole) (monoterpenoid)	
Chloroacetophenone	
Phenyl alcohol or like	
C_9 oxygenate; possibly nonenol or nonanal	
C_{10} oxygenate	

5.3.3 HYDROCARBON VOCS IN CSG SOURCED WELL GASES

The determination of minor hydrocarbon VOCs, that is those above C_5, in CSG sourced well gases was undertaken. This analysis was not a requisite of this project; however, it was considered that the determination might be informative in the recognition of a CSG source impact to ambient air and with respect to human and environmental health. The minor hydrocarbons are not commonly measured in well gases, as the focus is usually on determining the composition of the gas as its bulk components (i.e. methane and C_2 to C_5 hydrocarbons), and instrumental techniques are optimised for this purpose. The use of high sensitivity instruments, such as those implemented for VOC analysis in this project, enabled the analysis of minor constituents in the C_5-C_8 hydrocarbon range as well as aromatic compounds, including the air toxics; benzene, toluene and xylenes.

All hydrocarbons from the PAMS hydrocarbon VOC suite were targeted and non-methane hydrocarbons (NMHCs) in the range C_2 to C_5 were also determined to provide a measure of relative concentration to the C_5-C_8 compounds. For C_2 to C_5 compounds with concentration > 100ppmv the analysis was considered to be semi-quantitative and data from molecular composition analysis is referenced for these bulk constituents (refer Section 5.4.1).

The methodology for VOC analysis in ambient air samples was re-designed for well gas analysis to accommodate the methane sample matrix and an investigation for the determination of minor hydrocarbon VOCs in a selection of well gas samples was undertaken. The methodology adopted for this aspect of the work is detailed in Section 5.3.6.

5.3.4 ANALYTICAL METHODOLOGY FOR PRIORITY VOCS

The methodology for determination of ambient VOCs used passivated stainless steel canisters as the means of sample collection and instrumental analysis was undertaken using gas chromatography with flame ionisation detection (GCFID) and mass spectrometry (GCMS). Using these techniques, a whole air sample is obtained in a clean and relatively inert sampling medium and GCMS analysis provides high-level sensitivity and accuracy in species quantification and in the confirmation of compound identity. GCFID supports the determination of C_2 hydrocarbon isomers that cannot be determined under the GCMS instrumental conditions required to analyse for compounds in the range C_3-C_{12}, due mainly to the specific modes of pre-concentration required. This methodology is proven for ambient, trace level analysis of the species listed. A description of the methodology and its optimisation and validation follows.

Sampling and analytical procedures are based on USEPA TO-14A (USEPA (1), 1999) and TO-15 (USEPA (2), 1999) standard methodologies for determination of VOCs in ambient air using canister collection and gas chromatography with flame ionisation detection (GCFID) and mass spectrometry (GCMS), respectively. The species prioritised under the USEPA TO-14A methodology include primarily simple aromatics and halogenated compounds and hence a subset of compounds from the USEPA TO-15 priority air toxics listing were also determined to include a more comprehensive range of halogenated species and certain oxygenated species. The VOC assessment of C_2 to C_{12} compounds from the PAMS hydrocarbon suite was undertaken based on similar principles to that of USEPA TO-14A and TO-15 methodologies, incorporating in-house methods that are specific to the instrumental analysis of the PAMS suite of compounds.

Ambient sample collection involved the use of Silco® treated passivated stainless steel canisters. These undergo a rigorous cleaning procedure prior to sampling involving repeated evacuation and pressurisation under humidified nitrogen. The evacuated canisters are deployed to the sampling site, the canister is opened and the air is drawn into the canister, under vacuum, until it reaches atmospheric pressure. This mode of sampling is termed instantaneous or 'grab' sampling and provides a snapshot of ambient concentrations. At the laboratory, the canisters containing the sample are pressurised with zero air and the pressure difference is measured using a pressure transducer to determine sample dilution. A clean canister is filled with zero air with each batch of samples to check for the presence of zero air or system related artefacts.

The instrumental analysis involves the transfer of optimised volumes of the canister sample, under mass flow control, to dual cryogenic traps (a multicomponent adsorbent trap and a glass-bead trap) used to concentrate the VOC analytes, and their subsequent thermal desorption to a combined GC/FID/MS instrument (Varian CP-3800 GC/FID/4000 Ion-trap MS). A sample volume of 300mL and a pre-column split ratio of 10:1 were used to introduce the ambient samples to the instrument. A set of time-programmed valves regulates the flow path from the canister manifold to purge sample lines and traps, transfer sample to the cold-traps, and direct the sample path from the traps to a system of columns for pre-focussing and gas chromatographic separation of the organic compounds. This is accomplished using four GC columns; a CP-Sil 5CB methyl siloxane pre-column (15m x 0.32mm ID, 1µm DF), an Al_2O_3/KCl PLOT column (50m x 0.32mm ID) for separation of C_2-C_5 compounds, and a VF-1MS methyl siloxane column (60m x 0.32mm ID, 1µm DF) for separation of C_6-C_{12} compounds, prior to dual-FID detection. Another VF-1MS column of the same dimensions is used for simultaneous analysis of C_3-C_{12} compounds using MS detection.

The compounds detected in the samples were speciated against standard gas mixtures using GCMS analysis operated in the mode of electron impact ionisation (GCMS-EI) and using an ion-trap design of mass spectrometer. Software that compares both the retention time and the mass spectra of each of the sample components against the standard compounds is used to ensure that false positives are minimised. Integration of the component peak is based on selected ions that are specific to the compound. These operations are especially important in the analysis of trace level and complex samples such as those encountered in this study. The external standard method is used for quantification of sample components. GCFID analysis is used for C_2 isomers (ethane, ethene and acetylene) due to the required specificity of instrumental cold-trapping for these analytes. Higher hydrocarbons were also measured by FID analysis and were used as a check on GCMS derived results.

Of importance in the method validation is the observance and minimisation of method and system related artefacts, some of which may present as target compounds. Artefacts may also present as degradation products of collected analytes or from interactions with co-collected species. Equally, loss of target compounds can occur due to each of these parameters. Artefacts can be generated from, or on, canister surfaces, from gases used for canister pressurisation, from transfer lines and components of the instrument introduction paths, from the adsorbent materials used for cold-trapping and from compound reactions with adsorbent materials. The quality assurance process included batch monitoring of instrumental background and method blank samples and, where necessary, account was made for any artefacts found.

The method has been optimised, validated and calibrated based on a 57 component certified PAMS hydrocarbon standard gas mixture (Scott Speciality Gases Inc.) and a 65 component certified TO-15 standard gas mixture (Scott Speciality Gases Inc./Air Liquide Ltd/Restek Corporation). PAMS hydrocarbon VOCs are listed in Table 5.2 and TO-15 air toxics VOCs are listed in Table 5.3. The GCFID chromatogram of C_2 to C_4 hydrocarbon subset from the PAMS gas mixture is shown in Figure 5.9, and the GCMS chromatograms obtained from analysis of the PAMS and TO-15 standard gas mixtures are shown in Figures 5.10 and 5.11, respectively.

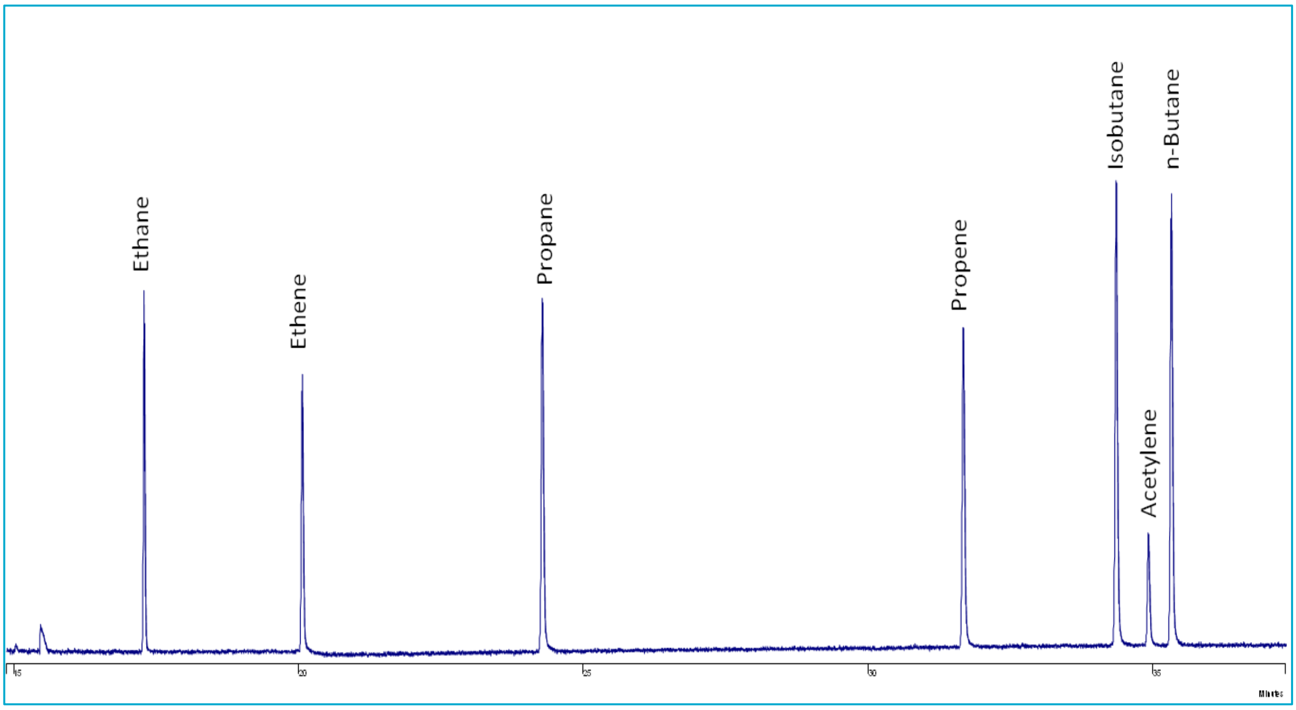

Figure 5.9 Portion of the GCFID chromatogram showing C_2 to C_4 hydrocarbons from the PAMS hydrocarbon standard gas mixture

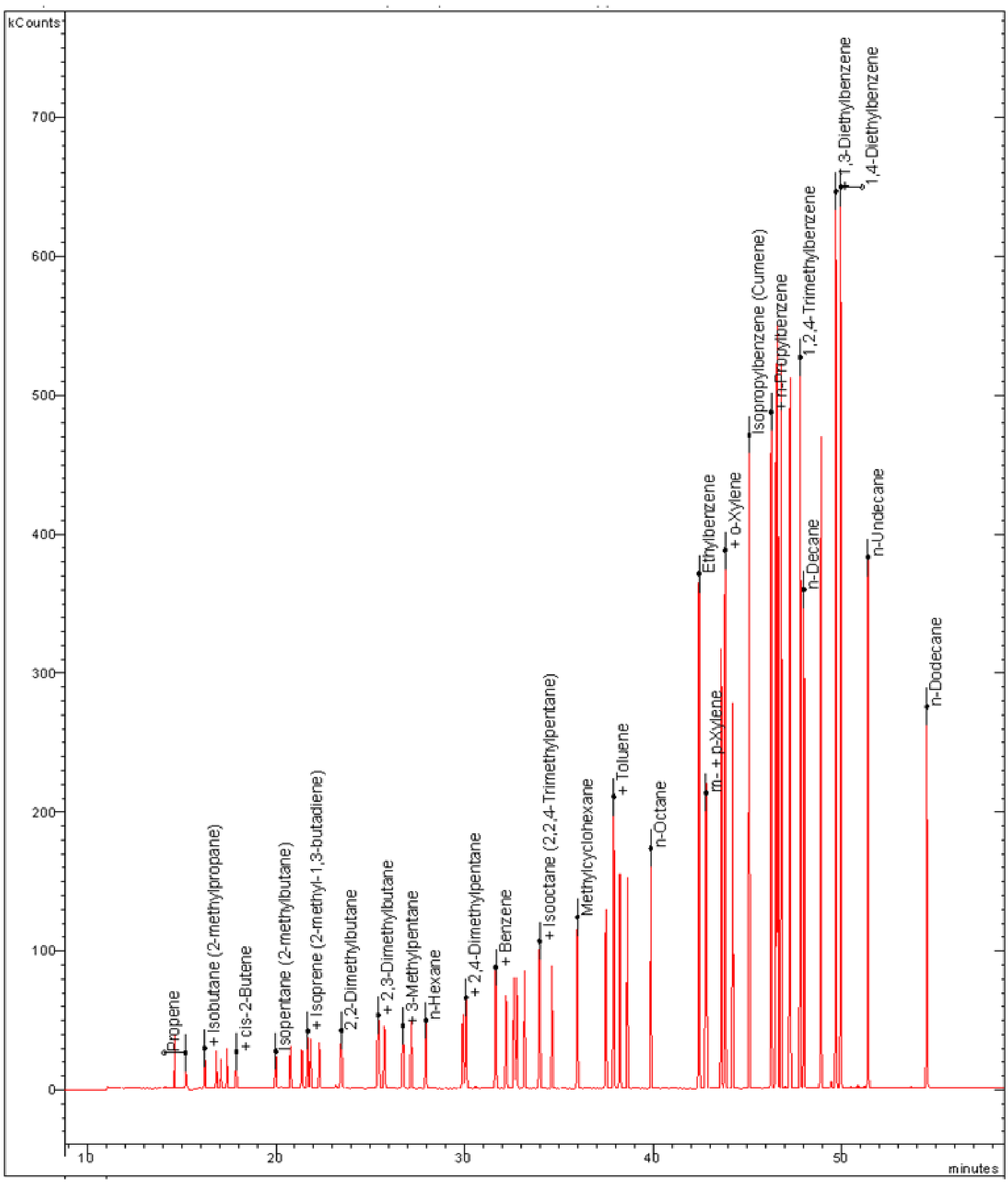

Figure 5.10 GCMS chromatogram of C_3 to C_{12} compounds from USEPA PAMS hydrocarbon standard gas mixture.
Note that all peaks from the 57-component standard are present (as listed in retention time order in Table 5.2). The peaks are labelled in this Figure to a readable size; some peaks are not labelled for the sake of clarity.

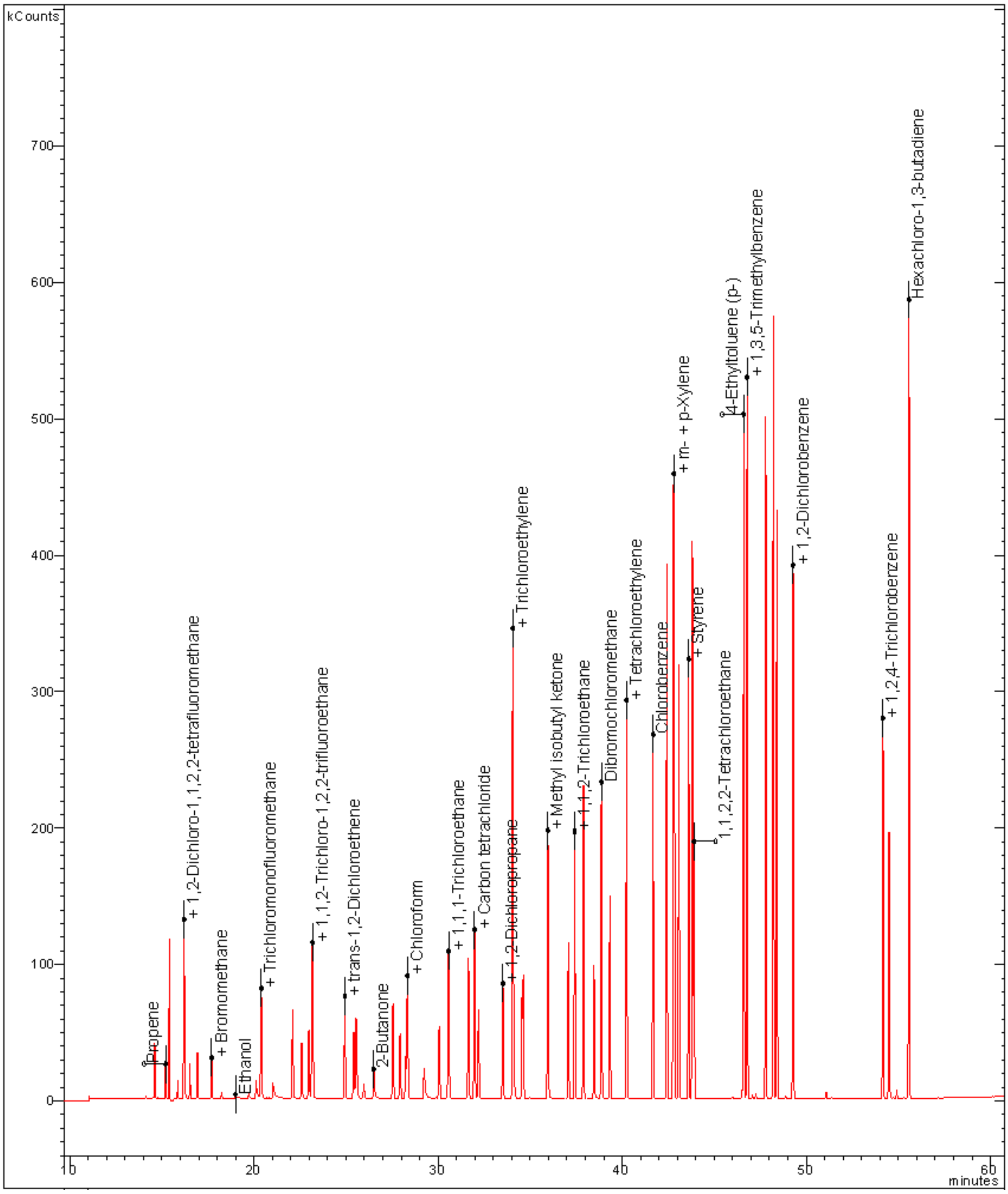

Figure 5.11 GCMS chromatogram from analysis of USEPA TO-15 air toxics VOC standard gas mixture.
Note that all peaks from the 65-component standard are present (as listed in retention time order in Table 5.3) but only some have been labelled for the sake of clarity.

Method Proficiency

The assessment of method proficiency complied with the requirements of the standard methods, and the results of method validation and on-going batch-to-batch quality assurance testing are summarised in the following paragraphs. For ease of reading, the results of method proficiency are reported as an average of all quality control data from GCMS and GCFID analyses of compounds from the PAMS and TO-15 suites. GCFID analysis of C_2 isomers generally returned similar levels of proficiency as GCMS. The exception is the lower sensitivity of the GCFID and hence method detection limits for GCFID are reported separately to GCMS, as described below.

The linearity of concentration was established from a multipoint calibration over the concentration range 1 to 100ppbv with a resultant r^2 value of > 0.99 obtained from the least-squares regression line (average for all compounds). The precision associated with the slope of the regression line (equivalent to the signal response factor) was 5-15% dependent on compound. Polar compounds inherently obtain lower precision due to their reactivity, surface interactions and water solubility (Kelly and Callahan, 1993).

The analytical precision obtained from replicate analysis of the gas standards at nominal concentration (0.98, 3.3, 8.3, 25.0ppbv, dependent on concentration range of individual compounds in the samples) averaged ± 4% RSD. Precision from duplicate analysis of samples at minimal concentration (0.05-0.5ppbv), averaged ± 10% RPD for the target compounds.

Accuracy, as the result from analysis of an independent standard at nominal concentration against the calibration, averaged 90-110% recovery. The compounds that were common to the PAMS and TO-15 standard gas mixtures were routinely compared using the results from calibration and from samples. Acceptable recovery, in the range averaging 85-100%, was found between the two suites. This also tested, to some extent, the validity of the certified mixtures.

The sensitivity of GCMS analysis using ion-trap and extracted ion manipulations allowed detection at concentrations down to parts per trillion by volume (pptv) levels. The minimum concentration achievable is specific for each compound and is primarily dependent on the ions selected for quantitation, ion intensity, presence of co-eluting species and the physical and chemical characteristics of each compound. Many compounds were identifiable at an ambient concentration of 5pptv (0.005ppbv) and, although not statistically relevant at this level, this provided valuable information for the source characterisation aspect of this work. The process of determining detection limits is quite complex and is described for the various aspects of the determination below. Appendix A lists the results of these determinations.

The *instrumental (or instrument) detection limit (IDL)* is the minimum detectable concentration in the sample as it is presented to the instrument's detector. This incorporates the volume of sample taken to the adsorbent trap and any instrumental variables prior to detection, in this case the outlet split ratio at the cold trap. The IDL was determined using both statistical analysis and by examination of chromatographic and mass spectral output, and these methods are described in the following paragraphs.

Statistical determination of the IDL was calculated from 5-replicate analyses of the standard gas mixture prepared at a concentration of 10-fold the expected detection limit (i.e. at a concentration of 1ppbv), as per the criteria for this evaluation. The t-value for 4-degrees of freedom at the 99% confidence interval was applied to the resultant standard deviation to calculate the detection limit for each compound. The statistically derived IDL for the PAMS hydrocarbon compounds ranged from 0.04 to 0.2ppbv and averaged 0.1ppbv across the suite. The IDL for the TO-15 air toxics suite ranged from 0.06 to 0.4ppbv and averaged 0.1ppbv. Results for individual compounds are listed in Appendix A.

An IDL determined from inspection of the chromatographic output is a method in common practice. Here the response of the analyte peak at minimal concentration is compared to the background noise and a detection limit is calculated based on a standard value of signal to noise of 2.5. The GCMS method adopted for this work achieves an analyte response using selected ions for each analyte. This not only provides superior selectivity in a complex ambient air matrix but also effectively minimises contribution of background ions to the analyte signal and hence increases the signal to noise ratio for each compound (i.e. improves the detection limit). Together with the advantage of the ion-trap MS system in also allowing simultaneous full-scan acquisition and mass spectral confirmation of each analyte at the time of peak integration, a higher level of confidence in qualitative compound detection is achieved. It must be understood however, that this does not necessarily mean a higher level of quantitative confidence as the error associated with the integration is the same. The chromatographically derived IDL for the PAMS suite ranged from 0.001 to 0.2ppbv and averaged 0.02ppbv. The IDL for the TO-15 suite ranged from 0.001 to 0.3ppbv and averaged 0.03ppbv.

In the case of the analytes measured by GCFID, the statistical and chromatographically based detection limits are very similar as, with no other means of assessment, the standard deviation of the response equates to the level of background noise. The FID detection limits are therefore higher than those from MS analysis. An average IDL of 0.4ppbv was determined for C_2 compounds measured by GCFID.

The *method detection limit (MDL)* is the value directly applicable to the minimum detectable concentration in the sampled air. In this work, the MDL accounts for pressurisation of the canister sample prior to analysis and therefore applies the appropriate dilution multiplier to the IDL. Additionally, a factor accounting for the effect of background artefacts on the sample detection limit is applied for affected compounds. For this study these factors resulted in a MDL which was generally a 2-fold multiple of the IDL, or somewhat higher for a minimum number of compounds. As a general guide, the MDL for PAMS compounds averaged 0.2ppbv and 0.05ppbv (by statistical and chromatographic derivation, respectively) and 0.3ppbv and 0.07ppbv for TO-15 compounds. Refer Appendix A for MDLs applicable to individual compounds.

The *limit of reporting (LOR)* is a convention that applies a multiplier to the MDL to account for sampling and analytical variables and therefore provides a more conservative and rigorous limit to the reported result. In this work, a 3-fold multiplier is applied to the MDL to determine the LOR.

The results for IDL, MDL and LOR under statistically derived confidence limits and under MS and FID chromatographic evaluation are listed for each compound in Appendix A. Reporting to the detection limit is described in the following sub-section.

Examination of the stability of individual compounds under the conditions of sampling and analysis found a somewhat inconsistent result for carbon disulphide, which is an analyte in the USEPA TO-15 suite. Carbon disulphide appeared somewhat unstable in the sample analysis and it was found in method blanks at somewhat variable concentration. Sulphur compounds are known to be reactive and many species tend to be unstable under canister collection and storage and under cold-trapping and thermal desorption. Variations in sample humidity can also affect the result obtained. As accuracy within the acceptable limits was therefore in doubt, this compound was not included in the reported VOC suite. All other compounds from the PAMS and TO-15 suites met with stability criteria.

VOC Reporting

Where PAMS and TO-15 compounds are common to both standard mixtures, the result from the PAMS suite is reported. As previously discussed, carbon disulphide was the only compound from the TO-15 which was not reported in this study.

The concentrations of target species measured in ambient samples are reported as a mixing ratio in units of parts per billion by volume (ppbv). For ease of reading and uniformity in the text, the term ‘concentration’ will be used as a substitute for the more correct term ‘mixing ratio’.

For emissions characterisation purposes, which is of importance to this project, is it considered acceptable to use the method detection limit obtained from chromatographic inspection as this provides a greater number of compounds on which comparison may be made or on which trends may be shown. It must be emphasised that this requires appreciation of the fact that a higher level of error must necessarily be associated with concentrations at these trace levels and hence a higher level of understanding of the significance of the data is required.

Where no chromatographic or mass spectral signal is observed at the retention time for a compound, or where this signal is less than the chromatographic IDL, the compound is reported as “not detected” (ND).

Note that if the results were to be used for air quality assessment purposes by OEH/EPA, only the data at and above the LOR provide sufficient statistical rigour for this type of assessment. Hence if the results are to be on-reported for air quality assessment or other purposes, only those data which are greater than the LOR can be used, and minimum data must be reported as < LOR.

5.3.5 ANALYTICAL METHODOLOGIES FOR NON-STANDARD COMPOUNDS

Non-standard compounds are those additional to compounds measured as priority VOCs. They may be observed to be present in the sample from canister based VOC analysis or those collected and analysed by sorbent techniques, using methodology described in the following sub-sections. Over 45 non-standard compounds were identified using these techniques, as listed in Table 5.4, and these are tabulated for each source category in the discussion of site results in Section 7.

Non-Standard Compounds by Canister VOC Analysis

The sample chromatograms obtained from the priority VOC analyses were re-examined for non-standard compounds. If a non-standard compound was found its organic characteristics were elucidated using mass spectra and structural library search. Where signal intensity and mass spectral purity allowed, the compounds were identified, else an organic class was determined and assigned to the component. For quantitative measurements, a thorough validation process would be required using authentic reference standards for each compound. Stability of certain species such as sulphur and oxygenated compounds would also require assessment. Whilst samples contained in Silco® treated canisters provided improved stability compared to nickel passivated canisters (Summa® canisters) this aspect would need to be validated for each new compound in order to ensure accuracy in quantitative measurements. As such, the results from these determinations were purely qualitative.

Non-Standard Compounds by Sorbent Tube Analysis

Some trace level compounds, especially sulphur, oxygen and nitrogen containing organics are not amenable to sampling with canisters due to their reactivity and instability on canister surfaces and in the presence of moisture. However, it is possible to collect certain classes of these species using sorbent tubes packed with suitable adsorbent materials (Hunter Daughtrey et al., 2001; Rodriguez-Navas et al*.,* 2012). This technique has the potential to provide additional information to identify compounds specific to particular sources of importance in this study, for example wastewater treatment plants and animal feedlots, which are not necessarily known to emit significant emissions of air toxics. Due to the specificity and complexity associated with both the sampling and instrumental aspects of this technique, this component of the project was designed to be investigative in nature. The sorbent tube methodology was therefore applied to the sampling of ambient air at sites that were found, by the canister analysis, to contain significant levels of non-standard compounds.

The sorbent methodology is based on USEPA TO-17 (USEPA (3), 1999) and uses pumped sorbent tube collection of ambient air, thermal desorption of collected analytes, cryogenic secondary trapping and GCMS analysis. UK Environment Directive LFTGN 04 was also used as guidance for monitoring of trace components in landfill gas (Environment Agency, 2004). The sorbent tubes that were selected for this project contained a combination of sorbent materials, namely; Tenax® and Sulficarb® (previously Unicarb®), from Markes Corporation. A schematic of the sorbent tube is shown in Figure 5.12. The sorbent combination was selected for its inert qualities in the presence of relatively reactive compounds, and for its amenability to collection and desorption of low to mid volatility hydrocarbon, oxygenated, and sulphur containing species which are likely to be relevant to this study. A secondary cold-trap adsorbent was selected to optimise for these compounds of interest and here a proprietary air toxics packing (Markes Corporation) was used.

Where canister results were suggestive of the relevance of the sorbent tube technique, tubes were deployed to those sites at a subsequent visit. Sample collection with a sorbent tube uses a portable sampling unit designed for mass flow controlled pumped sampling. Ambient air is drawn through the sorbent tubes at a calibrated flow rate for a specific time period. Flow rate is optimised for the tube parameters, within the limits of manufacturers specifications, and sampling time is optimised dependent on the physical and chemical nature of the compounds targeted (such as volatility and associated break-through volume) and the likely ambient concentrations of these compounds at the site under test. The sample collection volume must generate the required analyte mass for instrumental analysis. Flow rates of 100-150 mL min^{-1} for 10-20 mins were generally used. Using the sample volume and mass of analyte determined from the analysis the ambient concentration (ppbv) can be determined.

Analysis of sorbent tubes incorporates a thermal desorption stage and for this a Markes Ultra 2™ tube autosampler and Unity 2™ thermal desorption unit (Markes International Ltd) was used. This system is interfaced to the GCMS instrument that comprised a Varian 450-GC gas chromatograph and Varian 240-MS ion trap mass spectrometer (Varian Corporation, now Agilent Technologies Ltd). This instrument differs from the system used for VOCs by canister collection in that it is capable of collecting electron impact ionisation mass spectra as well as chemical ionisation mass spectra, giving it extra advantages in the characterisation of unknowns, as discussed further below. Later in the project the thermal desorption system was interfaced to an Agilent 7890A GC and 7000 series Triple Quad MS (Agilent Technologies Ltd). This instrument operates by different principles in its generation of electron impact mass spectra and provided further insight into the identification of non-standard compounds.

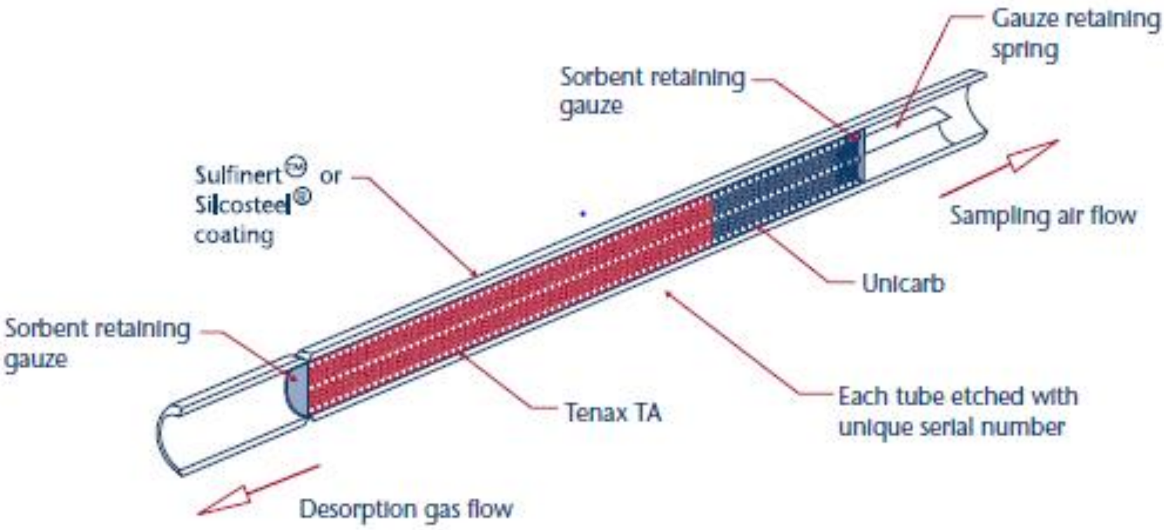

Figure 5.12 Sorbent tube schematic (reference UK Directive, LFTGN 04, EA 2004)

The thermal desorption protocol requires attention to various parameters effecting the efficiency of transfer of analytes through various stages of the process. Variables of temperature, flow and time were tested and optimised for initial purging of air and moisture from the primary collection tube, for desorption of the primary tube, for secondary cold-trapping, for purging residual oxygen from the cold trap, for thermal desorption of the cold-trap, for optimisation of the outlet split and analyte recollection, for control of analyte mass to the GC column and for the focussing of analytes at the head of the column. Chromatographic parameters affecting component separation and mass spectral detection parameters were also optimised. The PAMS and TO-15 standard gas mixtures were used for method optimisation and a system for transfer of aliquots of the gas standards onto the sorbent tubes was developed.

Of importance in the method validation is the observance and minimisation of method and system related artefacts, some of which may present as target species. They may also present as degradation products of collected analytes or from interactions with co-collected species. Equally, loss of target species can occur due to each of these parameters. Artefacts are particularly problematic with sorbent methodologies both in the tube collection phase and the cold-trapping and desorption phases of the methodology (Dewulf et al., 1999). This can be dependent on the type and grade of the material and other factors associated with the methodology such as co-collected species, and temperature and moisture control. Co-collected species, such as ozone, NO_2 and limonene can enhance certain degradation products (Clausen and Wolkoff, 1997) and benzaldehyde, phenol and acetophenone are candidates as Tenax® artefacts (along with others). These are also likely to be found as analytes from certain sources monitored in this project. In this work, sorbent tubes were monitored for sorbent artefacts as both field exposed and laboratory (unexposed) blanks. For example, artefacts in a field blank can be seen in Figure 5.13. These compounds were reported as identified in the sample only when present at greater than 20-times the blank levels. Consideration was also made for their formation in association with co-collected species.

The chromatographic output from desorption of the sorbent tube samples was examined for standard compounds and any additional peaks were then examined using their mass spectra obtained from electron impact ionisation (EI-MS). NIST software was used for mass spectral structure searching and compound matching to gain the identity of the compound. Using the Varian ion-trap mass spectrometer it was also possible to determine the molecular weight of a compound using chemical ionisation as the mode of analysis (CI-MS). The ion-trap uses methanol vapour as the reagent gas and positive ion CI-MS produces a clear mass spectrum containing the $[MH]^+$ ion (the protonated molecular ion) for certain compounds. This provides enhanced sensitivity and specificity particularly for oxygenated and nitrated compounds.

The knowledge of a compound's molecular weight, obtained from CI-MS, together with its EI mass spectra allowed structural elucidation and characterisation of a specific identity, or an organic class, for minor compounds in the source emissions. Using CI-MS it was also possible to search the chromatogram for the $[MH]^+$ ion of particular compounds of interest. Where a hit was found the EI-MS chromatogram was then examined for a peak at the exact retention time and its mass spectra evaluated for purity to the compound of interest. This technique was used to search for characteristic compounds such as odour compounds, for example thiols (mercaptans), various oxygenates, acids and nitrated compounds. This information was drawn from various sources of literature, such as Fang et al. (2012), Rodrigues-Navas et al. (2012) and the UK landfill directive (Environment Agency, 2004). Experience from previous projects undertaken in the assessment of biogenic emissions from eucalypt species also assisted in the identification of monoterpenes and related biogenic compounds (Nelson et al., 2000, Nelson et al. 2004).

In order to attain accurate quantitative results, sorbent tube analysis requires comprehensive validation of such variables as stability, artefact generation, sorbent collection and desorption efficiency, and the optimisation of instrumental parameters. The use of authentic standards for each new compound isolated is also required. However, on the basis that the sorbent is an improved medium for stabilisation of some targeted compounds when compared with canisters, it was considered useful to allow a semi-quantitative estimate of concentration to assist with source characterisation. The response of a similar class of compound, at known concentration, from the TO-15 suite was used for this determination. As the exact response of the compound is not known, the error associated with this approach will be necessarily high. As such, the data reported for the characterisation studies is reported as a range.

Characterisation of ambient samples using the sorbent tube methodology was successful in isolating many of the non-standard compounds identified from the canister characterisation studies as well as a number of additional compounds. The sorbent tube collection showed greater specificity towards monoterpenes and greater selectivity towards the more complex oxygenated compounds and nitrogen and sulphur containing compounds than the canister collected sample.

An example of the successful isolation of non-standard compounds by sorbent tube analysis is shown in Figure 5.13. This figure shows a portion of the chromatogram from the TO-15 air toxics standard gas mixture (plot 1) and the same portion of the chromatogram for samples from Singleton wastewater treatment plant (plot 2), from Summerhill landfill (plot 3) and the field blank (plot 4). A number of additional compounds to that of the TO-15 standard can be seen in the sample chromatograms and some differences in the type of compounds can be seen in those isolated from wastewater treatment compared to the landfill. Figure 5.13 also shows the importance of the field blank and the identification of components associated with the sorbent material itself in order that false positives are not reported as sample components.

Reporting of Non-Standard Compounds

Qualitative compound identification is reported for the characterisation studies undertaken using the canister samples for VOC analysis, as previously discussed.

Semi-quantitative data are reported as a concentration range, in units of ppbv, for the characterisation studies undertaken using sorbent technology. It must be stressed that this result can only be used to provide indicative information of the relative concentration of compounds found at a particular site, or for source comparison.

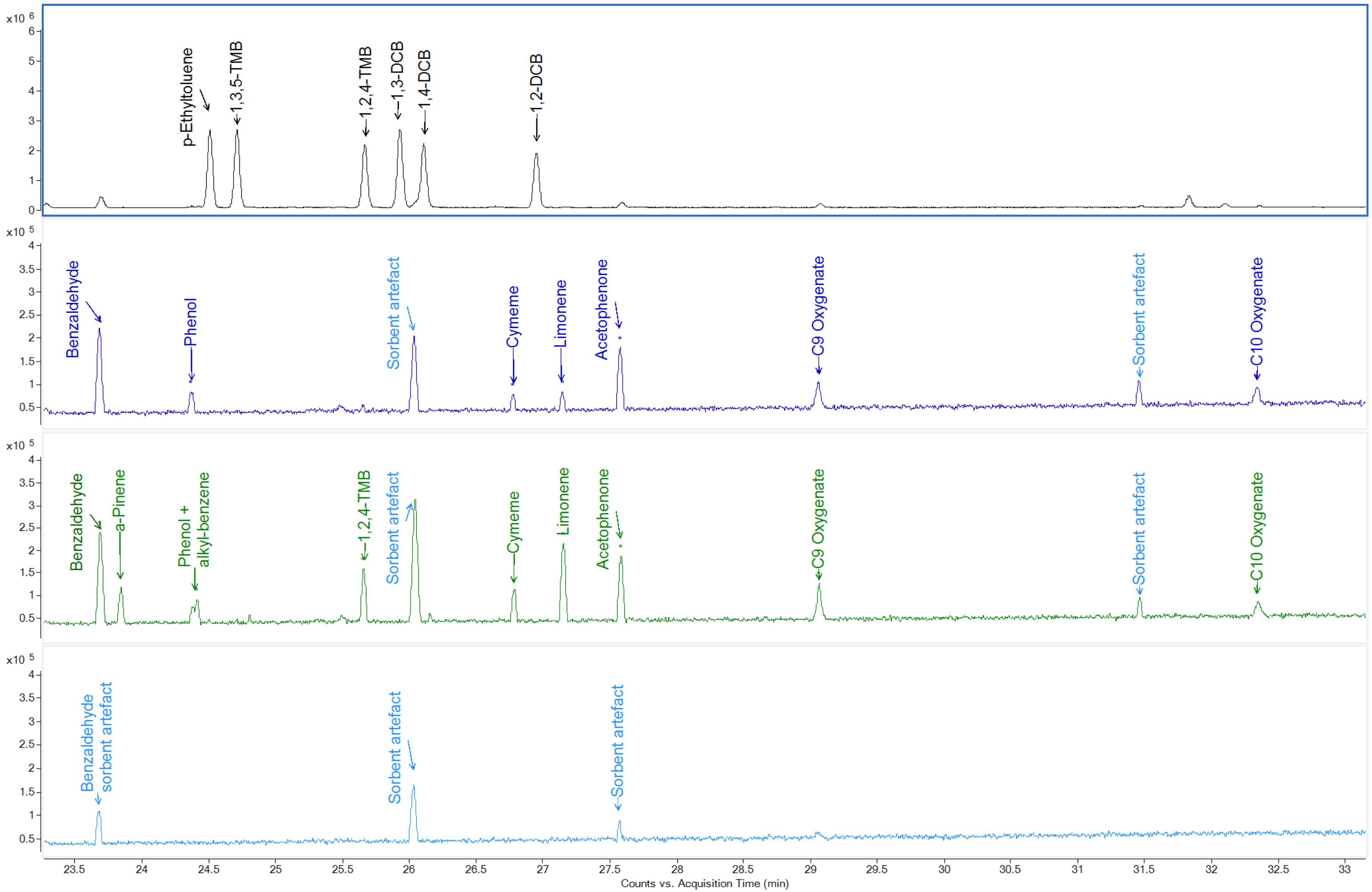

Figure 5.13 Section of EI-MS chromatogram from sorbent tube analysis. Plot 1 (top): TO-15 air toxics standard compounds. Plot 2: Mass spectral identification of non-standard compounds in an ambient sample from Singleton wastewater treatment plant. Plot 3: Summerhill landfill. Plot 4 (bottom): Sorbent artefacts isolated from field blank.

5.3.6 ANALYTICAL METHODOLOGY FOR HYDROCARBON VOCS IN CSG SOURCED WELL GAS

The minor hydrocarbons, that is those above C_5, are not generally measured in well gases, as the focus is usually on determining the composition of the gas as its bulk components (i.e. methane and C_2 to C_5 hydrocarbons), and instrumental techniques are optimised for this purpose. The use of high sensitivity instruments, such as those implemented for VOC analysis in this project, enabled the analysis of minor constituents in the C_5-C_8 hydrocarbon range as well as aromatic compounds, including the air toxics; benzene, toluene and xylenes. All hydrocarbons from the PAMS hydrocarbon VOC suite were targeted and non-methane hydrocarbons (NMHCs) in the range C_2 to C_5 were determined to provide a measure of relative concentration to the C_5-C_8 compounds.

The methodology for VOC analysis in ambient air samples was re-designed for well gas analysis to accommodate the methane sample matrix. The sample presented to the instrument must be substantially composed of nitrogen for operation of mass flow controllers in determining accurate flow and hence the volume of sample delivered for analysis. High levels of methane are also unsuitable in the cold-trapping process and will affect analyte trapping efficiency. Hence well gas samples require dilution to reduce methane concentration. In order to bring the concentration of other bulk hydrocarbons within the linear range of the instrument, large dilutions would be required. However, this would mean that the minor hydrocarbons would be at a concentration well below detectable limits. A compromise was therefore established which focused on the minor hydrocarbons at the expense of accuracy for C_2 to C_5 hydrocarbons. The flame ionisation detector (FID) was used for quantitation of C_2-C_5 hydrocarbons as this detector has a significantly wider linear range than the MS detector and effectively minimises the error due to non-linearity at high concentration. The GCMS was used for the target species due to its higher sensitivity.

The well gas samples collected into IsoTube® canisters for methane and isotope measurements were used for the NMHC determinations. Dilutions of the well gas sample were prepared between 1:1000 and 1:10,000 to assess instrumental requirements as well as determine the sensitivity to trace species in the well gas. A plot comparing the level of dilution to signal strength determined that quenching of the FID was evident where the smaller hydrocarbons were at very high concentration, as was expected. However, the deviation amounted to an error of up to 15% relative standard deviation (RSD) for the C_2-C_5 compounds across the dilutions tested, which was considered acceptable for initial investigation purposes. The 1:1000 dilution was therefore selected to maximise sensitivity to the aliphatic and aromatic hydrocarbons > C_5. The detection limit for this analysis under the parameters used is 7ppbv (0.007ppmv).

It must be emphasised that this method is optimised for the minor hydrocarbon components of the well gas. Hence, at concentrations > 100ppmv, the reported concentrations for C_2-C_5 hydrocarbons are considered semi-quantitative and the results are reported as a guide to the relative concentration of the C_5-C_8 hydrocarbon compounds. The concentrations of bulk constituents in the well gas are determined using the molecular composition analysis (refer Section 5.4.1).

5.4 Isotopic Analyses

A range of methane sources and varying methane concentrations were measured for their molecular and isotopic compositions at the sites listed in Table 5.1 using a range of methods, which are described in the following sections.

5.4.1 GAS SAMPLES

In the scope of the NSW EPA Methane Emissions project, there was a large diversity of gas samples that were scheduled to be taken, ranging from 'clean' air samples containing trace constituents (methane ~1.8 ppm) all the way to more concentrated samples such as landfill biogas (methane ~50-60 %) to commercial reticulated natural gas or coal seam gas taken at the wellhead (methane ~90-99 %). These large concentration ranges necessitated a varied number of sample collection strategies and the associated sample analyses.

The large dynamic range of methane concentrations (6 orders of magnitude) presented quite a challenge to have multiple analysis methods that could handle the concentration range. Prior experience with natural gas, coal seam gas and shale gas analyses for the fossil fuel energy sector meant that samples in the low to 100 % range had well established methodologies where gas was available at positive pressure. Locations and facilities that produced diffuse venting of methane at elevated concentrations would prove to be a challenge, particularly where no gas collection system was available. The biggest problem arose at having to analyse ambient methane concentrations. Although atmospheric scientists regularly measure global atmospheric methane levels at several sites around the globe, the instruments and sampling equipment are custom built and kept ultra-clean to minimise contamination issues (Umezawa et al., 2012). Access to clean air monitoring analytical facilities in Australia was not available. The problem was that no easily accessed facilities exist to measure high precision isotopes of methane at ambient air levels within an 'industrial landscape' full of heavier hydrocarbons, non-target volatile organic compounds and elevated levels of other permanent gases such as carbon dioxide, carbon monoxide, hydrogen sulphide, etc. To this end, an experimental program was enacted to investigate whether a prototype instrument could be built to achieve the stated aims; tailored for gas samples taken from rural/urban/industrialised environments.

For low level methane concentrations in ambient air, samples were collected for isotopic analyses using the same type of passive stainless steel canisters used for sampling of VOCs, which are described in Section 5.3.4. At the sampling site, grab samples or time averaged samples were then taken by varying the rate of atmospheric in-rush into the canister from the initial vacuum pressure in the canister. At the laboratory, samples were pressurised with helium to provide a positive pressure above atmospheric levels thus allowing several sample aliquots to be taken without isotopic fractionation (which progressively occurs as a gas sample in a rigid container is withdrawn causing the pressure to drop below atmospheric pressure, (Eby et al., 2015). The other alternative is to use an oil free piston compressor with stainless steel tanks fitted with stainless steel dip tubes and a double valve configuration to enable thorough flushing prior to sampling (Lowe et al., 1991). The later technique has the added advantage of being able to produce pressurised samples (typically 3 to 7 Atmospheres), thus ensuring sufficient volumes of sample to allow multiple aliquots to be taken.

With the more concentrated samples, multilayer composite material foil lined gas sampling bags (SKC Inc.), single use disposable aluminium canisters (Isotech Laboratories Inc.) and stainless steel sample cylinders (Swagelok Company) were utilised. Careful selection of sample containers was necessary as not all containers had sufficient integrity to limit diffusion and micro-leakage of the contents out or atmospheric contamination in; parameters critically important for stable isotope analyses. A prior CSIRO internal study on gas stability for carbon isotopes on a CH_4/CO_2 mixture found that from several different gas sample containers routinely encountered, 50 % fractionated the gas such that the results were erroneous and would have distorted the stable isotope interpretation. The main sources of fractionation were due to adsorption on wall material (CO_2 in Tedlar™ type gas bags), micro-leakage through glass vials with rubber septa (puncturing of septa by syringe needles never fully reseals) or micro-leakage with aluminised plastic bladders (originally designed for liquids, not gas samples).

Gas samples associated with water columns such as swamps and flooded rice paddocks required the use of bubble traps or custom liquid/headspace sampling jars from Isotech known as Isojars™. The bubble traps consisted of an inverted container from which the air could be displaced by water and then allow the accumulation of individual bubbles until a sufficient volume of sample gas was present. A small manifold at the top of the trap then allowed the gas to be moved to a gas sample container using hydrostatic pressure of the water column to produce a sufficient differential gas pressure, easily achieved by lowering the bubble-trap into the water column. The advantage of this sampling strategy allowed for gas to be collected with no water phase which would contain bacteria and organisms that would otherwise alter the gas mixture upon transport/storage. The disadvantage was that for very slow bubble formation (i.e. swamps, rice paddies and sewage settling ponds), days to weeks of accumulation could be required to achieve an isotopically equilibrated headspace gas. At industrial facilities, leaving long term bubble traps and a subsequent second trip to retrieve gas is not always feasible due to logistics and resourcing.

The use of Isojars allowed a grab sample of the water/sediment/gas bubbles to be taken quickly. Where sufficient gas bubbles can be sampled into the Isojar, the sealed system can then be injected with a bactericide to halt any further microbial re-work of the sample and kept refrigerated prior to laboratory gas analysis. For other Isojar samples where the sampling conditions prevent capture of any significant amounts of venting gas, water/sediment/mud could also be collected as a sealed microcosm container and a headspace created by injecting helium gas and withdrawing the same volume of water. Incubation at site temperature conditions allows methane to be generated insitu within 4-8 weeks, allowing sufficient methane to be generated for analysis; although not exactly the same as trapping methane gas in the field, the sealed microcosm can be used to produce analogous gas samples representative of the sampling location.

5.4.2 ANALYTICAL METHOD FOR GC-IRMS ANALYSIS OF GASES FOR C-ISOTOPES

The carbon isotopic composition of gases was measured by GC-C-IRMS (gas chromatography/combustion/isotope-ratio mass spectrometry). The GC-C-IRMS system consisted of a GC unit (6890N, Agilent Technologies, USA) connected to a GC-C/TC III combustion device coupled via open split to a Delta V Plus mass spectrometer (ThermoFisher Scientific, Germany). The analytes of the GC effluent stream were oxidised to CO_2 and H_2O in the combustion furnace held at 1000 °C on a CuO/Ni/Pt catalyst. Water was removed on-line by a Nafion membrane and the CO_2 was transferred to the mass spectrometer to determine carbon isotope ratios. 20-100 µL of sample gas was injected to the split/splitless inlet system (Agilent Technologies, USA), working in split mode (20:1 ratio). The inlet was held at a temperature of 200 °C. The gas components were separated on a fused silica capillary column (PoraPlot Q, 25 m x 0.32 mm ID, Varian). The GC was held isothermally at 40 °C. Helium was the carrier gas, set to a constant pressure of 14.3 psi. All gas samples were measured in duplicate with a standard deviation of ≤0.5 ‰ for the standards and samples. The quality of the carbon isotope measurements was checked regularly by measuring secondary standards of pure CH_4 and CH_4/CO_2 mixtures with known isotopic composition as determined by inter-comparison on dual bellows inlet mode on a Finnigan MAT 252 against international primary carbonate standards prepared by the phosphoric acid method.

In addition to the IRMS analyses, some samples were analysed for C isotopes using Picarro CRDS instruments. These instruments and the methods used are described in Section 8.3 of this report.

5.4.3 ANALYTICAL METHOD FOR GC-IRMS ANALYSIS OF GASES FOR H-ISOTOPES

The hydrogen isotopic composition of gases was measured by GC-TC-IRMS (gas chromatography/temperature conversion /isotope-ratio mass spectrometry). The GC-TC-IRMS system consisted of a GC unit (6890N, Agilent Technologies, USA) connected to a GC-C/TC III interface device coupled via open split to a Delta V Plus mass spectrometer (ThermoFisher Scientific, Germany). After passing through the GC, hydrocarbons were reduced to H_2 and elemental carbon in the temperature conversion reactor held at 1450 °C. H_2 was transferred on-line to the mass spectrometer to determine hydrogen isotope ratios. 20-200 µL of sample gas was injected to the split/splitless inlet system (Agilent Technologies, USA), working in split mode (20:1 ratio). The inlet was held at a temperature of 200°C. The gas components were separated on a fused silica capillary column (PoraPlot Q, 25 m x 0.32 mm ID, Varian). For CH_4 analysis, the GC was held isothermally at 40°C. Helium was the carrier gas, set to a constant pressure of 14.3 psi. All gas samples were measured in duplicate with a standard deviation of ≤3 ‰ for most of the compounds and samples. The H_3^+ factor was determined daily by measuring 10 reference gas peaks with increasing amplitude. This factor had an average value of 2.487 ± 0.056 ppm/nA. The quality of the hydrogen isotope measurements was checked regularly by measuring secondary standards of pure H_2 and pure CH_4 with known isotopic composition as determined by inter-comparison on a TC-EA against international primary solid hydrogen isotope standards.

5.4.4 ANALYTICAL METHOD FOR GC-IRMS ANALYSIS OF GASES BY A CRYOGENIC CONCENTRATOR

The analysis of atmospheric CO_2 at ~400 ppm was measured by conventional GC-IRMS and involved a 2 mL injection on the GC with a low split (5:1 ratio); this represented the lower concentration range that was achievable by direct injection. Analysing methane at typical atmospheric concentrations (~1.8 ppm) was not possible due to the IRMS detection limits for quantitative and linear results. In order to achieve suitable signal to noise ratios for methane and other hydrocarbons at such trace levels, a cryogenic concentrator was designed as a module to the front end of the GC-IRMS. The concentrator consists of three Valco valves and a cryogenic micro-trap utilising Poraplot Q packing material (100-120 mesh size) in a continuous flow of helium carrier gas. A splitless injection of sample (~20-50 mL air) is then passed through the trap at liquid nitrogen temperature while the carrier gas is vented. Following sufficient trapping time to flush the entire sample through, the microtrap is then put in-flow into the GC-IRMS. Ballistic heating of the micro-trap to 200°C then releases the components in a rapid manner, ensuring high signal to noise ratio peaks are available for GC-IRMS analysis. The analysis of the components by carbon and hydrogen isotopes using separate injection/analysis runs then follows the established isotope methods described previously.

5.5 Molecular Composition Gas Analyses

Certain samples collected during the course of the project had relatively high concentrations of methane present and hence were amenable to analysis using a dedicated natural gas analyser, which is based on an Agilent Technologies 6890N gas chromatograph. The gas sample container (i.e. FlexFoil bag, Isotube or stainless steel cylinder) was connected to the vacuum manifold on the Agilent GC to evacuate the air dead-volume. Then the gas sample was introduced through the vacuum manifold into a sample loop (0.25 mL) at atmospheric pressure for GC analysis on an Agilent 6890N Natural Gas Analyser, with a thermal conductivity detector (TCD). Four packed columns with Valco valve column switching are used to separate the gases, a 2 foot 12 % UCW982 on PAW 80/100 mesh (pre-column), a 15 foot 25 % DC200 on Paw 80/100 mesh, a 10 foot HaysepQ 80/100 mesh and a 10 foot Molecular Sieve 13X 45/60 mesh column. The oven was isothermally maintained at 90 °C throughout the 20 minute run. The amount of separated gas components was determined against an external standard calibration. At 90 °C, oxygen and argon co-elute on the 13X molecular sieve column to form one combined peak.

6 Results and Observations – Methane Emissions

Fifteen generic test sites covering a range of activities and locations were identified in the project brief for monitoring (refer to Section 5.1 for details on the selected sites). Specific sites were selected where possible to cover the range of activities required but also to provide a geographic distribution across NSW. As a result, many of the sites were hundreds of kilometres apart, which required careful planning to address logistical issues. Moreover, during the initial stages of the project it became apparent that measuring CH_4 emission rates from many of these sites would be challenging, with certain site-specific factors requiring consideration. Factors such as the local topography, presence of buildings and other infrastructure at and around the test sites, local weather conditions, land access, operations at test sites, all had the potential to affect measurement. Consequently, emission measurements generally required specific methods tailored for each site. To assist in method development, two sites that were close to the CSIRO Newcastle laboratories were selected to trial different approaches to measuring emissions (Summerhill Waste Management Centre and the Singleton Wastewater Treatment Plant). Accordingly, these sites were visited more frequently than most of the others selected for investigation.

Because of the number of sites and their geographic distribution along with the time constraints of the project, it was not possible to make CH_4 flux measurements at all sites (such as coal mines) as originally intended. Where we were unable to measure emissions directly, other techniques were used to estimate emissions based on accepted methodology. A summary of the site visits is shown in Table 6.1. The location of each site is also shown in Figure 6.1.

Table 6.1. Dates of field measurements made at each site.

Site	Autumn	Winter	Spring	Summer	Total Site Visits
Camden Gas Project	16/3/2016	19/8/2015	20/11/2015	12/1/2016	4
Gloucester Gas Project	21/3/2016	16/7/2015	23/9/2015	19/1/2016	4
Narrabri Gas Project	5/5/2015, 6/5/2015	21/7/2014, 28/7/2015, 29/7/2015	15/9/2015, 16/9/2015	9/2/2016, 10/2/2016	9
West Casino Gas Project	11/5/2015	25/7/2014	7/11/2014	25/2/2015	4
Parkes Waste Facility	23/4/2014	28/8/2014	No spring visit	3/12/2014, 19/2/2015	4
Summerhill Waste Management Centre	9/4/2015	1/7/2014, 16/7/2014, 7/8/2014, 9/7/2015	8/10/2014,	26/2/2015, 27/2/2015, 4/2/2016, 23/2/2016	10
Yanco Agricultural Institute	21/4/2015	4/8/2015	14/10/2014, 15/10/2014	1/12/2014, 2/12/2014, 22/12/2014, 23/12/2014, 18/2/2015	9
Rix's Creek Coal Mine	14/4/2015	22/7/2015	10/10/2014	18/2/2016	4

Site	Autumn	Winter	Spring	Summer	Total Site Visits
Wambo Coal Mine	No autumn visit	15/7/2015	29/9/2014, 21/10/2015	18/2/2015, 17/2/2016	5
Singleton Wastewater Treatment Works	26/3/2015	2/7/2014, 20/8/2014, 8/7/2015	9/9/2014, 2/10/2014, 31/10/2014	11/12/2014, 28/1/2015	9
Dubbo Wastewater Treatment Plant	4/5/2015	28/8/2014	11/11/2015, 12/11/2015	23/2/2015, 24/2/2015	6
Wagga Wagga Narrung Street Wastewater Treatment Plant	21/4/2015	26/8/2014	19/11/2015	17/2/2015	4
Picton Wastewater Treatment Plant	29/4/2015	6/8/2014	25/11/2015	13/1/2015	4
Jindalee Feedlot	22/4/2015	28/8/2014	18/11/2015	16/2/2015	4
Yaegl Nature Reserve	7/5/2015	12/7/2014	6/11/2014	25/2/2015, 26/2/2015	5
Camden Surveys[1]	29/4/2015	6/8/2014	20/11/2014	25/2/2015	4
Cuba State Forest	21/4/2015	4/8/2014	14/10/2014	2/12/2014, 18/2/2015	5

Note 1 – The Camden surveys did not include well pad measurements.

The results of the CH_4 field measurements are presented in the following sections.

6.1 Regional Surveys of Ambient CH_4 Concentration

During the project, mobile surveys were made using the Picarro analyser. While the vehicle was driven to and from test sites, the Picarro gas analyser was often operated to measure ambient CH_4 concentrations across NSW over about an 18-month period between July 2014 and November 2015. Measurements were mostly made during daylight hours from early morning to late afternoon, although some night time data were also collected. More than 25,000 km of such surveys were undertaken during the project (Figure 6.1). Most of these surveys were made while driving on public roads but measurements were sometimes made on private land near the selected facilities.

Figure 6.1. Map showing the routes of the mobile surveys. The selected sampling locations are also shown.

The results of the surveys are summarised in Figure 6.2 where the hourly average of CH_4 concentration are plotted for the period between June 2014 and December 2015. A large amount of data was also collected when the vehicle was engaged in measurements at the selected sampling sites but these are not included in the surveys because the CH_4 levels during these operations were generally much higher (often tens or hundreds of ppm) than background and were not representative of regional ambient CH_4 concentrations. The data in Figure 6.2 are presented on a dry basis (i.e. corrected for atmospheric moisture) to allow comparison of data measured under different humidity conditions. For comparison, data from the CSIRO atmospheric baseline monitoring stations at Cape Grim in Tasmania and Cape Ferguson in Queensland are also plotted.

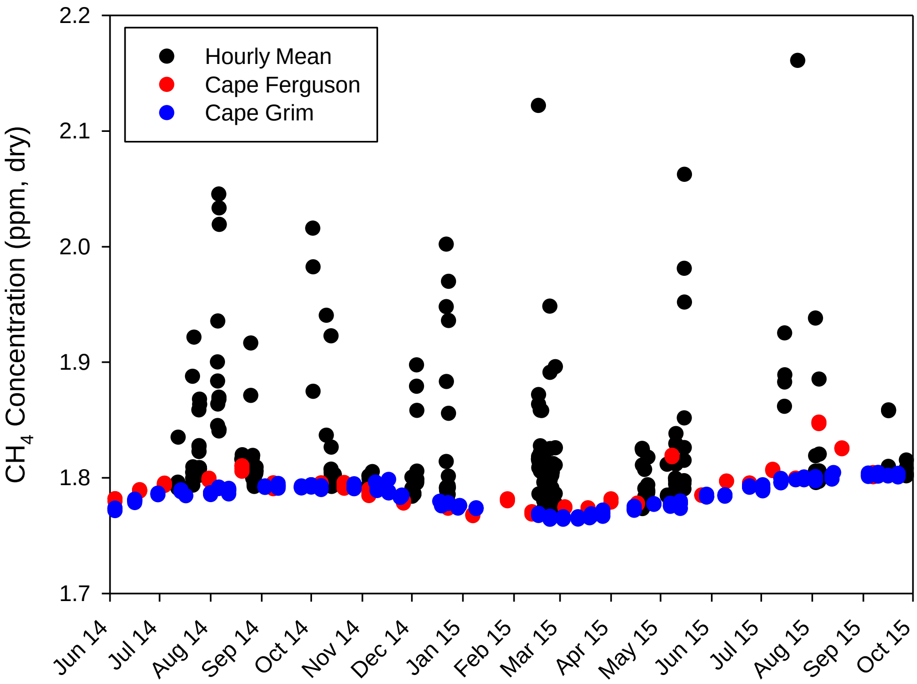

Figure 6.2. Hourly averaged CH_4 concentration data from mobile surveys for all monitored hours (black markers). Data from the baseline monitoring stations at Cape Grim (blue markers) and Cape Ferguson (red markers) are also shown.

In general, the hourly averages tend to cluster close to the baseline data measured at Cape Grim and Cape Ferguson; however it is obvious that there are many occasions when the ambient CH_4 concentrations measured during the survey were significantly higher. In many cases, this can be attributed to atmospheric conditions where CH_4 was more concentrated in the near surface layer during still early morning or night time conditions. To remove this effect, we filtered the data to include only those measured during the hours of 11 am to 4 pm local time when atmospheric mixing was highest. The scatter in the results was significantly reduced but nevertheless there were many occasions when the ambient levels were somewhat higher than baseline.

Almost all of the mobile surveys originated from Newcastle (the location of the CSIRO Energy Centre) and often passed through the Hunter Valley, which is one of Australia,'s main coal producing regions. Hence, it is not unexpected that ambient CH_4 levels along the main roads through the Hunter region are elevated compared to normal background levels in NSW, especially since many mines are adjacent to the roads. This high level of ambient CH_4 is not representative of NSW in general so the hourly data were further filtered to remove those surveys made through the coal producing region of the Hunter Valley. These data are shown in Figure 6.3, along with the Hunter Valley only data (green markers).

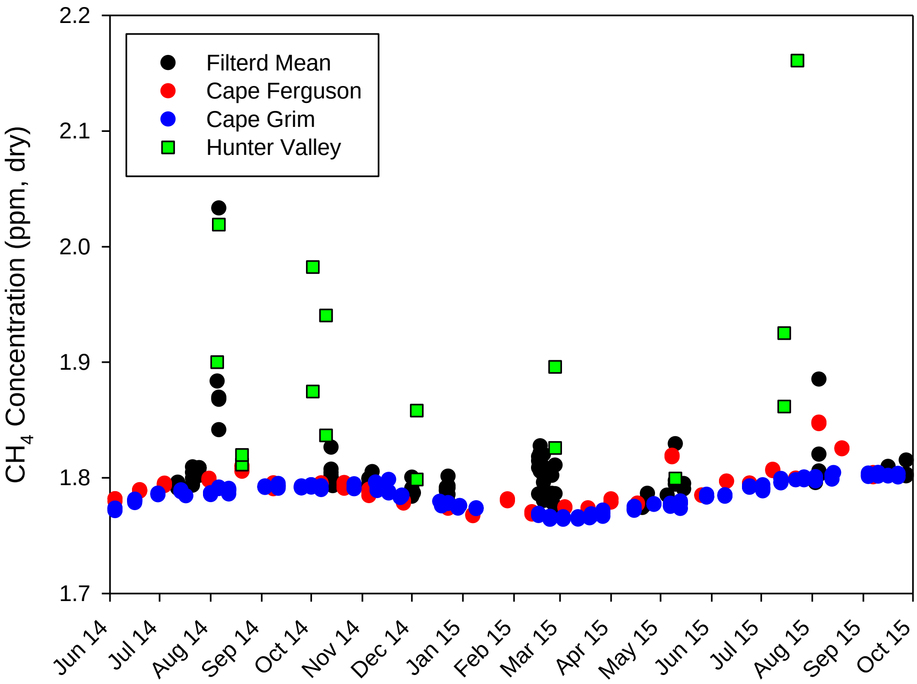

Figure 6.3. Hourly averaged CH_4 concentration data from mobile surveys collected between the hours of 11 am and 4 pm local time (black markers). Data from the Hunter Valley are shown separately (green markers).

In this case, the ambient levels are much closer to the baseline monitoring stations although there are still a number of occasions when substantially elevated levels of CH_4 were observed. These mostly corresponded to surveys through the metropolitan area of Sydney. Urban areas typically have higher CH_4 concentrations than non-urban areas (Blake, et al., 1984; Lowry et al., 2011; Phillips et al., 2013) although many of the peaks observed were clearly associated with nearby local sources. The Hunter Valley-only data in Figure 6.3 (green markers), clearly showing the generally higher levels compared to elsewhere in the state.

While the hourly mean CH_4 concentrations were generally well below 2 ppm, there were often short periods when much higher concentrations were measured. The highest ambient CH_4 recorded during the mobile surveys was 28.0 ppm or more than 26 ppm above ambient levels. Usually, these CH_4 concentration excursions lasted only a few seconds, although there were other occasions when elevated levels were measured over prolonged periods (e.g. through the Hunter Valley). Of the mobile data, which were collected over more than 300 hours, there were 102 instances where the peak CH_4 concentration exceeded 2 ppm, 31 above 3 ppm, 20 above 4 ppm, 16 above 5 ppm and 6 above 10 ppm. The top 20 source locations detected during this project (where the peak 3-second average CH_4 concentration was above 3.2 ppm) are listed in Table 6.2 where the maximum CH_4 concentration, location and description of the likely source are shown.

Table 6.2. Details of the top 20 peak CH_4 concentrations detected during the mobile surveys. The likely source is also indicated (note that site visits to these locations were not made). The CH_4 concentrations were averaged over 3-seconds and are reported on a dry basis.

Date	Maximum CH_4 (ppm, dry)	Location	Notes
26/02/2015	27.987	-32.9578, 151.5428	The source was the underground coal mine vent shaft next to M1 near Wakefield
6/08/2014	21.533	-33.1107, 151.4615	The source was the underground coal mine vent shaft and gas drainage facility adjacent to M1 near Morisset
19/11/2015	19.192	-34.1803, 150.7245	The source was the underground coal mine vent next to Hume Motorway at Douglas Park.
23/04/2015	18.220	-32.5447, 150.997	The source was immediately obvious but was likely to have been due to coal mining operations next to Golden Highway, west of Singleton
20/07/2014	15.291	-32.4281, 151.0517	The source was the underground coal mine vent shaft next to New England Hwy near Ravensworth
22/02/2015	14.796	-32.8239, 151.5938	The source was the underground coal mine vent shaft next to John Renshaw Drive near Beresfield
17/11/2015	14.675	-34.4451, 147.533	Sharp peak in Hoskins Street, Temora. Source unknown.
23/12/2014	14.075	-33.8224, 150.8529	The source was the Eastern Creek Waste Management Centre adjacent to M7.
23/04/2015	8.629	-32.9701, 151.6887	Large peak in suburban Charlestown (Newcastle) against a generally high background during early evening. Source unknown.
23/12/2014	8.235	-35.1201, 147.3779	Very narrow peak over railway at Wagga Wagga. Unknown source.
14/04/2015	6.841	-32.5992, 151.1992	Broad peak on New England Hwy near Singleton against a generally high background. Possibly from coal mining operations elsewhere in the Hunter Valley.
14/07/2015	6.109	-32.583, 151.0111	Emissions from coal mining operations near Wambo coal mine
19/02/2015	5.130	-33.419, 149.61	Sharp peak in Kelso on Great Western Hwy. Source unknown.

Date	Maximum CH_4 (ppm, dry)	Location	Notes
19/02/2015	4.819	-33.6349, 150.78	Hawksbury Waste Management Centre adjacent to Blacktown Rd, South Windsor.
20/07/2014	4.486	-32.6477, 151.2492	Broad peak off high early morning background on New England Hwy. Source not clear but possibly from coal mining elsewhere in the Hunter Valley.
5/08/2014	3.726	-34.0471, 150.7605	Broad peak in Narellan off high early morning background. Source unknown.
28/08/2014	3.721	-32.2166, 148.6331	Abattoir along Yarrandale Rd Dubbo
13/10/2014	3.617	-34.2442, 150.659	Hume Motorway near Pheasants Nest Bridge. Source unknown.
6/08/2014	3.311	-34.1828, 150.6074	Argyle Street, Picton. Source unknown.
23/12/2014	3.249	-33.7904, 151.1356	M2 adjacent to Macquarie Park Cemetery. Source unknown.

It is important to note that these sites represent only those where the highest CH_4 instantaneous (i.e. 3-s average) ambient concentrations were detected. However, high CH_4 levels alone do not necessarily correspond to large emission sources. The peak concentrations measured here are as much a function of the proximity to the source and prevailing atmospheric conditions as they are to the relative size of the source.

One of the most common CH_4 sources encountered during mobile surveys conducted within this project was coal mining activities, in particular emissions from underground mine ventilation shafts in the Hunter region but also in the Illawarra. These facilities typically have outlet flow rates of 200 $m^3 s^{-1}$ or more with up to about 1 % (10,000 ppm) CH_4 in the vented airstream. Because they are frequently within 200 m of roads, they were often readily detected by the surveys. As discussed previously, coal mining operations, including open-cut mining, resulted in elevated CH_4 levels in the Hunter Valley, with broad CH_4 peaks often detected during still, early morning conditions along the New England and Golden Highways.

Many of the sites listed in Table 6.2 were surveyed a number of times throughout the project period and while in most cases the emissions were detected during each survey (except when wind conditions were unfavourable), the maximum concentrations measured on each occasion differed markedly. For instance, CH_4 concentrations near the vent located near Wakefield, varied between 28 ppm and 3.5 ppm. This is a clear demonstration that caution must be exercised when interpreting concentration data in relation to emission sources.

Apart from coal mining, waste management facilities also often resulted in locally high CH_4 concentrations. In Table 6.2 above, the Eastern Creek and Hawksbury facilities both in the outer Sydney metropolitan area yielded amongst the highest CH_4 levels detected (excluding underground mine vents). Although not shown in Table 6.2, other landfills, wastewater treatment plants and intensive agriculture facilities located close to the survey routes also yielded elevated CH_4 levels when the wind conditions were suitable.

In addition to numerous CH_4 concentration maxima that could be attributed to particular sources, there were also many CH_4 peaks encountered throughout the surveys where the emission source was not obvious and could not be identified. Some of these were significant such as those shown in Table 6.2. In Temora, for instance, a large peak of 14.7 ppm CH_4 was detected whilst driving on the main street through the town. A similar narrow CH_4 peak was found in Wagga Wagga with a maximum of more than 8.2 ppm on the Sturt Highway near the railway overpass. Both the Temora main street and Wagga Wagga railway bridge peaks were found on several repeat visits to each site but at different concentrations. A significant unexplained CH_4 peak of 5.1 ppm was also found in Kelso (near Bathurst) but only one visit was made to this location.

Previous measurements made by this laboratory during 2013 have also found high levels of CH_4 in urban areas in Stockton (near Newcastle) that could not be explained by other local sources such as coal handling operations. Figure 6.4 shows a survey of the Stockton area where measurements conducted over several days revealed local CH_4 concentrations of up to 22 ppm. The peaks were generally very sharp suggesting localised, and numerous, sources within a relatively small area. Although CH_4 emissions were detected near the Kooragang Island coal loading facility, the low levels detected could not account for the high concentrations measured throughout Stockton.

Figure 6.4. Mobile survey of CH_4 concentration in the Newcastle region near Stockton. The maximum CH_4 3-s average peak measured in Stockton was approximately 22.0 ppm.

One possible explanation for the unattributed urban peaks encountered during this project is leakage of gas from natural gas distribution infrastructure. This could include high pressure mains but also domestic connections or even appliances. Methane emissions from leaking gas distribution systems is well known; Carras et al. (1991) reported significant gas loss from the Sydney reticulation system during the early 1990s. More recently, Phillips et al. (2013) found urban pipeline leakage throughout Boston in the United States, using ground based surveys similar to those used in the present study. A team from the University of NSW and Royal Holloway University of London also using mobile surveys recently reported elevated CH_4

concentrations throughout Sydney and various country towns, which they attributed to leaking gas distribution pipe networks (Kelly et al., 2015).

At this stage, the sources of the high urban CH_4 concentration peaks found during this project and elsewhere remain speculative but is an area that warrants further investigation to locate and quantify these sources.

6.2 Natural Sources

Initial measurements were made at Yaegl Nature Reserve which was a site selected by the EPA to represent a natural wetland. Additional measurements were also made throughout the project within Cuba State Forest, on the banks of the Murrumbidgee River (approximate sampling site location 34.60°S, 146.08°E). This site was selected by CSIRO staff primarily to provide a background site for comparison with the VOC surveys conducted around Camden (see Section 7.4) but also as a natural site largely unaffected by industrial or vehicle emissions. Limited measurements were also made in Bongil Bongil National Park, south of Coffs Harbour (approximate sampling site location 30.420°S, 153.033°E) during February 2015.

Yaegl Nature Reserve is a small protected area of melaleuca forest on the floodplain of the Clarence River, approximately 2 km west of the town of MacLean. It is mostly wetland with an area of 313 ha which is bounded by the Pacific Highway to the northwest and urban development and agricultural land on the other borders. There are no tracks within the reserve and consequently vehicle access is very limited. For this project, best access was via Fallows Lane that ran along the western edge of the reserve (Figure 6.5); however, this road was impassable during wet weather. Some limited vehicle access for flux chamber measurements was also available at one point on the southern edge of the reserve.

Because of the limited access to the reserve, mobile surveys were only conducted on public roads. The routes taken are shown in Figure 6.5. In general, the ambient CH_4 levels near the wetland were indistinguishable from concentrations measured away from the reserve. A summary of the average CH_4 concentrations measured during each survey is shown in Table 6.3. Because of the proximity to roads and urban areas, it is important to note that this site may not be indicative of more remote natural areas, especially in relation to VOC emissions (which are discussed in Section 7.1.1).

Table 6.3. Summary of the ambient CH_4 concentrations measured in and around Yaegl Nature Reserve.

Survey Date	Time	CH_4 Concentration (ppm, dry basis)			Notes
		Mean	Minimum	Maximum	
12 July 2014	9:14 am to 12:14 pm	1.8257	1.8059	1.9309	Ground was quite dry; little free water
6 November 2014	6:15 am to 2:52 pm	1.8000	1.7926	1.8895	Heavy rain the previous night; ground was very wet
25 February 2015	10:38 am to 3:22 pm	1.7802	1.7631	1.9193	Heavy rain had occurred during the previous week. The ground was saturated with large amount of free water.
26 February 2015	6:52 am to 8:22 am	1.9411	1.8794	1.9929	Conditions as described above. Survey made only in early morning.
7 May 2015	7:24 am to 10:19 am	1.8086	1.7944	2.3150	Very wet conditions due to recent rain.

Except for the result found on 26th February 2015, the mean CH_4 concentrations exhibited slight seasonal variation similar to that observed in the regional survey results where higher CH_4 levels occurred during the cooler months. However, the results from the 26th February (red trace in Figure 6.5) yielded a mean concentration over the survey of about 160 ppb or about 9 % higher than that measured on the previous day (25th February). This apparent anomaly is due to the time of the survey. Most of the other surveys were conducted over the entire course of a day when atmospheric mixing was highest. The survey made on the 26th February, on the other hand, was made during the early morning between about 7:00 and 8:20 am local time, under cool still conditions. Note that similar elevated CH_4 levels were also usually encountered on other surveys made at various other locations under these conditions, especially during the cooler months of the year.

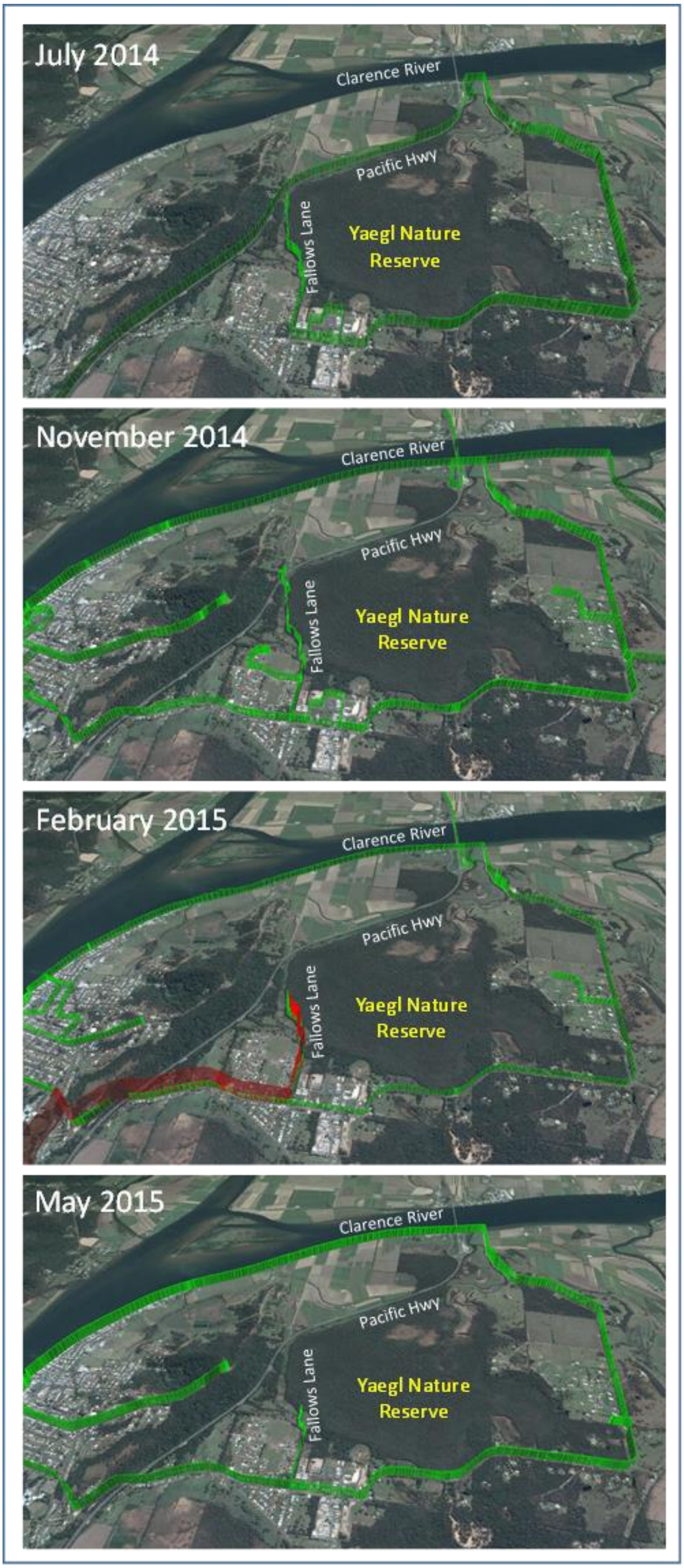

Figure 6.5 Mobile surveys of Yaegl Nature Reserve. The red trace represents data collected in the early morning, which were significantly higher than later in the day.

As well as the mobile surveys, surface flux chambers were used during each visit to Yaegl Nature Reserve to attempt to determine the CH_4 emission rates from various surfaces. CO_2 emission rates were also measured since CO_2 is usually associated with gas emissions from natural surfaces. However, as discussed, access to the site was very limited and consequently chamber measurements were restricted to the edges of the reserve. Nevertheless, we were able to conduct flux measurements on a range of surfaces from grassland to flooded wetland within the forest. A summary of the surface emission fluxes measured using the chambers is provided in Table 6.4 (units are in g m^{-2} day^{-1}).

Table 6.4. Summary of the surface flux chamber emission rates in g m^{-2} day^{-1} measured at Yaegl Nature Reserve.

	July 2014		Nov 2014		Feb 2015		May 2015	
	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2
Mean	0.0102	5.35	0.0078	25.02	0.0056	24.37	0.0087	13.68
Min	-0.0010	3.20	-0.0085	3.36	-0.0021	4.99	-0.0022	2.01
Max	0.0628	7.88	0.1095	65.47	0.0330	65.47	0.0390	24.18
Std Dev	0.0258	1.69	0.0262	13.62	0.0085	13.74	0.0142	6.84
n	6	6	19	33	40	40	16	16

The data are also shown in Figure 6.6 where the mean CH_4 emission flux are plotted as a function of the time of year. Average CH_4 fluxes were generally below 0.01 g m^{-2} day^{-1} although as shown in the errors bars in Figure 6.6 (which represent the maximum and minimum values measured during each site visit) there was a significant amount of variation within each data set. High variability is often a feature of chamber measurements on natural surfaces due to the inherent heterogeneity of natural soils (Denmead, 2008). Highest emission rates were usually associated with wet surfaces that had stagnant water present. Figure 6.6 shows that there was generally little variation in the average emission flux over the sampling period, although the high variability in this dataset would tend to obscure any seasonal effects.

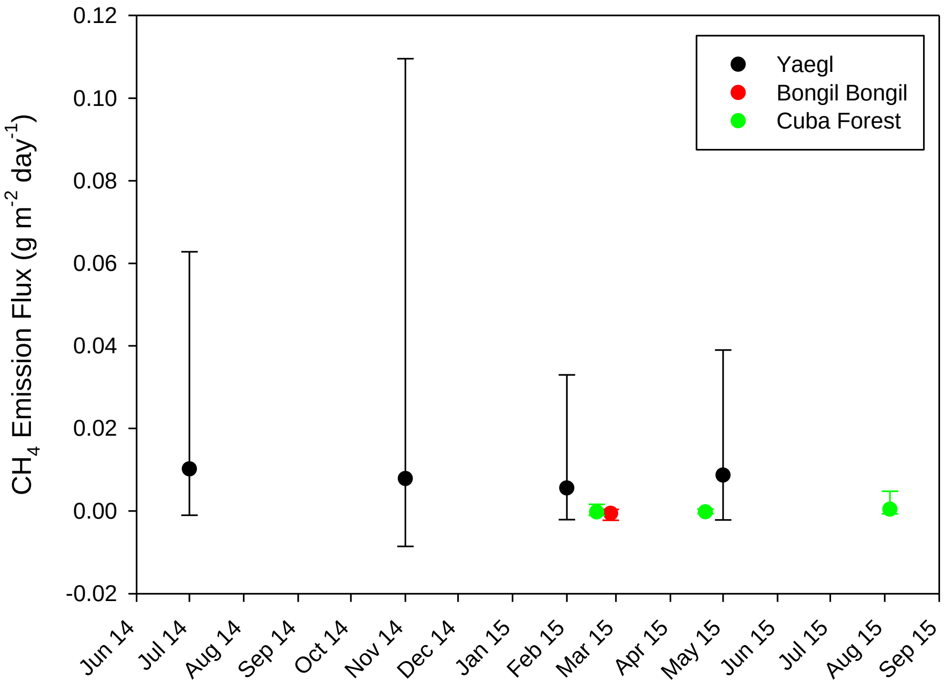

Figure 6.6. Mean CH_4 emission flux measured during each sampling campaign. The error bars represent ±1 standard deviation from each data set.

The CH_4 emission rates measured at the Yaegl site are consistent with other Australian wetland emissions. Dalal et al. (2008) cited results from several studies made between 1995 and 2007 ranging from 3 μg CH_4 m^{-2} h^{-1} (0.072 mg CH_4 m^{-2} day^{-1}) to 44 mg CH_4 m^{-2} h^{-1} (1.06 g CH_4 m^{-2} day^{-1}). In our study, the mean CH_4 emission rates were between about 5 and 10 mg CH_4 m^{-2} day^{-1} with the maximum value of 110 mg CH_4 m^{-2} day^{-1}. The results are also very similar to those measured at an artificial wetland in Ohio in the U.S. where emission rates within the wetland varied between 74 and 192 mg CH_4 m^{-2} day^{-1} (Waletzko and Mitsch, 2014). Assuming that the average rate of all site visits (i.e. 0.007 g m^{-2} day^{-1}), the total CH_4 emission from the 313 ha site 22 kg day^{-1}, or approximately 8,000 kg $year^{-1}$. However, it should be noted that only a very small fraction of the total area was surveyed and only for a limited time during each 24-h period so the uncertainty on these estimates is high.

For comparison with the Yaegl results, surface flux measurements were made in rainforest at Bongil Bongil National Park during February 2015 and at Cuba State Forest between February and August 2015. Like all of the flux chamber measurements presented in this report, measurements were made during daylight hours.

Parts of Cuba Forest are also designated wetlands (Department of the Environment, 2015b), although the surface flux measurements were made in the drier parts of the forest (i.e. there was no flooding at the time of the measurement). The results of the measurements made at other sites are also plotted in Figure 6.6. These sites yielded lower CH_4 emissions that were close to zero or slightly negative largely due to the absence of free water at these sites. At Yaegl, highest surface emissions were associated with stagnant water, presumably due to the activity of anaerobic microbial activity. In contrast, negative emissions fluxes indicate that atmospheric CH_4 is being consumed by the soil. Methane uptake by soils is well known and indeed is an important sink – it has been estimated that globally, as much as 6 % of atmospheric CH_4 is consumed by aerobic soils (Dalal et al., 2008).

The range of CH_4 emission rates measured at Cuba State Forest was much less than seen at Yaegl. This is likely due to the similarity of ground surfaces across the Cuba SF during the measurement campaigns (i.e. dry open forest floor, whereas at Yaegl, the ground surface was more variable in respect of the vegetation coverage and especially the amount of water present.

Given the very low CH_4 emission rates, the ranges of values was also correspondingly less than observed at the Yaegl site.

In contrast to the CH_4 emissions, CO_2 emission fluxes appeared to show seasonal variation with highest emissions occurring during the November and February Yaegl sampling campaigns (Figure 6.7). The results from the Cuba Forest site also show a similar cyclical pattern. Although only one set of measurements was made at Bongil Bongil National Park and so in isolation does not provide temporal information, it nevertheless yielded the highest average CO_2 emission flux, which was during summer.

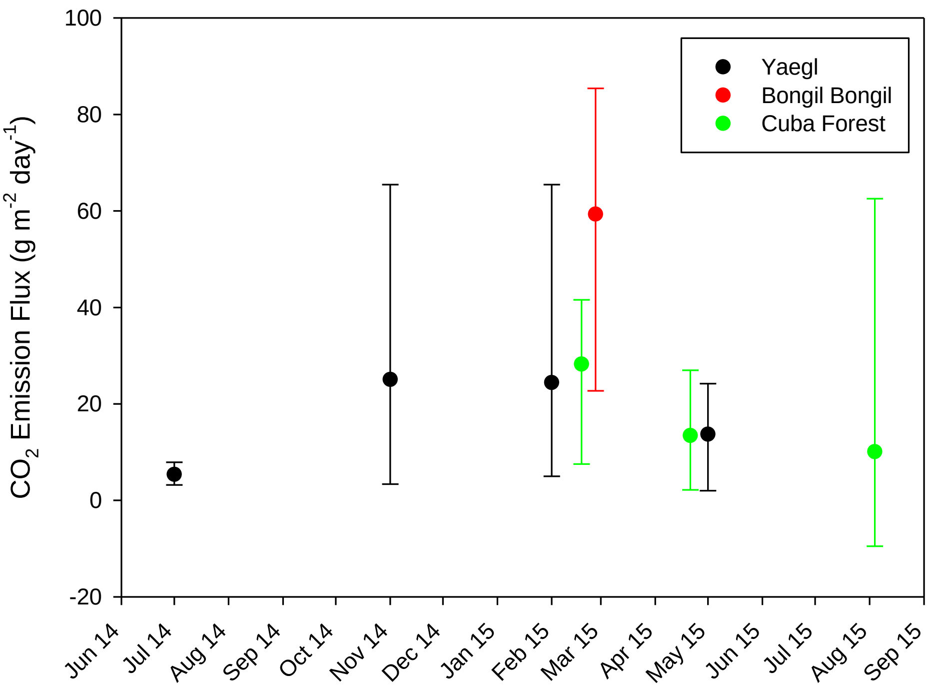

Figure 6.7. Mean CO_2 emission flux measured during each sampling campaign. The error bars represent ±1 standard deviation from each data set.

While the CO_2 emission rates appeared to exhibit some degree of seasonal variation, it is also possible that local weather events may affect emissions. In the week or so preceding the February and May visits to the Yaegl site, for instance, there had been very heavy rain in the area so that emissions may not have been representative of the season. To properly discern seasonal variations in flux, more frequent measurements over a longer period would be required, which were beyond the scope of this project.

6.3 Rice Farm

Measurements were made during six site visits on an experimental rice crop (Reiziq variety) at the NSW Department of Primary Industry Yanco Research Station. The area of the paddock where the measurements were performed was about 7,400 m^2. The flux chamber bases were installed in the paddock on 14^{th} October 2014 about one week after the crop had been sown. At that time, the paddock had not been flooded and was essentially freshly tilled bare earth. The results of the flux chamber measurements are presented in Figure 6.8 and show the average emission flux measured during each site visit (note that all of the measurements made during this project were made during daylight hours).