Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia 2017

AWE Limited Submission

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FOREWORD

AWE Limited (AWE) is a respected mid-tier Australian energy producer with a growing onshore domestic gas business in Western Australia. AWE has no plans or need to use Hydraulic Fracture Stimulation (HFS) for its existing activities or the proposed development of the Waitsia gas field given the large volumes of conventional hydrocarbons available for production. However, as an industry participant with expertise in HFS, a well completion technique, AWE provides this submission as a contribution to the understanding of this technique and trusts it will help allay concerns regarding its use.

AWE's submission is structured to present an overview of the Company's operations and context, the comprehensive and robust regulatory framework we operate within, and our commitment to effective stakeholder engagement.

Section 1 is an overview of AWE Limited as well as our Perth Basin onshore activities, a brief outline of HFS and the history of HFS use in the northern Perth Basin.

Section 2 details the environmental management framework of AWE's northern Perth Basin activities including a summary of the regulatory approvals processes, stakeholder and community engagement, land access as well as how we plan, develop and operate our activities to mitigate potential environmental issues.

Section 3 highlights several case studies including demonstration of HFS being contained to the target zone for both exploration and production wells, Woodada Deep-01 monitoring showing controlled microseismic activity as well as groundwater monitoring results from Drover-01 and Senecio-02.

Section 4 describes results of two regional studies AWE co-sponsored researching seismic monitoring as well as baseline groundwater and air quality monitoring.

Section 5 summarises information on stakeholder surrounds including local businesses and the agricultural and tourism sectors.

EXECUTIVE SUMMARY

AWE Limited (AWE) is committed to delivering safe, reliable and affordable energy. A respected mid-tier Australian energy producer, AWE is publicly listed on the Australian Securities Exchange (ASX: AWE). The Company has extensive domestic and international experience and expertise in upstream oil and gas operations, including Hydraulic Fracture Stimulation (HFS). AWE is currently focused on delivering the Waitsia Gas Project, a major conventional onshore gas development in the Mid West region of Western Australia.

The northern Perth Basin has been an active hydrocarbon province since the 1950s, with the first commercial gas field development in the state, commencing production in 1971. AWE operates several gas production facilities in the region and has an extensive appraisal and development program. AWE is also undertaking a decommissioning project for wells and facilities that are no longer in use.

Waitsia – a significant development project for WA

AWE's flagship development project, the Waitsia Gas Project, is a gas field development with estimated 2P Reserves of 820 PJ gross. AWE estimates that the Waitsia field is the largest onshore conventional gas discovery in Australia for the last 40 years and ranks in the top five largest onshore discoveries in Australia[1].

The first stage of the Waitsia Gas Project, effectively an extended production test, commenced production in August 2016. Further development will produce gas from conventional reservoirs and has the capacity to supply the Western Australian domestic market for decades. As a conventional development the Waitsia Gas Project does not require the use of HFS.

AWE's Contribution to the HFS Scientific inquiry

As an experienced Mid West operator, AWE, is able to provide evidence-based information to the Inquiry on HFS in a Western Australian context.

AWE's experience as a long term onshore operator in Western Australia with HFS expertise is that

- Western Australia has a comprehensive and robust regulatory framework
- There have been no observable environmental impacts from AWE's HFS activities
- Effective stakeholder engagement is key to onshore regulatory and operational success

Robust regulatory framework in WA

There is a broad legislative framework which governs onshore oil and gas activities in Western Australia. Apart from the *Petroleum and Geothermal Resources Act 1967* (PGER Act), which is administered by the Department of Mines, Industry Regulation and Safety (DMIRS), there is a suite of other legislation including the *Environmental Protection Act 1986* (EP Act) that are administered by other agencies. This provides appropriate separation of regulatory oversight to ensure the integrity and independence for compliance and environmental decision making.

[1] Source: Based on IHS Markit International Exploration and Production database "Australian Onshore Conventional Fields Discovery History (1900 -2014)", applying AWE estimates of Reserves as at 31 December 2017. AWE discovered the Waitsia field in 2014.

This framework is regularly reviewed and updated to reflect the continual improvement in health, safety and environmental standards. A summary of key legislative changes affecting WA onshore operations are presented in Figure 9.

The Western Australian regulatory framework includes a 'whole of government approach' for regulating HFS, which facilitates efficient and transparent regulation and includes many checks and balances. The approvals processes include transparency of information such as the disclosure of an Environment Plan Summary which incorporates full disclosure of downhole chemicals.

In relation to resources development activities, including HFS, the mechanism for identification of potential impacts is risk-based. In this context risk mitigation measures are proposed and assessed as part of routine practice. This approach delivers effective management of risk in line with best practice risk management principles.

Importantly, many of the environmental risks raised as concerns relating to HFS apply to conventional onshore drilling and are managed, in the same way that a conventional well is managed, through high quality well design and construction.

No observable environmental impacts from AWE's HFS activities

As an operator, AWE has direct experience of wells involving HFS including: three exploration wells (ie Woodada Deep-01; Senecio-02, Drover-01) and also seven production wells in the Corybas and Dongara gas fields. AWE routinely engages independent consultants with appropriate subject matter expertise to help design monitoring programs, undertake sampling analyse and verify results. There have been no observable environmental impacts from HFS at any of these sites as follows:

- Groundwater - There has been no observable impact on groundwater from AWE activities, including HFS. AWE has groundwater monitoring programs in place at many of its operated wells, including those which have involved HFS. This empirical data demonstrates that HFS operations have had no discernible influence on groundwater conditions. This is also consistent with the production data of all HFS wells in the northern Perth Basin which demonstrates that connection to a potable aquifer has not occurred. Microseismic studies have also shown HFS containment to the target zone (ie no interaction with aquifers).
- Flora and fauna - There has been no significant impact to flora and fauna, including from HFS. The HFS wells in the Dongara and Corybas fields have taken place in cleared agricultural sites and the Woodada Deep-01 HFS activity occurred in a nature reserve. Monitoring shows that none of these activities have had significant flora or fauna impacts.
- Air quality - Monitored emissions from HFS activity at Woodada Deep-01 demonstrated the emissions were minor and much less than those reported at an industrial centre with high traffic density or refuelling a car at a service station and were in line with that expected at a remote rural area.
- Aboriginal Heritage - During planning and operations, heritage surveys are undertaken, and traditional owners are engaged to avoid any impacts on Aboriginal heritage.
- Agricultural - AWE's exploration and production activities occur in agricultural regions. The footprint of AWE activities is small compared to broad acre farms and readily accommodated by effective communication during planning and operational stages. This engagement allows AWE to make infrastructure (eg gravel tracks, water bores, fences and cattle grids) available for agricultural use which can be significant property improvements.

- Human health and community - Air quality studies conducted by AWE during HFS activities demonstrated that air contaminant concentrations were negligible and did not pose an adverse risk to human health.

The specific scientific evidence for each of the HFS wells which AWE has operated are provided in detail in the body of this submission.

Baseline Regional Studies

In addition to the above, AWE co-sponsors ongoing seismic monitoring research by the Seismology Research Centre and has co-sponsored a baseline groundwater and air quality monitoring study undertaken by CSIRO. Results of these studies showed no impact from onshore petroleum activities and the baseline data assists with project planning to further mitigate any potential risks.

Stakeholder engagement an essential element

Stakeholder engagement is required throughout all phases of a project. This helps AWE ensure that local communities are aware of activities being undertaken in the region and are able to give feedback during the full cycle of a project. Constructive engagement fosters a better understanding of stakeholder interests and concerns and allows AWE to respond accordingly.

The regulatory approvals processes include an assessment of the stakeholder consultation undertaken for each activity. AWE's approach is to engage early and often to ensure key issues are understood and responded to as early as possible.

Industry initiatives such as AWE's sponsorship of the independently facilitated community roundtables has proven to be helpful in ensuring local residents and other key stakeholders are kept up to date about project developments and also feel able to ask questions of subject matter experts.

AWE's view is that the onshore petroleum regulatory and policy framework is appropriate. However, more needs to be done by both Government and Industry to broadly raise awareness of the comprehensive checks and balances in place, the safety and environmental performance record of the industry and its public benefits. This requires effective engagement with communities directly affected by onshore activities as well as those who are not.

AWE sees itself as a leader in this area as it participates in the broader economic and social context of the Mid West region. It is a member of the Mingenew Irwin Group, an internationally recognised research and development organisation promoting and developing economic and environmentally sustainable agriculture. Mingenew represents approximately 95% of farmers in the Mingenew area. AWE also helped develop the Farming Land Access Agreement Template, a joint initiative between WA Farmers Federation, Pastoral and Graziers Association, vegetablesWA and the Australian Petroleum Production and Exploration Association (APPEA).

AWE considers community and stakeholder engagement an essential element in the development of our projects and our ongoing activities. We work closely with local stakeholders to help ensure we coexist with the agricultural and tourism sectors also based in the Mid West. This approach is critical for the long-term success of our industry, the regions where we work and to the state of Western Australia.

Conclusion

AWE's key focus in Western Australia is the development of the Waitsia Gas Project, one of the largest onshore conventional gas discoveries in Australia for the last 40 years. HFS is not required to produce the Waitsia field's estimated 820 PJ of gross 2P Reserves.

In the past AWE projects have safely utilised HFS on specific wells under highly regulated conditions. AWE's experience as a long term onshore operator in Western Australia with HFS expertise is that:

- Western Australia has a comprehensive and robust regulatory framework;
- There have been no observable environmental impacts from AWE's HFS activities; and
- Effective stakeholder engagement is key to onshore regulatory and operational success.

1.0 INTRODUCTION

AWE welcomes the opportunity to contribute to the Western Australian Government's *Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia 2017*. AWE has no plans or need to use Hydraulic Fracture Stimulation (HFS) for its existing activities or proposed Waitsia Gas Project given the field's large volumes of conventional hydrocarbons. The Waitsia Gas Project is a gas field development with estimated 2P Reserves of 820 PJ gross. The Waitsia Gas Project will be a conventional development and the field has the capacity to supply the local Western Australian domestic market for many decades. The field is the largest onshore conventional gas discovery in Australia for the last 40 years and ranks in the top five largest onshore discoveries in Australia[2].

Being a conventional development the Waitsia Gas Project does not require the use of HFS. However, as an industry participant with expertise in this area, AWE trusts this submission contributes to the understanding of HFS and helps allay community concerns regarding this technique.

AWE notes the increased public focus on HFS interest has been heightened by issues in eastern Australia and overseas, where activities are often in shallow coal seams with a small separation from potable groundwater resources, rather than the deep saline sandstone reservoirs that prevail in Western Australia. AWE also notes the conclusion of previous inquiries conducted into HFS, particularly the Western Australian Parliamentary Inquiry held 2013-2015. The inquiry report, *Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas,* concludes that potential HFS impacts can be acceptable given appropriate regulation and operational measures are implemented and it broadly supports the existing regulatory framework in Western Australia for HFS activities[3]. These findings align with the many other Inquiries and Reports that concluded the risks associated with HFS can be managed effectively.

The history of oil and gas operations in the northern Perth Basin reaches back approximately 50 years with exploration drilling beginning in 1954 near Dongara and the first discovery at Yardarino-1 in 1964. This led to the first gas production facility, Dongara Production Facility (DPF), and the Parmelia Pipeline, in Western Australia. Since 1971, the Parmelia Pipeline has continually delivered gas from the Dongara area for domestic consumption in the Perth metropolitan area by various customers. Wells in the Dongara and Corybas gas fields have had HFS, initially at Dongara-3 in 1974, thus this is not a new activity in the northern Perth Basin.

Since the initial discovery, AWE, and the permit holder predecessors, have been investing and operating in the northern Perth Basin and has successfully developed a number of commercial oil and gas fields over this time. This has required a range of activity including field exploration, seismic acquisition, exploration and development drilling, construction of production and storage facilities and the installation of infrastructure and gas pipelines.

AWE's current key focus in the Perth Basin is the conventional Waitsia Gas Project. The Waitsia field, a conventional gas play in the Kingia and High Cliff Sandstone formations, was discovered in September 2014

[2] Source: Based on IHS Markit International Exploration and Production database 'Australian Onshore Conventional Fields Discovery History (1900 -2014)', applying AWE estimates of Reserves as at 31 December 2017. AWE discovered the Waitsia field in 2014.
[3] Legislative Council Western Australian, Thirty-Ninth Parliament, *Report 42 Standing Committee on Environment and Public Affairs: Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas*, November 2015.

while drilling the Senecio-03 well. AWE is similarly a Joint Venture Partner in the Beharra Springs field, which is also a conventional gas field.

Although AWE has no plans to utilise HFS for its existing activities, as an industry participant, the Company supports efforts made to progress constructive dialogue on both the merits and perceived risks of unconventional gas exploration and production including the use of HFS in Western Australia, and the policy and regulatory frameworks that governs it.

For the purposes of this submission AWE has sought to provide the Independent Scientific Panel with relevant information about the Company's operations in the Mid West region of WA, rather than repeating the general HFS information contained in submissions and provided by the Independent Scientific Panel on its website[4].

Of particular relevance, are the findings from AWE's groundwater, air quality and seismic monitoring of the Woodada Deep-1 HFS undertaken in 2012, which demonstrated there was no detectable negative impact on the surrounding environment. The Woodada Deep-01 well was drilled in 2010 and was targeting the Carynginia Shale as a potential future resource. As well as the Woodada Deep-01 Case Study, AWE can cite examples from the Senecio-02 and Drover-01 exploration wells and production examples from the wells in the Corybas and Dongara gas fields.

AWE, along with the industry's peak industry body, APPEA, works to ensure evidence-based information is clearly communicated to properly inform and build public confidence in our operations. AWE is also a participant and co-sponsor of the CSIRO's baseline monitoring project and conducts regular monitoring of seismic activity.

AWE provided a submission to the Parliamentary Inquiry into the Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas in 2013, participated in the hearing process and hosted the Committee for a site visit. AWE also participated in the Senate Select Committee on Unconventional Gas Mining in 2016.

AWE routinely engages extensively with stakeholders, especially with the local community. We consider community and stakeholder engagement an essential element in the development of our projects and are proactive members of the Mid West community.

Western Australia has a comprehensive and robust regulatory framework in place to ensure exploration and development activities, including the use of HFS operations, meet the highest safety and environmental standards administered by DMIRS[5]. Onshore sector activities are subject to multiple layers of regulation during approvals, operating and decommissioning phases.

Furthermore, the industry operates under regulatory frameworks that are supported by both international and national standards for exploration, development and operation.

[4] https://frackinginquiry.wa.gov.au/about-hydraulic-fracture-stimulation.

[5] Tina Hunter. "Shale gas resources in Western Australia: An assessment of the legal framework for the extraction of onshore shale gas" Murdoch University Electronic Journal of Law Vol. 18 Iss. 2 (2012) p. 29 - 52 ISSN: 1321-8247.

AWE has an excellent safety and environmental history across its exploration and development operations and has achieved this through meeting international best practice. The Company is particularly proud of its environmental record and works continually to minimise the environmental impacts on native flora, fauna, conservation areas, surface and groundwater, soil and landform and cultural heritage sites.

Moreover, the Company's safe and responsible operating practices comply with the industry's voluntary *Code of Practice for Hydraulic Fracturing in Western Australia* and its guiding principles[6].

AWE was a founding signatory to the Code of Practice, an initiative which responded to the community's requirement that oil and gas operators must be committed to:

1. Community, landholder and stakeholder interaction
2. Protection of aquifers
3. Sustainable use of water
4. Transparent use of chemicals in HFS
5. Fluid flowback and produced fluids containment
6. Low fugitive emissions
7. Continual improvement

1.1 Company Overview

AWE is a respected mid-tier Australian energy company committed to delivering safe, reliable and affordable energy. The company is listed on the Australian Securities Exchange (ASX: AWE) and continues to actively explore for, and produce, oil and gas in Australia and Asia. The Company is a competent and capable operator and has extensive domestic and international experience and expertise in upstream oil and gas operations including HFS.

AWE currently has three main producing assets:

- BassGas project - offshore Bass Strait, Tasmania (AWE 46.25%)
- Casino gas project - offshore Otway Basin, Victoria (AWE 25%)
- Onshore Perth Basin interests, Western Australia (AWE 33-100%)

In addition to its producing assets, AWE possesses exploration, appraisal and development opportunities both in Australia and overseas. Of these, the significant development opportunities comprise:

- Waitsia gas project, onshore northern Perth Basin, Western Australia (AWE, 50% Operator)
- Ande Lumut oil project, offshore Natuna Sea, Indonesia (AWE 50%)

AWE's major production and development assets are outlined in the figure below (Figure 1).

[6] Western Australian Onshore Gas Code of Practice for Hydraulic Fracturing. APPEA.

1	**BASS BASIN, AUSTRALIA** BassGas Project (AWE 35%)	6.5 MMBOE 2P Reserves	30.6 MMBOE 2C Contingent Resources
2	**OTWAY BASIN, AUSTRALIA** Casino Gas Project (AWE 35%)	5.6 MMBOE 2P Reserves	1.3 MMBOE 2C Contingent Resources
3	**PERTH BASIN, AUSTRALIA** Waitsia Gas Project (AWE 50%, Operator) Onshore Perth Basin (AWE 33-100%, some Operated)	69.9 MMBOE 2P Reserves	34.1 MMBOE 2C Contingent Resources
4	**NATUNA SEA, INDONESIA** Ande Ande Lumut Oil Project (AWE 50%)		28.4 MMBOE 2C Contingent Resources

Figure 1. Map of AWE operations as of February 2018

1.2 AWE Perth Basin onshore activities

AWE and its predecessors have been investing and operating in the northern Perth Basin for almost 50 years and have successfully developed a number of commercial oil and gas fields over this time (Figure 2). The history of oil and gas activities in the Perth Basin dates back to 1959[7] when exploration began. The first discovery was made at Yardarino-01 in 1964. Producing operations have been occurring continuously in the northern Perth Basin since 1971 (Figure 3).

[7] Western Australian Petroleum and Geothermal Information Management System (*WAPIMS)* (https://wapims.dmp.wa.gov.au/WAPIMS), 5 December 2017.

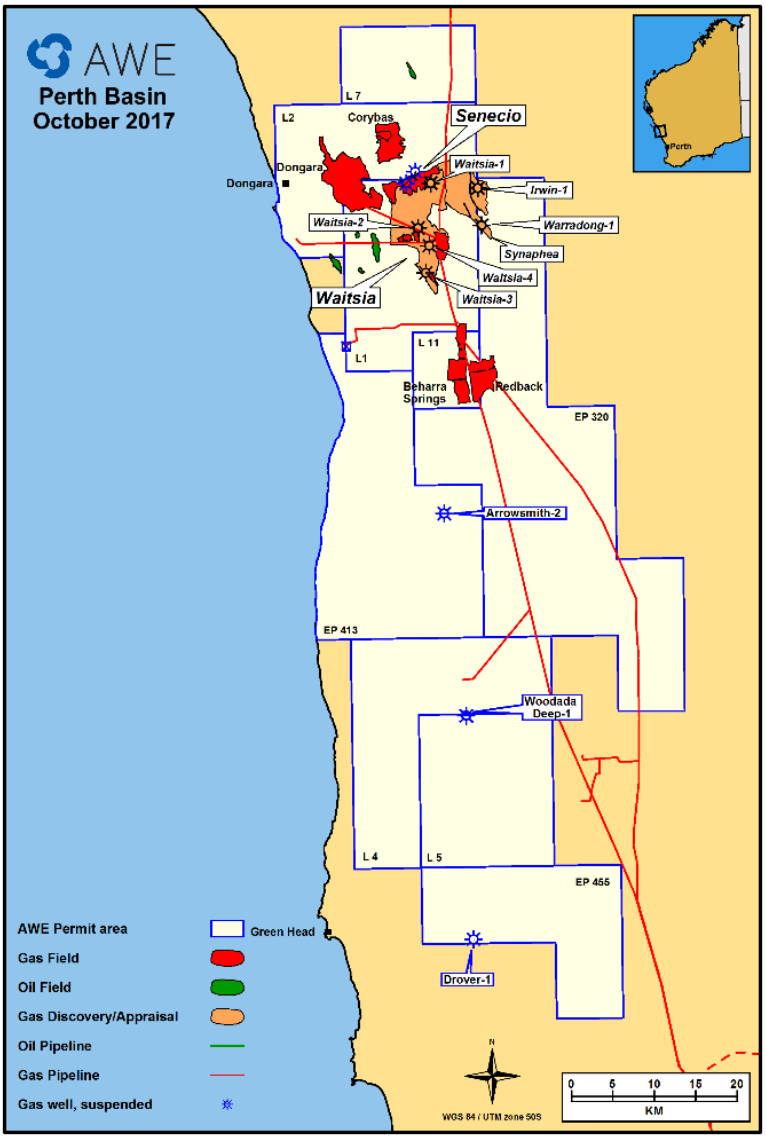

Figure 2. AWE permit map in the northern Perth Basin

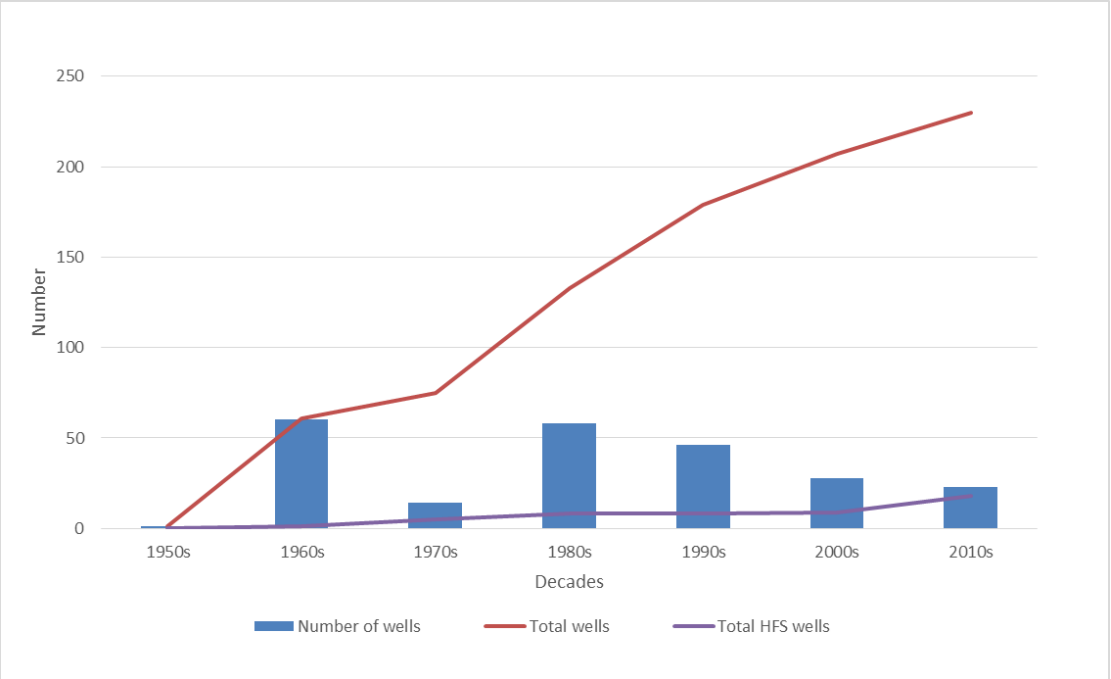

Figure 3. Exploration and appraisal drilling in the northern Perth Basin, including HFS

Since the initial discovery in the area, a number of commercial oil and gas operations have been developed. This has required a range of activity including field exploration, seismic acquisition, exploration and development drilling, the installation of infrastructure and gas pipelines and decommissioning of infrastructure no longer in use. The lifecycle of onshore activities AWE routinely undertakes is provided in Figure 4.

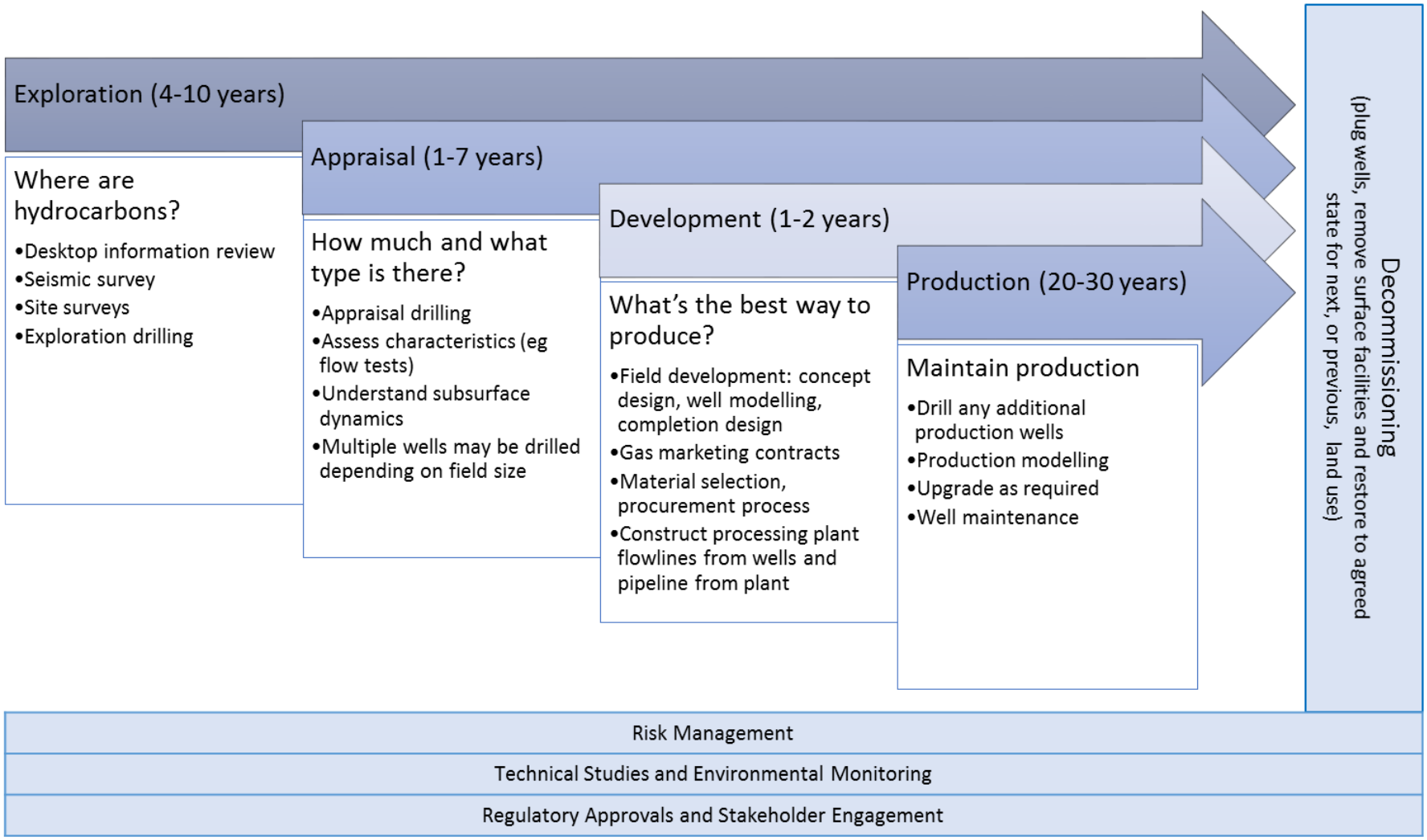

Figure 4. Lifecycle of onshore upstream activities with estimated timeframe and key activities shown

1.2.1 Recent Exploration and Appraisal Activities

Exploration activities undertaken by AWE and its Joint Venture Partners since the Company merged with ARC Energy Limited began in March 2009. More recent drilling campaigns were in 2010, 2011, 2012, 2014, 2015 and again in 2017. This has resulted in the appraisal and discovery of the Senecio and Irwin Gas fields and more recently in 2014, the Waitsia Gas Field, which is proposed for further development (refer to Section 1.2.3).

1.2.2 Production Facilities Operated by AWE

AWE has one active gas production facility in the Mid West region, the Xyris Production Facility (XPF), with the DPF and Hovea Production Facility (HPF) active in part. AWE engages a lead contractor, Upstream Production Solutions, to operate and maintain these facilities under AWE management. There are, no drive in drive out (DIDO) or fly in fly out (FIFO) staff and all of our operational personnel live locally in the Mid West region.

1.2.2.1 Dongara Production Facility (DPF)

The DPF began operating in 1971 when the Parmelia Gas Pipeline was commissioned. During almost five decades of production, more than 50 wells have been drilled in the Dongara and adjacent gas fields which coexist amongst the primary regional land use, broad acre farming. The DPF has mainly produced gas, as well as some liquids, which are normally called condensates (hydrocarbon liquids), and produced water.

Gas is transported and sold through the Parmelia Gas Pipeline operated by APA Group and any oil and condensate is trucked approximately 360 kilometres to the BP Kwinana oil refinery, located south of Perth.

The Dongara gas fields are nearing depletion and are not currently producing. They have been temporarily shut-in. AWE is preparing care and maintenance plans for DPF and decommissioning plans for the associated wells and infrastructure no longer in use will follow.

1.2.2.2 Xyris Production Facility (XPF)

The Waitsia gas field began producing natural gas in August 2016 when the Waitsia Gas Project Stage 1A was commissioned. Gas flows from the Senecio-03 and Waitsia-01 wells to the XPF, which was refurbished in 2016 following a period of care and maintenance, and now provides an ongoing source of gas to consumers and jobs for local employees. The XPF is operating and producing 10 TJ/day of gas for domestic gas supply. No HFS has been used for Waitsia Gas Project Stage 1A or is required for the future Waitsia Gas Project.

1.2.2.3 Other Production Facilities

AWE has several other production facilities in the Mid West region that are in care and maintenance and are no longer producing.

The HPF, an oil production facility constructed in 2003, is located within Production Licences L1/L2. The Hovea field has been in care and maintenance since 2012. Since then, the HPF area has been used to support general regional operations (eg equipment laydown storage, evaporation ponds).

The Mount Horner Oil Field, an oil production facility located in Production Licence L7, has been in care and maintenance since 2010. Several wells have been decommissioned and a decommissioning program for the site is being prepared.

The Woodada Gas Field (WGF), located in Production Licences L4/L5, was discovered in June 1980, with production commencing in May 1982. In December 1987, the area surrounding the field was declared a nature reserve known as Lake Logue Nature Reserve. The WGF was placed under care and maintenance in 2011.

Other facilities in the northern Perth Basin, including the Mondarra Gas Storage Facility and Beharra Springs Gas Processing Plant, are run by other operators.

1.2.3 Development Activities – Waitsia Gas Field

AWE commissioned Waitsia Gas Project Stage 1A in August 2016, which is an extended production test of the Waitsia Gas Field. AWE is now progressing the Waitsia Gas Project proposal.

1.2.4 Decommissioning and Rehabilitation Project

The Decommissioning and Rehabilitation program is another key project AWE has been undertaking steadily since 2014. Wells and infrastructure that are no longer being used are being progressively decommissioned and rehabilitated, so the land can be made available for its prior use. This project effectively means that AWE's development well footprint in the Dongara area (inclusive of the Waitsia gas development project) is reducing overall. This demonstrates an ongoing commitment to reducing potential impacts especially on the natural environment as well as visual amenity.

1.3 HFS overview

HFS is a well stimulation technique used to improve the flow of gas from formations that are difficult to access due to depth and low rock permeability. It improves flow rates by fracturing a portion of the host rock so the gas or oil is released and can move into the well. The well is encased with steel and cement to ensure it is separated from any groundwater.

HFS involves pumping fluids, comprised of approximately 99.2% water, and 'proppants' (solid material such as fine sand grains or ceramic beads) into low-permeability rock under high pressure to induce fractures[8].

HFS was introduced commercially in the 1950s and is most commonly now known for its use in helping improve oil and gas flow rates. The potential HFS impacts vary greatly depending on the site conditions including depth from aquifers and host geological formations and are managed appropriately by regulatory and operational controls, before, during and after drilling.

In Australia, HFS has historically been used to extract gas from conventional sandstone reservoirs which have low permeability (tight gas). More recently, gas has been produced from coal seams and some early stage appraisal of shale deposits. The majority of HFS activity in the northern Perth Basin has been tight gas extraction with limited HFS in shale deposits.

[8] About Hydraulic Fracture Stimulation, https://frackinginquiry.wa.gov.au/about-hydraulic-fracture-stimulation#4.

1.4 History of HFS in the northern Perth Basin

HFS has been used since 1968 in the northern Perth Basin area[9] with a total of 18 wells stimulated in the region. This includes HFS treatments in the Dongara and Corybas gas fields (including production wells), the Woodada Gas Field, the Arrowsmith-02 well, and the Warro Gas Field. A list of HFS well treatments within AWE production licences are provided in Table 1 and locations are shown on Figure 4 and Figure 5.

Table 1. HFS treatments at wells located in the northern Perth Basin within AWE operated production licences

Well	Production Licence	Reservoir Type	Treatment Date	Operator
Mondarra-02	L1	Tight	December 1968	WAPET
Dongara-03	L1	Tight	March 1974	WAPET
Dongara-09	L2	Tight	April 1974	WAPET
Dongara-09	L2	Tight	July 1984	WAPET
Dongara-15	L1	Tight	March 1974	WAPET
Dongara-15	L1	Tight	March 1974	WAPET
Dongara-21	L2	Tight	December 1981	WAPET
Dongara-24	L2	Tight	July 1985	WAPET
Corybas-01	L2	Tight	May 2009	AWE
Senecio-02	L2	Tight	August 2012	AWE
Woodada Deep-01	L4/L5	Shale	August 2012	AWE
Woodada Deep-01	L4/L5	Shale	August 2012	AWE
NB: Senecio-03 and Drover-01 were each approved for HFS treatment which did not proceed. The gas at Senecio-03 was found to be free-flowing so there was no need to use HFS. Initial Drover-01 exploration results indicated HFS would be sub-economic.				

[9] Western Australian Petroleum and Geothermal Information Management System (*WAPIMS), December 2017.*

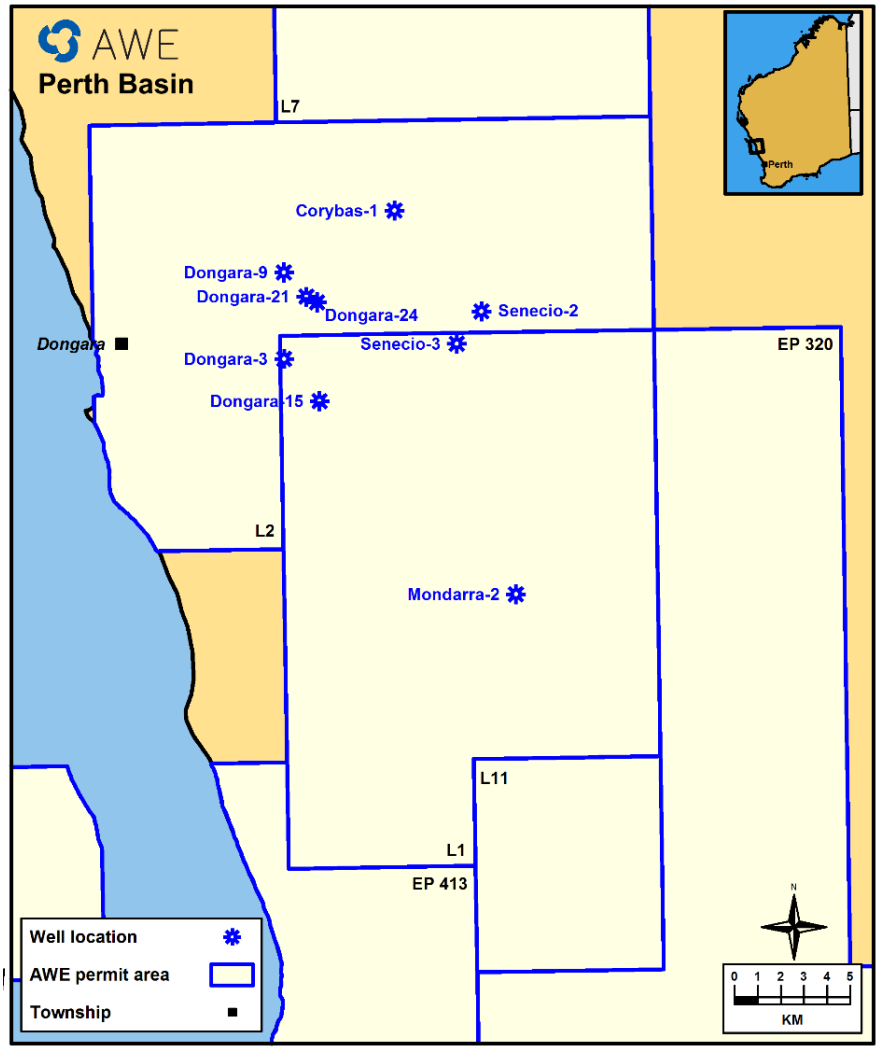

Figure 5. HFS approved wells located in Production Licences L1 and L2 (Note: Senecio-03 was approved for HFS treatment which did not proceed)

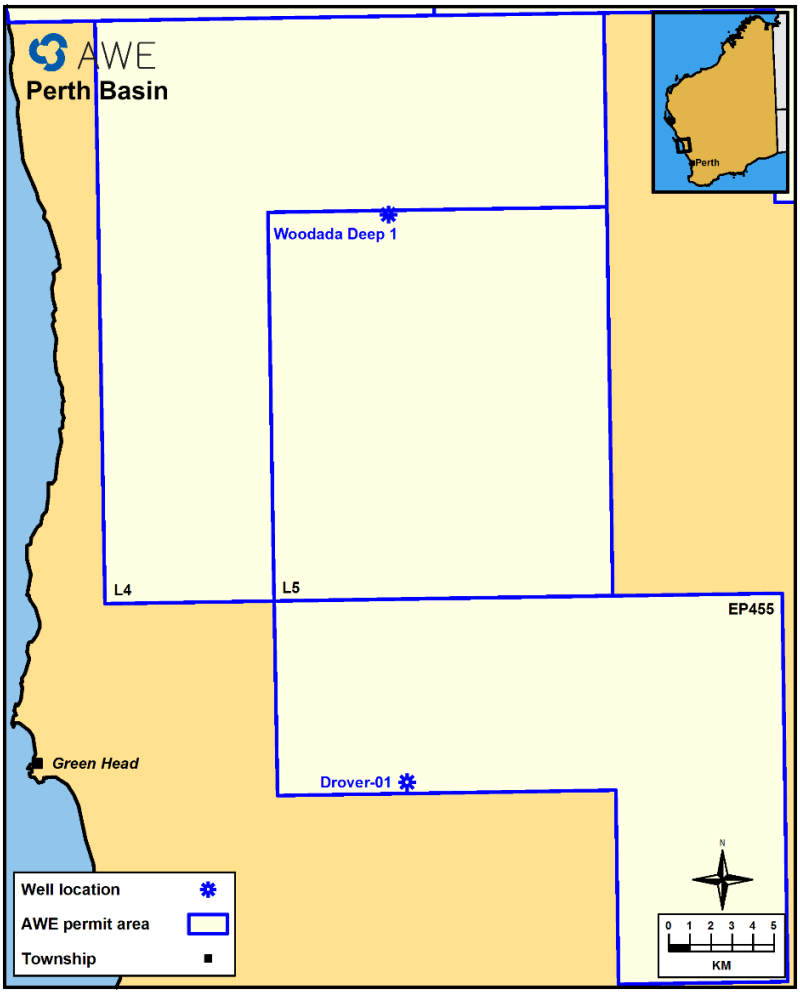

Figure 6. HFS approved wells located in Production Licences L4, L5 and EP455 (Note: Drover-01 was approved for HFS treatment which did not proceed)

As outlined by the Independent Scientific Panel, WA's shale and tight oil and gas resources fundamentally differ from coal seam gas[10]. HFS techniques vary depending on the host geological formation. The geologic nature of most major sources of natural gas is shown in schematic form (Figure 7)[11].

- Coal Seam deposits are typically at shallow depths of 300 m - 1,000 m, are predominantly in Australia's east coast and not prospective in the Perth Basin or elsewhere in WA. HFS is sometimes used for improving coal seam gas reservoir flow rates.
- Shale HFS involves very deep targets at depths of between 2,000 m – 4,000 m, where high pressure and multi stage horizontal fractures are used to create reservoir production. HFS is always used to extract gas from shale deposits. In the northern Perth Basin, extraction of natural gas from shale deposits is still in its early appraisal stage (ie no production to date).

[10] How do WA's shale and tight oil and gas resources differ from coals seam gas?, https://frackinginquiry.wa.gov.au/about-hydraulic-fracture-stimulation, 12 February 2012.

[11] US Energy Information Administration, https://www.eia.gov/todayinenergy.

- Tight gas refers to conventional sandstone reservoirs with low permeability, with targets typically located at depths of 2,000 m – 4,000 m. They generally require relatively low pressure HFS to mobilise gas.

AWE has used HFS to create production performance improvements from tight gas sandstone reservoirs and understand the extent and production potential of prospective shale resources.

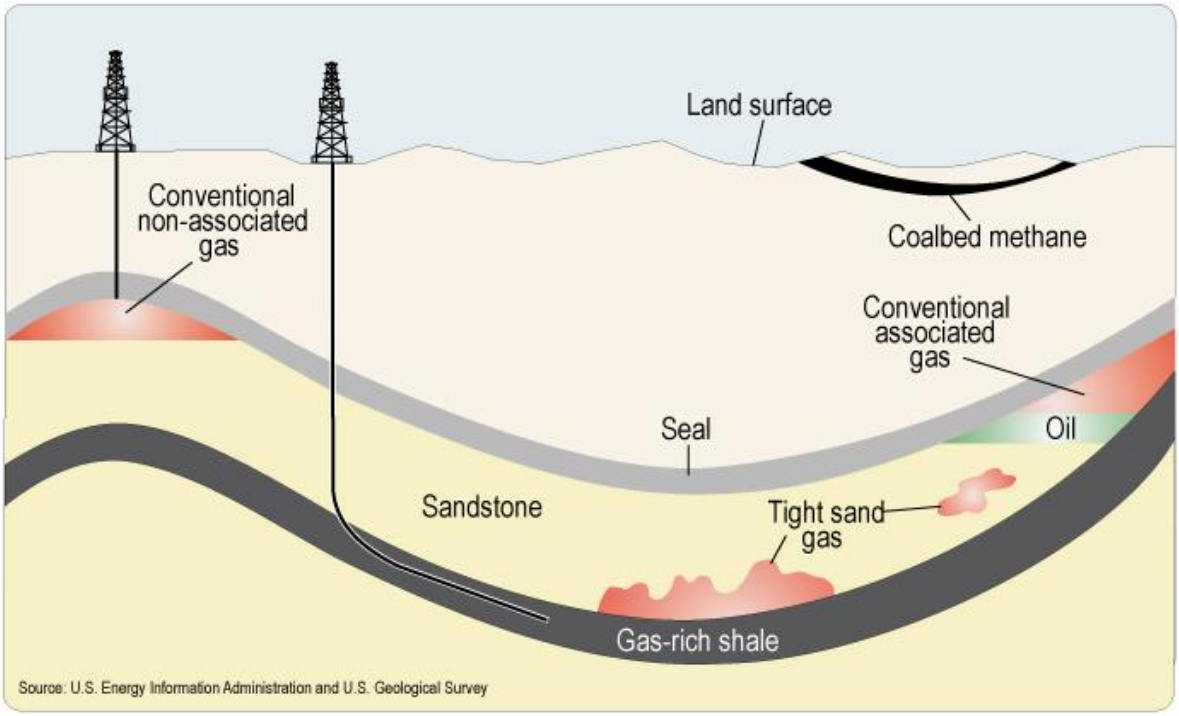

Figure 7 Geology of natural gas resources

The areas where AWE has used, or considered using, HFS featured tight (low permeability) sandstone reservoirs and shale formations. These include Dongara, Corybas, Senecio (tight gas sandstone) and the Woodada Deep-01 wells (gas rich shale) and the use of HFS on specifically targeted zones was identified as a way of improving permeability and flow rates.

The Western Australian Petroleum and Geothermal Information Management System (WAPIMS) includes data showing HFS has been used for decades in WA to extract gas from tight conventional reservoirs[12]. HFS is also used on a regular basis in the Cooper Basin in accordance with the comprehensive and robust regulatory regime of South Australia.

Case studies provided in Section 3.0 give further information about the aspects being considered by the Independent Scientific Inquiry. These case studies include useful monitoring data providing evidence of no significant environmental impacts at any of the HFS wells. An outline of the aspects, impacts and most relevant case studies is provided in Table 2.

Table 2. Summary of environmental aspect, impact and most relevant case study

[12]Western Australian Petroleum and Geothermal Information Management System (WAPIMS), https://wapims.dmp.wa.gov.au/wapims.

Aspect	Impact	Case Study
Land	Terrestrial Environmental Quality	Woodada Deep-01
	Biodiversity	Woodada Deep-01
	Beneficial Use	All
Air	GHG Emissions	CSIRO baseline monitoring study
	Air Pollutants	Woodada Deep-01
Water	Quality	HFS containment Woodada Deep-01
	Quantity	All
	Beneficial Use	All, although not as relevant where small volumes of water are used
Social Surrounds	Aboriginal Heritage	All
	Amenity and Aesthetic Enjoyment	Senecio-02 and Woodada Deep-01
	Public Safety	All
	Seismicity	Senecio-02 and Woodada Deep-01

One of the key concerns often raised with AWE during engagement activities is what a producing gas field would look like and how many wells would be required. Images of unconventional fields in other countries and jurisdictions are commonly used as a reference, which often portray a large footprint with extensive networks of pipelines and infrastructure and have the potential to create a false perception and cause unnecessary concern.

A more relevant and local example of a producing gas field is readily available by viewing an aerial image of the Dongara and Xyris production facilities (Figure 8). This image shows that the long-standing presence of gas field infrastructure does not necessarily significantly impact the agricultural amenity or visual aesthetics of the region, the scale of well sites and facility is clearly shown against the farming infrastructure. This area has unobtrusively hosted gas exploration and production, including some HFS treated wells, for decades amidst farming, intensive horticulture and other agricultural sector activities.

Figure 8. Image of the Dongara and Xyris production facilities located in the Irwin agricultural region

As for future developments, drilling techniques are continually improving where multiple wells can now be drilled from the same well pad. Using this technique could further reduce the potential development footprint.

2.0 REGULATORY MECHANISMS AND ONSHORE ENVIRONMENTAL MANAGEMENT

Most of AWE's historical production has been from free-flowing reservoirs and all current and planned gas production expected to last for at least 20 years is from free-flowing reservoirs.

Evidence from AWE's exploration and production activities is provided to outline the measures undertaken to operate safely and efficiently in all circumstances. The same regulatory approach is used for both planning and operating under HFS or conventional activities.

Since gas was first discovered in the northern Perth Basin several significant changes have occurred in parallel:

- exploration, production and decommissioning techniques have developed and become more efficient
- industry has continually incorporated lessons learned into all phases of activities (ie planning, exploration, production, decommissioning) where impact assessment and monitoring are integrated activities
- regulations, especially environmental and safety, have become more rigorous
- community expectations of regulators and industry have increased and 'social licence to operate' is now a familiar term
- approximately 15 HFS inquiries have been conducted in Australia
- industry performance has become more transparent

Industry continues to respond to these changes and incorporates them into its general practices. Development and use of the HFS technique is a good example of how industry has responded to changing technology, knowledge and societal expectations.

2.1 Approvals Processes in Western Australia

2.1.1 Regulatory Overview

AWE refers to the Regulatory Environment background paper provided by the Panel and notes the regulatory framework rests on five key principles[13]:

- Transparent, effective and risk-based regulation
- Whole-of-government approach
- Consistent State and Commonwealth Government objectives
- Effective engagement with stakeholders, particularly local communities, and
- Compliance and enforcement, which is one of the key pillars of the role of DMIRS.

Western Australia has an effective regulatory framework for petroleum activities that is comprehensive, robust and transparent. This framework has been steadily developed over the last 8 or so years and been informed by reviews, expert input such as the 2011 Hunter review[6] and key stakeholder feedback. A summary of key milestones showing steady progression in regulatory improvements is shown in Figure 9.

[13] The Regulatory Environment, https://frackinginquiry.wa.gov.au/sites/default/files/3_regulatory_environment.pdf.

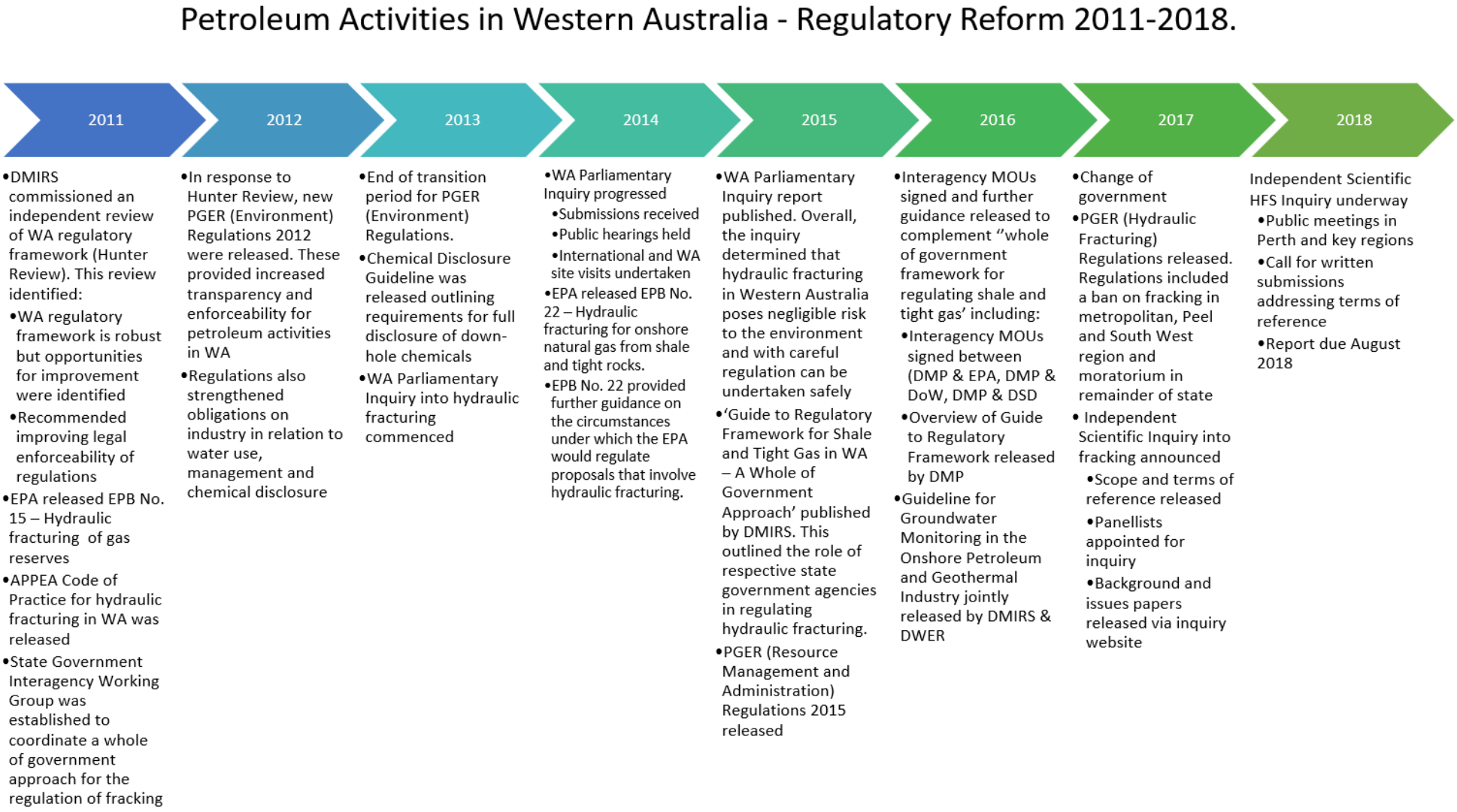

Figure 9. Key milestones of WA onshore regulatory development

DMIRS is an effective lead agency for regulating the resources sector broadly and the petroleum sector under the PGER Act and associated regulations. AWE recognises that DMIRS shows world leading technical expertise in relation to resources sector regulation ensuring environmental compliance and implementation of best practice environmental management.[14]

The WA regulatory framework includes a 'whole of government approach' for regulating HFS which facilitates efficient and transparent regulation and includes many checks and balances. The approvals processes includes= transparency of information such as disclosure of an Environment Plan (EP) summary document at EP lodgement and full disclosure of downhole chemicals.

In 2015, the *Guide to the Regulatory Framework for Shale and Tight Gas in Western Australia, A Whole of Government Approach*, was released. The guide, which was endorsed by heads of all nine agencies and in place until 2017 when the HFS moratorium was introduced, emphasised five key principles[15]. Other useful administrative arrangements are the Memorandum of Understanding (MOU) between the Environment Protection Authority (EPA) and DMIRS[16] and the Administrative Agreement between DMIRS and DWER[17] which each reinforced the application of using a significance test in applying risk-based regulation.

AWE also recognises that the Part IV of the EP Act provides additional regulatory oversight for activities that are likely to have a significant impact on the environment. The EPA, an independent statutory authority, would assess environmental impacts of any proposal that may have a significant impact on the environment and make recommendations to the Minister for Environment who decides whether to approve the proposal, and if so under what conditions. This formal environmental impact assessment process is used for resources proposals with potential significant environmental risks that cannot be adequately regulated by the DMIRS led process alone. An important and powerful provision of the EP Act is that decision-making authorities are constrained from issuing approvals on a proposal subject to formal impact assessment under Part IV of the EP Act. This is not common in other jurisdictions.

Current approvals assessments processes led by key agencies include:

- DMIRS
  - Environment Plan and Environment Plan Summary
  - Chemical disclosure documentation
  - Oil Spill Contingency Plan
  - Safety Management Systems/Safety Case
  - Technical programs – Field Management Plan, Well Management Plan
- Department of Water and Environment Regulation

[14] http://www.dmp.wa.gov.au/Environment/Environmental-regulation-8311.aspx.

[15] Guide to the Regulatory Framework for Shale and Tight Gas in Western Australia, A Whole of Government Approach, 2015 Edition, Government of Western Australia.

[16] Memorandum of Understanding between the Department of Mines and Petroleum and the Environmental Protection Authority in relation to the referral of Mineral and Petroleum (Onshore and Offshore) and Geothermal Proposals, http://www.epa.wa.gov.au/sites/default/files/Publications/EPA-DMP-MOU-290709.pdf.

[17] http://www.dmp.wa.gov.au/Documents/Environment/ENV-PEB-162.pdf.

- Licences to construct groundwater wells and extract superficial aquifer groundwater

In addition, AWE engages with other regulators, who routinely provide advice during the assessment and operational phases, including:

- Department of Aboriginal Affairs (now Department of Planning, Lands and Heritage)
- Department of Water and Environmental Regulation
- Department of Biodiversity, Conservation and Attractions
- Department of Health
- Environmental Protection Authority
- Department of the Environment and Energy (Commonwealth)

Following regulatory approval for the proposed activity, AWE is required to fulfil the various conditions and commitments of the approvals as well as of any associated licences and regulation. For example, routine environmental monitoring of operational activities, Annual Environmental Reports, reporting Greenhouse Gas Emissions in accordance with federal legislation.

2.1.2 Regulatory Development

AWE takes an active role engaging with regulatory and policy review affecting the onshore petroleum sector. For example, AWE made a submission to the WA Parliamentary Inquiry and hosted the Committee on a Mid West site visit[18]. AWE also carefully followed the independent review of the regulatory framework review conducted by Dr Tina Hunter and response to recommendations for further strengthening and improving legal enforceability through developing new environmental and resource management regulations[19]. AWE has continued to liaise through APPEA on any proposed regulatory changes affecting the onshore sector.

Improvement opportunities for regulation identified by AWE based on operational feedback include the following:

- The 'whole-of-government' approach – AWE strongly supports this framework and DMIRS role as the lead agency coordinating expert advice from other organisations as required. Further removing information duplication within and between departments would improve and clarify approvals efficiencies making operations and compliance tracking easier to manage.
- Further develop the objective (risk) based regulation for petroleum activities as provided for in the PGER Act and EP Act by categorising petroleum activities based on the level of environmental risk (eg High, Medium, Low) to better focus on higher risk activities. This is consistent with existing government policy (eg EPA Bulletin No 22).
- Develop standard approaches or reference cases for activities that are undertaken using standard industry approaches with known risks. In the first instance, reference cases would be developed for 'low risk' activities (eg airborne surveys). Reference cases may be applied regionally (eg Perth Basin) or state-wide. Reference cases could be published and would provide increased transparency regarding environmental risks and mitigation measures.

[18] AWE Limited: Submission to the Environment and Public Affairs Committee – "Inquiry into the Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas".

[19] Regulation of Shale, Coal Seam and Tight Gas Activities in Western Australia, Dr Tina Hunter.

- Chemical disclosure regulatory requirements – This regulatory requirement was included in August 2012, following an independent regulatory review and in response to public interest in onshore activity. It aims to improve transparency and trust by making down-hole chemical usage information widely accessible, EP summaries are posted on the DMIRS website as well as the AWE Mid West website. Typically, 90% of EP Summary documents are comprised of chemical disclosure and Safety Data Sheets (SDS). Feedback from AWE stakeholders indicates the disclosure requirement has not yet achieved its intended aims of improving transparency and trust, possibly because the information is highly scientific and hard to interpret at times. AWE is liaising with other operators, stakeholders and DMIRS regarding observations from applying these obligations since they were introduced. For example, it would be beneficial for products that are essentially the same (eg same components but a different brand name) to be interchangeable. Also, if products proposed for use in a new activity are being used in the same setting as those recently used for another activity, a streamlined approval option should be available. Changes like this would better reflect the operational requirements of drilling whilst maintaining transparency and enforceability.
- Stakeholder engagement – The role of effective stakeholder engagement in gaining and retaining a social licence to operate is key. Evidence provided to WA Parliamentary HFS Inquiry during the public hearing held in October 2014 clearly showed that where stakeholders are familiar with whole of government regulatory framework and with industry activities, they are more confident that the industry is being regulated acceptably. The Shire of Irwin representatives spoke of their experience with the onshore sector that has been operating continuously in the Shire for many decades. Their views differed markedly to those from the Shire of Coorow representatives who were much less familiar with the sector as there had been less onshore petroleum activity in this Shire. This showed the importance of being familiar and aware of the onshore sector as well as the benefit of effective engagement and ensuring regulatory processes are well understood[20].

AWE notes the attention given to review and development of WA petroleum regulations that has occurred since 2011, as well as the fifteen inquiries and reports undertaken into HFS throughout Australia. AWE notes the conclusion of previous inquiries undertaken into HFS, particularly the Western Australian Parliamentary Inquiry conducted from 2013 to 2015. The Inquiry report, *Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas*, concludes potential HFS impacts can be acceptable given appropriate regulation and operational measures are implemented and it broadly supports the regulatory framework in Western Australia for HFS activities[21]. These findings align with the many other Inquiries and Reports, Australia wide that concluded the risks associated with HFS can be managed effectively.

AWE welcomes the opportunity to help constructively address the interest shown by drawing on its significant operational experience to ensure regulations continue to be robust and transparent whilst also enabling efficient and safe operations.

2.2 Land Access

Prior to commencing operations on private land, the petroleum title holder is required to develop a land access agreement with the landowner. The agreement identifies the area of activity, agreed terms of compensation, notification protocols and other administrative details. AWE respects that HFS sentiment

[20] Public hearing held in Dongara, 27 October 2014, Inquiry into the Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas.

[21] Legislative Council Western Australian, Thirty-Ninth Parliament, *Report 42 Standing Committee on Environment and Public Affairs: Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas*, November 2015.

amongst landowners can vary and engages with each landowner to ensure land access agreements are mutually satisfactory

AWE considers post-drilling land uses from the early project design stage wherever they are located. The footprint of AWE activities are very small compared to broad acre farming practices. For example, the five wells and their access tracks on Irwin Park Farm AWE, which is 4,649 hectares (ha) in size, have an average footprint of 3.4 ha. This equates to a footprint of 0.37% of the overall farm.

AWE recognises the benefits of coexistence and has developed its landowner agreements to include feedback from its landowners and prioritises its relationships with them. All wells drilled by AWE, including any associated infrastructure, have land access agreements and were negotiated in good faith with the respective landowners. AWE routinely engages with directly affected property owners about proposed activities during planning stages so relevant requested infrastructure installed can be used as a property improvement when the land is returned to the landowner. In most cases, the landowner requests some infrastructure to remain following the drilling activity. For example, gravel tracks, water bores, gates, cattle grids and well pads are usually seen as property enhancements, especially when the landowner has been involved in the design stage of the activity.

AWE was an active contributor to developing the Farming Land Access Agreement Template, a joint initiative between WA Farmers Federation, Pastoral and Graziers Association, vegetablesWA and the Australian Petroleum Production and Exploration Association. This document was developed in response to landowner feedback and provides a template for use in developing agreements for onshore activities. AWE drew on its experiences with landowners directly affected by its activities to help ensure the document reflected lessons learned and was useful.[22]. The template was released in October 2015 and covers many of the items addressed in AWE's land access agreement.

2.3 Planning, Developing and Operating Activities

AWE considers the life-cycle of a project from the initial planning phase through to development and decommissioning to ensure environmental, health and safety, community as well as business factors are addressed and that each of our projects or activities is undertaken safely and responsibly.

AWE understands the high value placed on the environment by Mid West landowners, community members and other stakeholders. We are committed to protecting these values and undertake comprehensive and rigorous risk assessments as part of project planning and in preparation for seeking project approvals.

AWE prepares approvals documentation in accordance with legislated approvals processes administered by the DMIRS, the EPA and other government agencies.

At early stages of developing a proposal, AWE undertakes the following:

1. A comprehensive risk assessment
2. Engaging with our key stakeholders
3. Maintaining communication and transparency

[22] Farming Land Access Agreement Template: For Petroleum Exploration Activities under the Petroleum and Geothermal Energy Resources Act 1967, October 2015.

2.3.1 Project and Activities Planning

AWE takes a systematic and deliberate approach to protecting the environment during all of its operations. By routinely undertaking a comprehensive risk assessment to identify all of the potential impacts an activity or project may have on an area, then proceeding to understand how these could be effectively managed by implementing protection measures.

Risk assessment is a key part of project planning. The aim is to ensure the activity is managed to As Low As Reasonably Practicable (ALARP). ALARP refers to the point where the cost involved in further reducing the environmental impacts and risks of the activity would be highly disproportionate to the environment benefit gained. The principle arises from the reality that resources are finite and should focus on reducing the environmental impacts and/or risks that will deliver the best environmental outcomes possible[23].

Risk assessment is fundamental to the regulatory approvals processes used in Western Australia[24]. A risk management framework provided by DMIRS outlines the key steps involved and used by AWE (Figure 10).

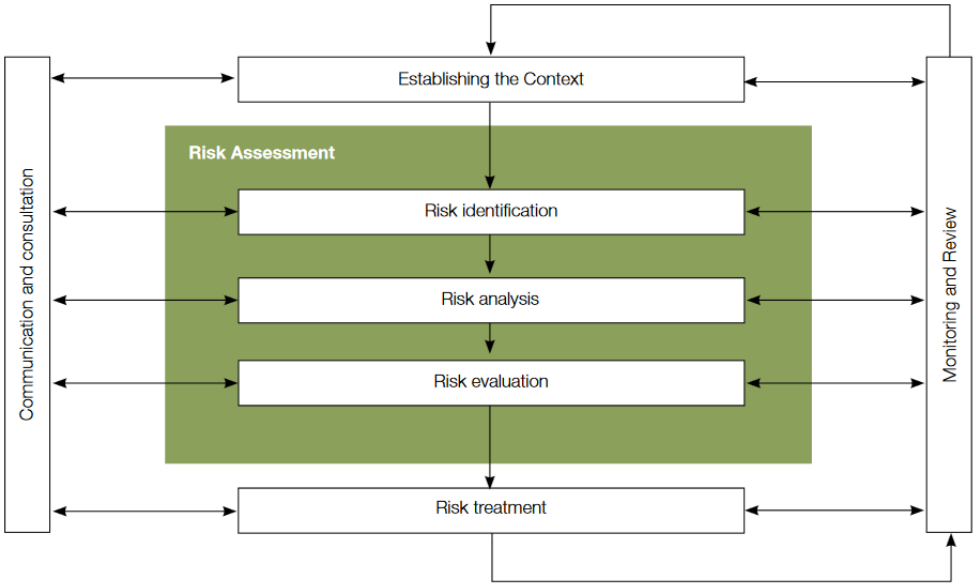

Figure 10. Risk Management Process ISO 31000:2009

The approach undertaken towards risk management for each aspect involves a review of the residual risk post treatment to determine if the environmental impacts and risks of the activity will be managed to an acceptable level[25]. Where additional implementation measures are necessary to reach a level of acceptability they are considered and adopted. The risk assessment process involves:

- Discussion and agreement of the scope of the risk assessment
- Line-by-line assessment and population of the hazard register with risks relevant to the activity

[23] Regulation of Shale, Coal Seam and Tight Gas Activities in Western Australia, Dr Tina Hunter.

[24] Guideline for the Development of Petroleum and Geothermal Environment Plans in Western Australia, November 2016, Department of Mines and Petroleum.

[25] Waitsia Gas Project Commissioning and Operations Environment Plan [21/HSEQ/ENV/PL06 Rev 2].

- Determine appropriate treatment / control measures and continue to propose and assess measures until the group consensus is that the residual risk has been reduced to ALARP
- Actions are undertaken where additional investigation or additional data is required to support a risk position
- Risk mapping of environmental risks is undertaken to assign a level of risk to each hazard

Potential key environmental issues and impacts which are typically identified during the project planning phase are listed in Table 3.

Table 3. Key environmental issues factored into general project planning and management measures

Key Issues	Management Responses
Surface water	Study catchment to identify location of potential receptors (eg rivers, streams, ponds). Design activities to minimise interaction from any runoff (eg pond construction, install bunding) and manage erosion. Ongoing monitoring.
Groundwater	Study aquifers to identify location and characteristics. Design project to minimise water use as well as potential interaction from flowback and produced formation water. Construct and operate accordingly, monitor and manage.
Chemicals	Materials selection process considers environmental aspects and is subject to regulatory approvals. Products are stored on-site safely according to regulations. All products used down-hole are publicly disclosed.
Conservation	Investigate conservation values and consider throughout project planning to minimise potential impact on biodiversity values. Dieback/weed hygiene management measures. Note most of AWE's activities occur on cleared agricultural land.
Aboriginal heritage	Conduct surveys during project planning to avoid potential impact. Involve traditional owners in monitoring ground works to ensure conservation of any heritage values.
Traffic	Identify regional traffic flow, factor into design and manage so minimal increases during peak work periods.
Air quality	Potential emission sources identified, select materials/equipment appropriately and maintain to reduce any emissions.
Noise	Identify noise levels and patterns in proposed activity area, conduct noise modelling if needed to help ensure activity has been planned to minimise potential impact on noise sensitive receptors. Implement measures to minimise noise. Advise local residents of planned activities in advance and monitor levels when conducting activities.
Fire	Firefighting equipment on site with staff trained in firefighting techniques. All equipment hazard zone rated for drilling operations. Gas detection on site.
Rehabilitation	Sites rehabilitated to landowners' requirements or agreed post-activity land use.

AWE is committed to employing industry best practice at every stage of the project's lifecycle. There are management measures which play an important role in minimising potential environmental impacts during the activity. Each measure provides individual protection, but when combined provide multiple redundancy

safeguards against significant environmental impacts. The management measures relevant to drilling activities, including HFS are outlined in Table 4.

Table 4. Management Measures during Drilling Activities

Management Measure	Why it's important	AWE examples
Depth of shale and tight gas formations	Shale and tight gas reservoirs are located deep below the surface, up to 5,000 metres below ground level Fresh water aquifers are not impacted by drilling and HFS operations (fresh water aquifers are usually within 100 metres below ground level)	On average, AWE's wells are drilled to approximately 2,500 metres below ground level (equivalent to the height of ~10 Central Park Towers)
Robust well construction and design	Well planning and design is undertaken by a team of highly qualified and experienced professionals Each well design is overseen and approved by DMIRS	**please refer to Figure 14 outlining the structure of the well casing and multiple barriers involved in its design*
Multiple steel casing and cement barriers used during well design	Multiple layers of cement and steel casing provide a six layer barrier to shallow aquifers, ensuring that drilling activities remain completely separate from the surrounding outer environment below ground This form of well design is industry best practice and used globally to ensure the integrity of the drilling operations The barriers are pressure tested and then monitored on an ongoing basis until the well is decommissioned	**please refer to Figure 14 outlining an illustration of the Woodada Deep-01 well design, in which there were no negative impacts on the surrounding environment (as supported by AWE's water and air quality testing results)*
Significant natural barriers between target reservoir & aquifers	Shale and tight gas formations exist deep underground and are separated from surface aquifers by natural geological barriers in the form of impermeable rock formations Natural geological barriers such as these are impermeable to hydrocarbon migration	AWE's Woodada Deep- 01 well possessed natural barriers between the formation that was hydraulically fractured and the closest aquifer Appendix D outlines details of the deepest aquifer (Lesueur). There are 100's of meters (>700m at Woodada Deep-01) of low permeability strata between it and target zones (making any hydrocarbon migration risk immeasurable)
Environment Plans	Every activity which takes place during a drilling program is firstly detailed in an Environment Plan (EP) which companies submit to DMIRS for assessment and approval EPs include a thorough and detailed report of every single function relating to the drilling program including risk factors, land clearing, spill response plans and well design	AWE makes its EP summaries publicly available via its Mid West website awemidwest.com.au

Management Measure	Why it's important	AWE examples
Experienced regulator	DMIRS is a highly experienced and robust regulator which oversees every aspect of a drilling campaign, from the initial awarding of acreage to the approval to drill an exploration well	
Safe treatment of HFS fluids returned to surface	Fluid used for HFS is returned to surface and stored in a pond lined with two layers of HDPE Once tested, the fluid is either transported to a special waste treatment facility or recycled	
Chemicals used during drilling (down-hole)	Chemical products used down-hole must be assessed and approved by DMIRS prior to use. Reporting on chemical usage is included in annual environmental reports submitted to DMIRS.	Down-hole chemical usage is made publicly available within the EP summary posted on AWE's midwest website awemidwest.com.au and also DMIRS website.

The risk assessment and management measures are detailed in each Environment Plan submitted to the regulators for approval. AWE makes Environment Plan summaries for each activity and project available on its Mid West website (www.awemidwest.com.au) and they are also posted on the DMIRS website for a six month period. As stated in the table above, these summaries include management measures for key risks and details on all down-hole chemicals used at each well.

2.3.2 Stakeholder Engagement

Stakeholder engagement is a key part of early project planning and integrated into the lifecycle of each activity. AWE stakeholders include members of the community such as landowners, traditional owners on whose land we operate, local business owners and shire residents. They also include relevant regulators, decision makers and elected officials.

AWE has established an extensive consultation and engagement process in the Mid West to support fostering positive relationships within the community. It is based upon the internationally recognised AccountAbility 1000 Stakeholder Engagement Standard (AA1000SES) 2015 as an appropriate strategic framework for Western Australian projects. AA1000SES prescribes that stakeholder engagement strategy should be built on the principles of inclusivity, materiality and responsiveness, and around the four cyclical phases shown in Figure 11.

Figure 11. AA1000SES stakeholder engagement process

AA1000SES also builds on principles and tenets published by the International Association for Public Participation (IAP2), in particular the IAP2's Spectrum for Public Participation[26], which holds that engagement strategy should be calibrated against the level of public impact. AWE uses this approach to help estimate the level of public impact associated with its project and activities, for the purpose of selecting modes of engagement against the IAP2 spectrum in line with Western Australian regulatory stakeholder engagement requirements.

AWE engages extensively with key stakeholders, especially with the local community where it operates. AWE holds community information exchange meetings, advertises engagement opportunities in the local newsletter, communicates project information directly to local residents and responds promptly to any enquiries received. AWE has developed a website specifically tailored for stakeholders interested in its Mid West activities and encourages feedback from locals.

During recent projects, AWE has held regular discussions with the local shires and elected officials so that community leaders are aware of proposed activities.

AWE believes community and stakeholder engagement is part of an ongoing process with the local communities in which it operates. Regular community and stakeholder engagement is a routine part of AWE's forward exploration and development plans.

An example of this is the Shire of Irwin Community Roundtable, established following positive feedback about a similar forum AWE sponsored in the Shire of Coorow in response to interest in the Drover-01 Exploration Well (refer to Section 3.2.3.5). The Shire of Irwin Roundtable was established to help effectively engage over the development of the nearby conventional Waitsia gas field. The Roundtable consists of regular, independently facilitated sessions aimed at developing a better understanding of AWE's planned activities and foster discussion about the various community members' views – with the purpose that any concerns are addressed and identified benefits are maximised.

[26] http://www.iap2.org.au/documents/item/84.

Another example of integrated engagement practices is the annual stakeholder survey that AWE has undertaken by an independent consultant since 2015 with a range of stakeholders (eg regulators, local residents, elected officials). The latest survey identified the following key topics:

- Stakeholders main questions could be more effectively answered by industry and regulators
- State government policy direction relating to the onshore energy sector is seen as a risk
- Information complexity about the onshore energy sector persists
- The onshore sector has many success stories that could be better communicated
- Environmental performance stories elsewhere are affecting attitudes to the WA onshore sector operators and industry

While the exercise demonstrates that there is more work to be done, the survey has proven to be a useful tool to help check that the stakeholder engagement activities are being effective, for AWE to better understand the range of stakeholder views and then be able to respond as required by updating the stakeholder engagement plan. AWE also makes the survey results available to various other stakeholders for their use. A copy is provided in Appendix A.

Beyond AWE's social responsibility to inform and listen to the local communities about our operations, our aim is to enhance the communities in which we operate. AWE supports the local community by partnering with organisations and local not-for-profit groups to provide better services for locally driven initiatives.

AWE has contributed to local organisations including a local regional tertiary institution, charity fund-raising events, sporting clubs, primary schools and attractions.

All of AWE's operational staff live in local communities and AWE does not employ Drive-in/Drive-out or Fly-in/Fly-out employees in its Mid West operations.

2.3.3 Maintaining Communication and Transparency

Beyond initial discussions, AWE continues to maintain open communication with stakeholders about our activities as they develop. Forums for communication may be at community information meetings, updates in the local paper on progress and direct mail to local residents or through the independently facilitated Community Roundtable workshops. Information is also available via our AWE in the Mid West website (www.awemidwest.com.au).

The Shire of Irwin Community Roundtable operates independently of AWE, although AWE does provide information specifically requested by participants and, like a number of other stakeholders, including regulators and subject matter experts, participates in the group by invitation.

Through the Roundtable workshops, participants have identified the key issues of interest and information addressing these topics has been presented for discussion. A summary of key topics discussed, including HFS, is provided (Appendix B)[27].

[27] Shire of Irwin Community Roundtable Q&A Tracking Table, http://meet2create.com

It is interesting to note that the Roundtable was established in August 2016, prior to confirmation that the reservoir was free-flowing. Participants have been advised that the development project does not require HFS and that AWE has no plans to use this technique[28]. The participants who indicated they initially attended as they were particularly interested in HFS, have stated that they are not opposed to conventional gas activities. To assist discussion and understanding by workshop participants, DMIRS and DWER regulators have regularly responded to questions about the HFS technique, regulatory oversight, land access and the HFS inquiry[29]. Attendance levels have remained constant at the workshops and the issue of HFS has remained a topic of interest for some participants.

2.3.4 Onshore Sector Stakeholder Engagement

AWE and other WA onshore operators recognise the general public's interests in petroleum operations and the story of energy more generally especially with regard to potential environmental impacts. Industry, along with government and recognised independent scientific experts such as CSIRO, professional educators and other subject matter experts have a role in responding. It would be helpful for engagement with the general public to occur more broadly as well as more locally in relation to specific projects as they arise and to provide information.

Fundamental to this approach is understanding what key issues are of interest to various groups and responding appropriately to them by engaging respectfully and with a focus on outcomes. AWE experience is that understanding the range of stakeholders' views and priority questions is a first step to developing an effective engagement plan and supports methodologies involving surveys and opportunities for ongoing feedback.

A broader public engagement initiative could be led by independently facilitated groups representing a cross-section of stakeholders. This approach could be used in areas that have strong onshore presence as well as those that are less prospective for petroleum and/or there are no petroleum operators active depending on the level of interest.

Engagement should occur using a variety of mediums (e.g. websites, media, social media) to make information accessible to a broad range of interested parties as well as to receive feedback. A range of stakeholders (e.g. industry, government, CSIRO) could respond to key issues of public concern.

Project level consultation should be led by the operators of the relevant projects. Project level consultation should emphasise effective consultation with relevant stakeholders (ie landholders, traditional owners, people directly affected or who live in close proximity to the development) in relation to the project.

Consultation should be in a manner that allows the stakeholder group to get access to clear, reputable information (i.e. effective consultation with remote indigenous communities in the Canning Basin will likely be different to effective consultation with communities in the Perth Basin).

[28] Strategic Workshop – Shire of Irwin Community Roundtable workshop notes (1-6), http://meet2create.com/shireofirwincommunityroundtable.html.

[29] Strategic Workshop – Shire of Irwin Community Roundtable workshop notes (1-6), http://meet2create.com/shireofirwincommunityroundtable.html.

In all cases, access to clear and independent information should be made available as requested by relevant stakeholders.

2.4 Operational Management Measures

AWE onshore activities operate under the comprehensive and robust safety and environmental approval framework defined by various petroleum acts and regulations and led by DMIRS. Facilities are also covered by a site licence issued by DWER under Part V of the EP Act.

AWE has developed an integrated Health Safety Environmental (HSE) Management System to maintain and continually improve its operational performance across all onshore activities. It is structured around a series of HSE Elements that define the principles and expectations relating to the overall management of HSE throughout the organisation as outlined by ISO14001:2005. The HSEMS adopts the method of a Plan-Do-Check-Act cycle which provides a framework for continual improvement.

The HSEMS forms the basis for the development and application of supporting documents such as HSE Management Plans, Safety Cases, Environment Plans and Contractor HSE Bridging Documents with the following objectives:

- establish and formalise expectations for the progressive development and implementation of more specific requirements within each AWE Business Unit
- provide auditable criteria against which the HSEMS can be measured
- provide a basis from which to drive continual improvement

Implementation of the HSEMS assists AWE achieve its environmental goals through review, evaluation and improvement of environmental performance

For example, management measures used for routine drilling programs include: eg baseline surveys of flora, fauna, groundwater and surface water; monitoring during as well as post-operational activities to confirm environmental management measures are effective and any remedial action required can take place at an early stage.

In addition, AWE applies international standards as required by regulations. For example, AWE operates in accordance with “Norsok Standard D-010: Well integrity in drilling and well operations”. The standard defines the minimum functional and performance-oriented requirements and guidelines for well design, planning and execution of safe well operations. The focus of the standard is well integrity.[30]

[30] Norsok Standard D-010: Well integrity in drilling and well operations, Rev.4, June 2013.

3.0 CASE STUDIES

Case studies of wells that have been treated with HFS are provided to help demonstrate how use of this technique in the northern Perth Basin has not resulted in any observed environmental impacts. It is important to note that most activities undertaken by AWE have involved conventional reservoirs, as like the proposed Waitsia Gas Project the reservoirs have been free flowing. Whether the activity involved HFS or not, a risk based approach was used for each activity and similar management measures were successfully employed. The case studies also show how the 'whole of government' approach to approvals and regulation is applied and that opportunities for public comment are provided and used.

In this section of the submission, the initial part describes the HFS rock horizons, their relative depth, location and containment barriers. Followed by, case by case examples which describe and explain the associated environmental impact of the individual activities. Finally, a production section is provided that includes all prior HFS wells that have been on production and an explanation of produced gas and water rates which provide further evidence for HFS containment.

3.1 Demonstrating HFS Sub-Surface Containment

Potential impacts to groundwater is one of the key issues the Scientific Panel is considering, and a key topic identified by AWE's stakeholders through its annual stakeholder survey.

There are several factors preventing HFS used by AWE from extending beyond the target zone up into an aquifer. Firstly, the target zones are at depth, there is usually 1-2 kilometres of impermeable rock that separates the target zone from the aquifer. The pressure used to fracture the target zone is not sufficient to fracture further than planned.

The fractures are designed based on extensive geological analyses, so that they do not extend out of the target zone. Fractures are controlled and monitored during HFS operations to ensure:

- Environmental protection
- Economic efficiency (an HFS extending beyond the target zone is ineffective, thus targeted fractures are designed)

The geological make-up of the tight sandstones and shales mean that the fractures extend horizontally. When they do extend vertically, it is mostly, but not exclusively, in a downward direction.

Production history data helps demonstrate HFS has been contained sub-surface at each of AWE's HFS treated wells. During HFS treatment of a well, the high pressure, injection process is short lived (hours). The subsequent production phase of that well (over many years), results in bottom-hole pressures lower than the normal in situ pressure. For northern Perth Basin Gas Fields, the reservoir pressure will continue to fall as gas is extracted.

If the fractures induced by the HFS treatment were to connect to a conductive fault or somehow migrate upward into potable aquifers, then hydraulically, the aquifer water would flow into the HFS target zone.

The well's production would be dominated by flow from the connected aquifer by the pressure sink created at the production interval. Hydrocarbon production would effectively cease.

The actual production data of all HFS wells in the northern Perth Basin demonstrates that connection to a portable aquifer has not occurred. Production data is shown within each of the individual case studies

included in this submission. Details of wells treated with HFS in the northern Perth Basin is provided (Table 1) and HFS target zones are shown (Figure 12).

Table 5. Details of wells treated with HFS in the northern Perth Basin within AWE operated production licences

Well	Treatment Date	Operator	Formation	Hydrocarbon Type	Interval Treated (m)	Fluids Pumped		Total Sand Pumped	
						(kL)	(bbls)	(kg)	(lb)
Mondarra-2	Dec-1968	WAPET	Dongara	Gas	2740 - 2736	N/A	N/A	N/A	N/A
Dongara-3	Mar-1974	WAPET	Carynginia	Gas	1638.0-1639.8	N/A	N/A	N/A	N/A
Dongara-9	Apr-1974	WAPET	Irwin River Coal Measures	Gas	1707.2-1726.7	N/A	N/A	14	
Dongara-9	Jul-1984	WAPET	Arranoo A+B	Gas	1500.0-1537.0	146	920	31,818	70,000
Dongara-15	Mar-1974	WAPET	Irwin River Coal Measures	Gas	1684.3-1717.9	N/A	N/A	13,636	30,000
Dongara-15	Mar-1974	WAPET	Carynginia	Gas	1647.7-1672.7	N/A	N/A	13,636	30,000
Dongara-21	Dec-1981	WAPET	Arranoo B	Oil	1589.5-1601.2	134	840	27,273	60,000
Dongara-24	Jul-1985	WAPET	Arranoo A+B	Oil	1451.0-1508.0	144	905	60,455	133,000
Corybas-1	May-2009	AWE	Irwin River Coal Measures	Gas	2514 - 2536	260	1633	71,364	157,000
Senecio-2	Aug-2012	AWE	Dongara/Wagina	Gas	2800 - 2805	197	1241	53,608	117,937
Woodada Deep-1	Aug-2012	AWE	Carynginia - Stage 1	Gas	2370 - 2425	1206	7588	124,505	273,911
Woodada Deep-1	Aug-2012	AWE	Carynginia - Stage 2	Gas	2283 - 2330	956	6012	142,506	313,514

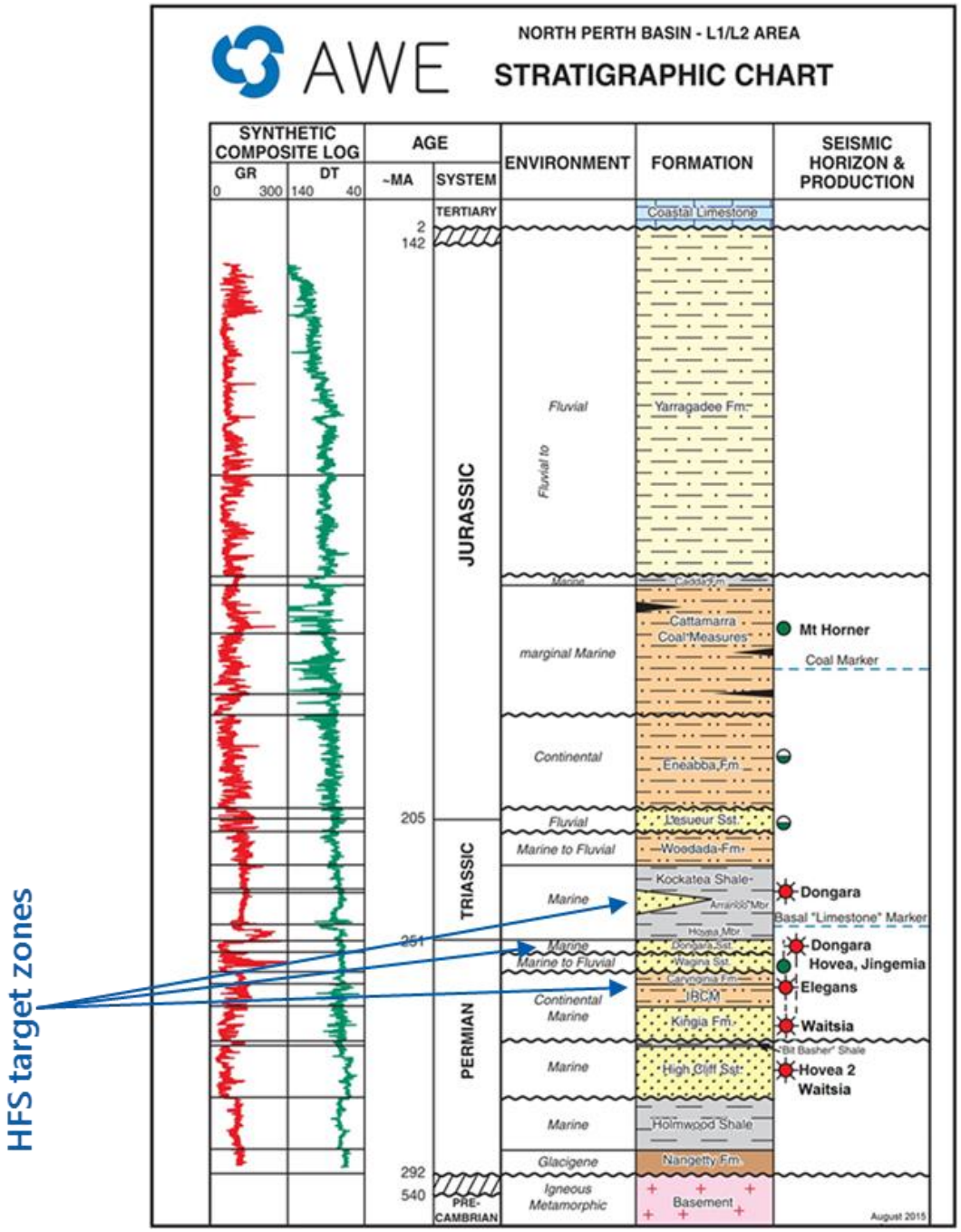

Figure 12. HFS target zones

3.2 Exploration/Appraisal

3.2.1 Case Study Woodada Deep-01 - HFS

The HFS of the Woodada Deep-01 well in 2012 is an important case study of how HFS can be conducted safely and efficiently in onshore Western Australia. The Woodada Deep-01 case study looks at what happened, and the measurements obtained rather than what may or not happen.

The WGF was first discovered in June 1980, with production commencing in May 1982. The area surrounding the field was declared a C-class nature reserve known as Lake Logue Nature Reserve (LLNR) in December 1987 (Figure 13). The reserve is managed by the Department of Biodiversity, Conservation and Attractions (DBCA).

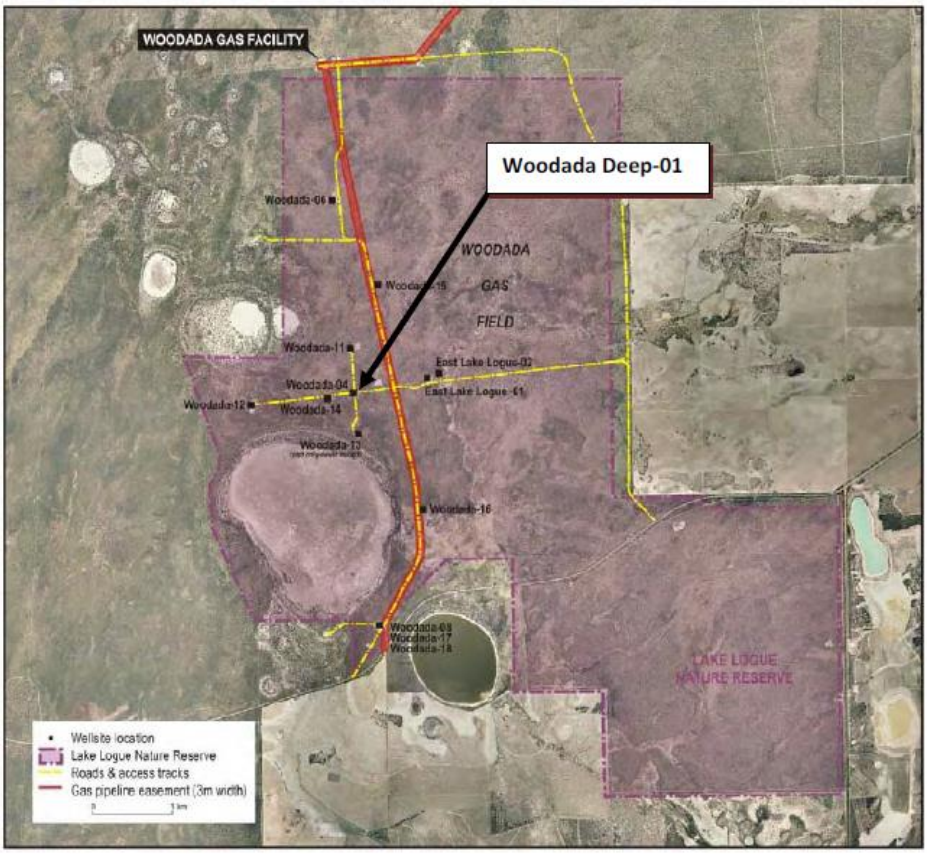

Figure 13. Woodada Gas Field and Woodada Deep-01 location

Since 1980, the WGF has produced some 52.9 billion standard cubic feet of gas (approximately 1.5 billion cubic metres of gas) from the Beekeeper Formation and is currently on care and maintenance.

The Woodada Deep-01 shale gas project which occurred between 2010 and 2012 targeted the shales which lie beneath the Beekeeper Formation. AWE conducted robust data monitoring from the drilling and HFS of the Woodada Deep-01 well.

The baseline studies of water and air quality when measured against post-HFS results proved the safety of AWE's operations. In addition, AWE engaged a specialist company to assess the impact and extent of the HFS process using microseismicity to improve AWE's and wider industry knowledge of the extent and direction of fracture propagation.

3.2.1.1 Environmental Approvals for Woodada Deep-01

The Woodada Deep-01 well was drilled in March/April 2010 and approval for HFS activity was then proposed. A member of the public referred the proposed Woodada Deep-01 HFS activity to the EPA on 7 July 2011. The Level of Assessment was set as 'Not assessed' and the decision was appealed. The Minister of Environment dismissed the appeal on 2 March 2012 (095/2011) on the following basis[31]:

- The proposal was considered 'proof of concept' and the EPA had enough information to make an assessment that HFS activities are unlikely to have a significant impact on the environment

[31] Report to the Minister for Environment, Appeal in Objection to Decision not to Assess, Woodada Deep-01 Hydraulic Fracture Stimulation, Appeal number 095 of 2011, December 2011

- The EPA provided public advice to DMIRS consistent with EP Bulletin "Hydraulic fracturing of gas reserves"
- The EPA was of the opinion, that DMIRS has the capacity and expertise to evaluate the environmental acceptability of HFS proposals and considers HFS activities can be adequately managed by DMIRS.

It was noted by the EPA that they would continue to assess the environmental acceptability of HFS proposals that were referred to it on a case-by-case basis, with consideration given to the individual characteristics and merits of each proposal.

The proposal then proceeded through the DMIRS led approvals processes and was granted approval in May 2012.

Consultation undertaken as part of the approvals process is summarised in the following table (Table 6)[32].

Table 6. Summary of consultation undertaken during Woodada Deep-01 approvals processes

Agency/Authority	Approval Required	Application lodged Yes / No
Department of Mines and Petroleum (DMP), Environment Division, Petroleum Environment Branch	Approval of Woodada Deep-01 Exploration Program Environmental Management Plan (HSE-E-069, Rev 0)	Lodged and approved.
	Approval of Well Intervention Activities Environmental Management Plan [21/HSEQ/ENV/PL01] and Environmental Bridging Document [HSE-E-071]	Lodged and approved.
DMP, Environment Division, Native Vegetation Branch	Issue of Clearing Permit	Clearing Permit (CPS 4209/1) Issued
DMP, Resources Safety Division, Petroleum Safety Branch	Approval of AWE/Halliburton/Third Party HSE MS Bridging Document [HSE-OP-083 Rev 0] and Halliburton Emergency Response Plan Woodada Deep-01, Woodada-14 ST1 and Senecio-02 Well Intervention Activities [ERP-AUST-HAL-HSE-003 Rev 1]	Lodged
DMP Environment Division	Approval of Works Program	Lodged and approved
Department of Environment and Conservation, Environmental Management Branch	Minister for Environment signoff on 15A referral under the Petroleum and Geothermal Energy Resources and advice provided on clearing permit application	Lodged and Minister for Environment signed off on 15A referral Advice on clearing permit provided
Department of Water, Midwest – Gascoyne Region	Advice on Woodada Deep-01 HFS Proposal	Lodged and advice provided
Department of Water, Midwest – Gascoyne Region	Issue of Licence to Construct a Water Bore for W-14 water bore and proposed monitoring bores	Applications lodged and W-14 water bore Licence CAW172884 and monitoring water bore licence CAW173877 issued
Department of Water, Midwest – Gascoyne Region	5C Licence to abstract groundwater	Obtained GWL155753 for abstraction of 32 ML of water
EPA	Third Party Appeal against EPA decision not to assess the Woodada Deep-01 HFS proposal under Part IV of the EP Act	EPA dismissed the appeal

[32] Woodada Deep-01 Hydraulic Fracture Stimulation Supplement to EPA Referral Document [HSE-E-072].

3.2.1.2 Activity Overview - Woodada Deep-01 Exploration Well

The Woodada Deep-1 exploration well, drilled in March/April 2010, was a deepening of the Woodada-4 well. It was part of the Woodada Deep 01 shale gas project targeting the shales which lies beneath the Beekeeper Formation. Drilling and extraction of core samples occurred over a 27-day period in 2010 to reach the target depth of 2,552 metres.

Cores taken from the drilling indicated that the middle interval of the Carynginia Shale alone could potentially hold a significant Gas in Place. As a result, AWE successfully applied for permission from DMIRS (then DMP) to hydraulically fracture two zones of interest.

The key activities for the Woodada Deep-01 HFS included[33].

- Modifications to the existing wellsite area to ensure the site is capable of supporting the WIA equipment
- Mobilisation of equipment, personnel and supplies
- Set plug in Bottom Hole Assembly and cement to isolate on Woodada-14 via wireline
- Cement bond log on Woodada Deep-01 via wireline
- Pressure test Woodada Deep-01 wellhead
- Pressure test Woodada Deep-01 casing, perforate and conduct Diagnostic Fracture Injection Test
- Woodada-14 microseismic monitoring
- HFS and flowback with coil tubing
- Demobilisation of equipment, personnel and supplies
- Restoration of the site following the completion of activities

In July 2012, AWE successfully hydraulically fractured two zones with the Woodada Deep-1 well, targeting the Middle Carynginia (2,370 to 2,425 metres) and Upper Carynginia (2,283 to 2,330 metres) shale formations (Figure 14).

[33] HSE-E-071 and Well Intervention Activities Annual Environmental Report June 2011 to June 2012 [AWE0708REP] and June 2012 to June 2013 [AWE0816REP].

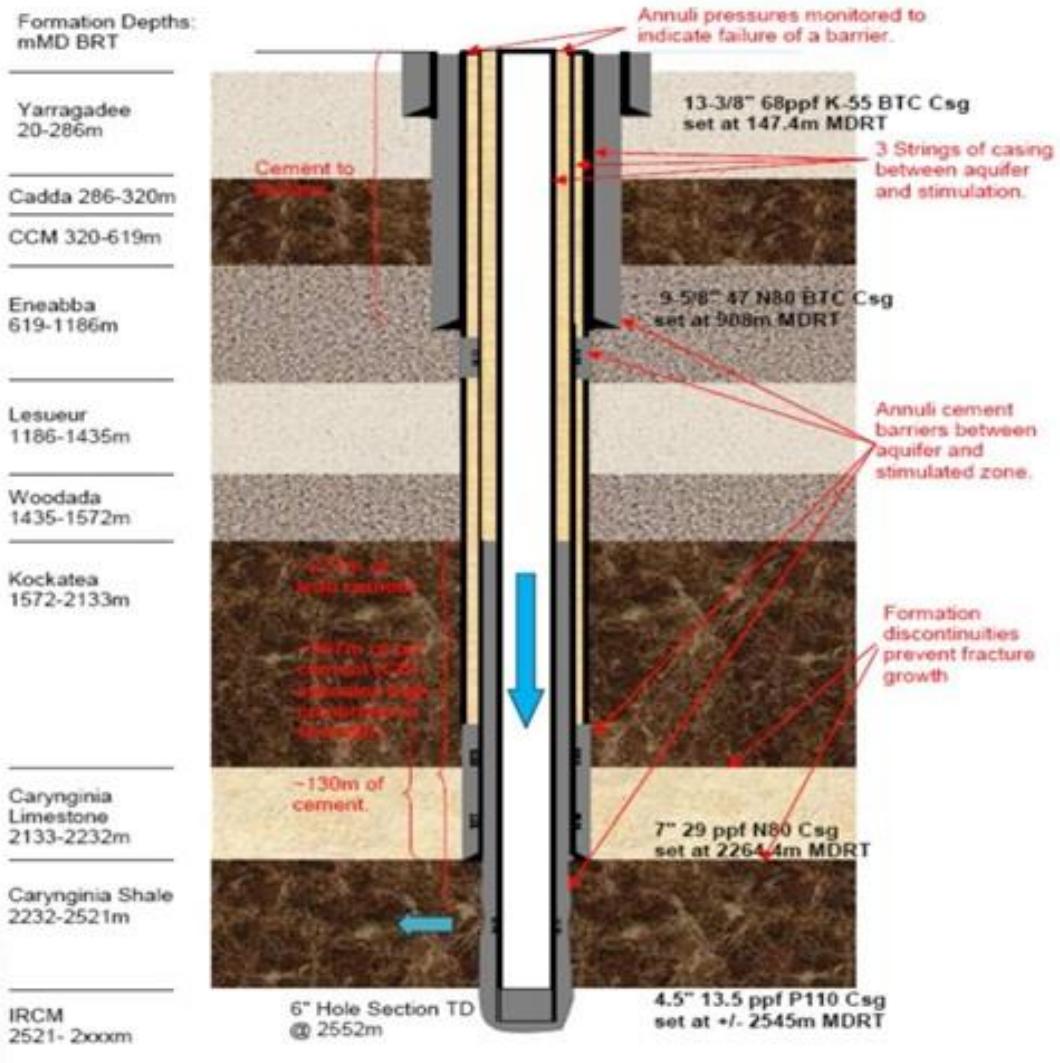

Figure 14 Woodada Deep-01 Cross Section

Commercial flows of gas were not obtained, however, and the well remains on care and maintenance.

3.2.1.3 Environmental Management

The environmental management of all aspects of the Woodada Deep-01 HFS activities were managed under the approved Onshore North Perth Basin Well Intervention Activities Environmental Management Plan[34].

Rehabilitation completion criteria were developed for the Woodada Deep-01 site by an independent botanical consultant[35]. This consultant had undertaken surveys and rehabilitation activities in the nature reserve for over six years and had rehabilitation experience for more than 20 years with the local mineral sand mines. The completion criteria was reviewed, commented on and approved by DBCA. The completion criteria include aspects associated with decommissioning, landform, vegetation, weeds, keystone and priority species.

[34] 21/HSEQ/ENV/PL01 and Woodada Deep-01 Hydraulic Fracture Stimulation Environmental Bridging Document [HSE-E-071].

[35] Woodada Deep-01 Completion Criteria February 2017 AWE11-51-01 Rev 1.

A clearing permit for less than 3 ha was approved by DMIRS Native Vegetation Branch based on the independent consultant's assessment of the proposal against the clearing principles. The cleared area totalled 0.8 ha.

A desktop study was undertaken by Rockwater[36] to:

- Determine the hydrostratigraphy and aquifers in the area
- Discuss the aquifer connectivity in the area
- Identify groundwater users, locations of production bores and their aquifers
- Identify potential risks to the groundwater resources in the area from HFS
- Recommend suitable hydrogeological monitoring to be undertaken within the project

The existing WGF Licence to Take Water [GWL155753] had an entitlement of 32 ML however, only the anticipated volume required for the activity was consumed (4 ML)[37].

The environmental impact assessment of the Woodada Deep-01 HFS was incorporated into the Well Intervention Environment Management Plan (WIA EMP) and was not a standalone document. The risks identified and managed under the WIA EMP were implemented to minimise the impact of the activity on the environment. This included the following aspects identified in the Well Intervention Activities Environmental Management Plan[38]:

- Groundwater Protection
- Native vegetation
- Fauna and fauna habitat
- Soil disturbance
- Impact to existing infrastructure and services
- Equipment integrity
- Disturbance of indigenous heritage sites
- Disturbance of heritage sites
- Noxious weeds and vermin, dieback, exotic species, flora and animal diseases
- Local traffic
- Noise (wildlife, local residents, adjacent activities)
- Visual amenity
- Facility lighting
- Materials handling
- Gas release
- Hydrocarbon liquid release
- Flaring
- Waste Disposal
- Rehabilitation

[36] "Woodada Deep-01 Well Aquifer Connectivity Report" [387.0/11/01].

[37] "End of Well Intervention Activity Environmental Report [21/HSEQ/ENV/PL01/FM01 Woodada Deep-01 8th September 2012].

[38] Well Intervention Activities Plan AWE:21/HSEQ/ENV/PL01.

The post activity monitoring of nearby soil quality demonstrates that there has been no soil contamination from activities associated with the Woodada Deep-01 well. The LDPE (double) lined Woodada Deep-01 retention pond, within a nature reserve, temporarily stored flowback fluids from the HFS activity. Results from two years of groundwater monitoring and soil sampling during remediation activities verified that the pond had successfully contained flow back fluids.

AWE remediated the Woodada Deep-01 pond in March 2015 and contracted an independent environmental consultant to complete soil validation sampling below the liner to confirm no contamination had occurred (Figure 15). The results indicated that there were no detections of hydrocarbon contaminants (BETXN/TRH) above the adopted screening levels. The majority of the results returned values that were below the laboratory detection levels[39]

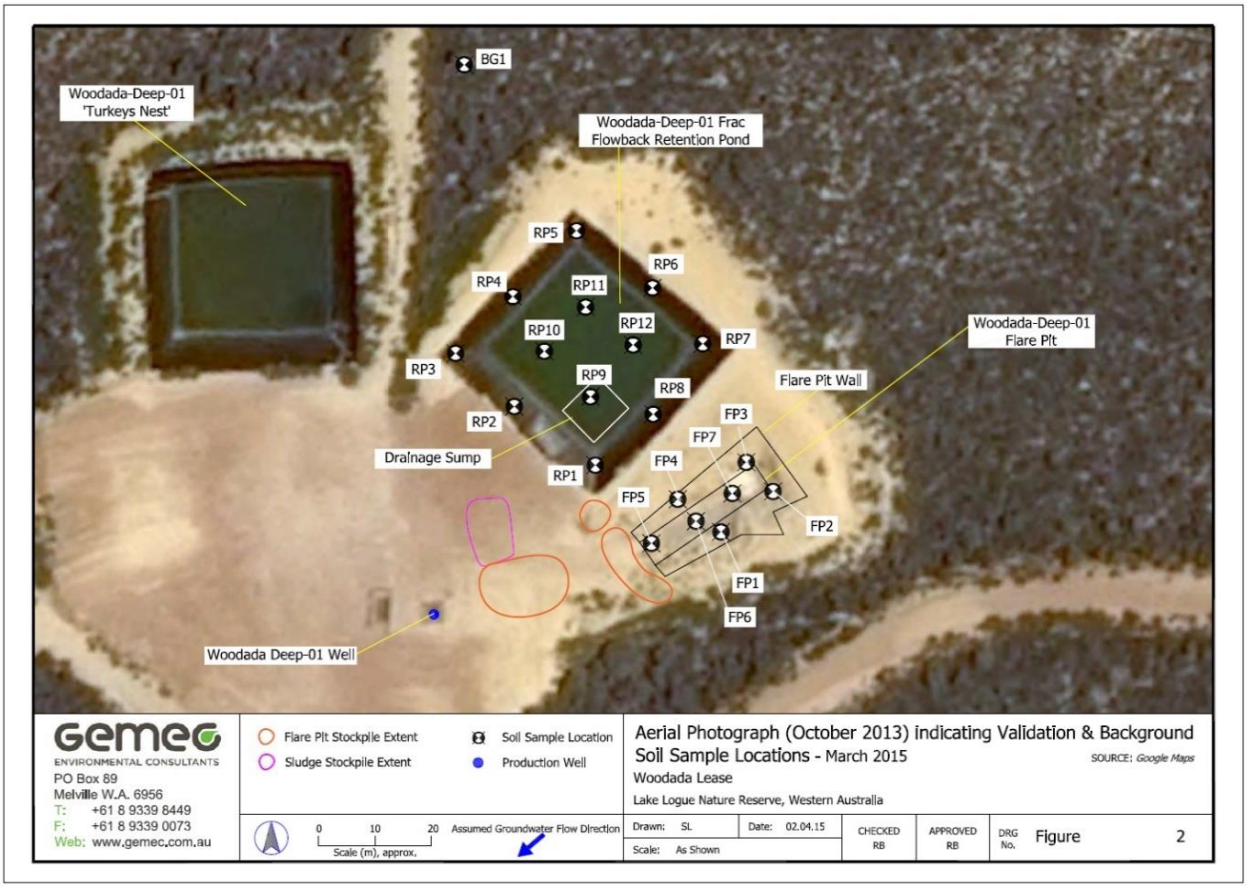

Figure 15. Woodada Background Soil and Validation Sampling Locations (Note: freshwater "Turkey's Nest" marked)

3.2.1.4 Land

The Woodada Deep-01 flora community is heath dominated by *Banksia attenuata* and *Melaleuca leuropoma* with emergent *Banksia prionotes*, *Banksia menziesii* and *Eucalyptus todtiana* on yellow sand (AWE11-51-01). The area cleared consisted of Carnaby's Black Cockatoo foraging habitat[40]. The completion criteria requires the emergence of *Banksia elegans*, a priority 4 species found on the Woodada Deep-01 site. No Declared

[39] Retention Pond & Flare pit Decommissioning Soil Assessment Report, Gemec Environmental Consultants, March 2015

[40] Woodada Deep-01 Level 1 Vertebrate Fauna Assessment, February 2011, ecologia, 2011

Rare Flora (DRF) were identified, the priority flora *Banksia elegans* (P4) was recorded throughout the survey area.

Based on the results of database searches and a review of surveys previously undertaken in the area, the potential native fauna of the survey area comprises 19 native and 9 introduced mammal species, 190 bird species, 79 reptile species, and 13 amphibian species. Of these, 33 are species of conservation significance. However, only ten conservation significant species have a medium to high likelihood of occurrence within the proposed clearance area, including 1 mammal, 6 birds, and 3 reptiles[40].

Desktop and reconnaissance survey have found that due to the small size of the survey area and the presence of similar surrounding habitat, little impact to species of conservation significance is expected from the proposed project[40].

AWE cleared 0.8ha (out of 3 ha clearing permit) by utilising the existing Woodada-04, Woodada-14, Top Hill and East Lake Logue-01 cleared areas for some of the activities (1 ha saving). The central WGF intersection was widened to remove the need for a turnaround area. Monitoring bores were placed on cleared areas with established access points. A freshwater pond was placed at Woodada-14 and a PVC pipe run to the Woodada Deep-01 site.

Fill material (ie gravel for laydown areas and track maintenance) from within the WGF was utilised to prevent import of dieback affected material from offsite. The gravel, from the existing gravel pit 5, was tested by the Department of Agriculture to determine if the gravel was pathogen free prior to use. Topsoil was stockpiled for later rehabilitation.

The proppant brought on site was sourced from Western Australia and sieved and heat treated to ensure that it would not transfer any weeds or pathogens.

A Weed and Dieback Hygiene Procedure[41] was in place for the HFS campaign and required that all machinery and equipment brought into the WGF was inspected and cleaned to remove all vegetation, seeds and soil material. Vehicles and equipment were rechecked at a quarantine station located on the main WGF access track adjacent to the East Lake Logue-01 well site (existing clear area). The quarantine station consisted of a large containment bay draining to a holding tank and a treatment tank. Treated wash down water was released to well pad drainage point. The site was manned 24 hours/day during HFS operations.

All equipment was placed on prepared areas only. Vehicles remained on access tracks and designated parking areas.

AWE maintains the access track / DBCA firebreak network applicable to AWE operations in the LLNR. This includes weed spraying and grading activities. This work allows DBCA access for management of fires in and around LLNR. During rehabilitation of the Woodada Main Camp, AWE created an access track to a water tank that AWE no longer required to be used for DBCA's fire management activities. The Woodada Deep-01 HFS activity was conducted outside of the restricted burning period, minimising the area of clearing required.

[41] Weedback and Hygiene Procedure Woodada Deep-01 [21/HSEQ/ENV/PL01/WI01]

The process undertaken for rehabilitation at Woodada generally comprises the following:

- Develop rehabilitation plan
- Decommissioning the hydrocarbon well
- Decommissioning the groundwater bore (unless DBCA would like to retain)
- Order keystone species seed
- Removal of all waste and infrastructure remaining on site
- Clear well pad and areas around well pad where vegetation has encroached, and landform requires reinstatement
- Recovering all gravel on site to Gravel Pit 1 or utilising immediately for maintenance of the access track network
- Mulch and stockpile any cleared vegetation for future spreading over rehabilitated area
- Recover any stockpiled top soil
- Reinstate pre-drilling landform
- Spread any stockpiled top soil
- Spread mulch material
- Hand scatter seed mix
- Apply fertiliser prior to break of season
- Spot spray any weeds regularly
- Monitor annually for three years
- Determine if intervention is required if completion criteria are not achieved within three years

3.2.1.5 Air

AWE also retained Gemec Environmental Consultants (Gemec) to undertake monitoring, testing and reporting of air quality around the HFS fluid retention ponds to ascertain any impact on surrounding air quality, and therefore on native flora and fauna populations.

The consultant was responsible for installing the sampling equipment and providing independent analysis of the chemical characteristics of the vapour emissions. Samplers were installed at each of the four corners of the retention pond. The samplers were placed on custom made stainless steel tags and housed within galvanised steel cowls to protect them from inclement weather. The readings were conducted immediately after HFS flowback fluids were deposited in the retention pond and up to three months later.

Gemec compared the Woodada Deep-01 site test results to a set of reference locations which included a remote rural area, an industrial centre with high traffic density and refuelling a car at a service station. The comparison indicates that the concentrations reported at the Woodada Deep-01 site are considered to be minor compared to those reported at the reference locations. These included a remote rural area, an industrial centre with high traffic density and refuelling a car at a service station [42](Figure 16).

[42] Retention Pond Air Sampling - Woodada Deep-01 letter report, Gemec Environmental Consultants, November 2012

	Compound			
Location	Benzene	Toluene	Ethylbenzene	Xylenes
Woodada Deep-01	*0.51*	*0.59*	*1.01*	*0.22*
Remote rural area	**0.2 – 16**	**0.5 – 260**	**0.2 – 1.6**	**<0.1 – 3**
Industrial centre with high traffic density	Up to **349**	Up to **1,310**	Up to **360**	Up to **775**
Refuelling a car at a service station	Up to **10,000**	Up to **9000**	–	–

Notes: concentrations reported in micrograms per cubic metre ($\mu g/m^3$)
Source of data: ATSDR, IPCS, NTP

Figure 16. Air quality comparison - remote rural, industrial and service station

Gemec concluded:

> "Given the generally minor to trace concentrations reported (at or marginally above the limit of reporting, the vapour emissions emanating from the flowback fluid contained in the retention pond do not present an adverse risk to native fauna in the vicinity. The wind dispersion factor would further reduce concentrations away from the immediate vicinity of the retention pond.
>
> In a human health context, a comparison of the benzene, toluene, ethylbenzene and xylene concentrations reported during the sampling programme with the ATNEPM MILs* and those reported in various settings indicate that the concentrations reported at the Woodada site are negligible and do not pose an adverse risk to human health."
>
> *ATNEPM MIL – Air Toxic National Environmental Protection Measure Monitoring Investigation Level

3.2.1.6 Water

AWE typically plans to use between approximately 4,000-6,000kL of water, for drilling a traditional vertical well. This amount includes the water for the camp and drilling operations.

To put this into perspective that is the equivalent of two-and-a-half Olympic-sized swimming pools. For example, the drilling and HFS of AWE's Woodada Deep-01 well used 0.034% of the total allocation of water extraction for this specific activity from the Lesueur Aquifer.

Gemec was also engaged by AWE to conduct the water quality monitoring and advise on potential groundwater contamination risks.

The monitoring bores that were the subject of Gemec's evaluation accessed the Yarragadee formation located at approximately 20 to 286 metres below ground surface.

The consultant analysed water obtained from the HFS fluid flowback retention ponds as well as water from two existing water bores and three purpose designed monitoring stations at varying distances from the Woodada Deep-01 well head (Figure 17). It is important to note that, these ponds were double LDPE lined to prevent leakage into groundwater and double fenced.

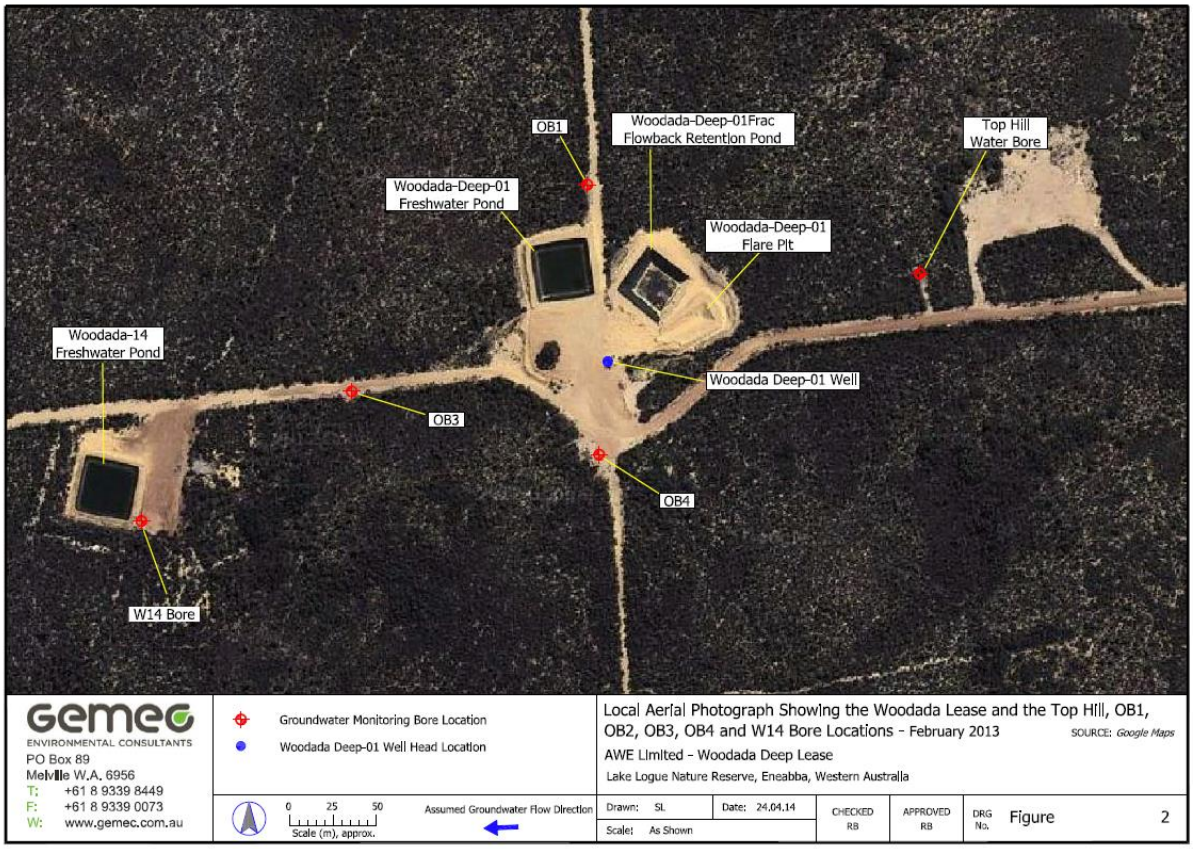

Figure 17. Woodada-Deep 1 groundwater monitoring locations

Gemec concluded that a comparison of the data against previous groundwater monitoring events indicated that the HFS operations have had no discernible influence on groundwater conditions in the vicinity of the Woodada Deep-01 site[43]. No chemical of potential concern was identified that had the potential to present a risk of harm to the environment.

AWE was licenced to extract 32,000kL of water from a superficial aquifer to hydraulically fracture its Woodada Deep-01 well. However, AWE used less than 5,000kL. AWE's use represented less than 0.034% of total annual superficial aquifer use with the state having allocated 14,600,000kL for use in 2012.

AWE did not HFS the well for commercial production and so has used less than 5,000kL.

3.2.1.7 Woodada Deep-01 HFS Treatment Monitoring Results

Woodada Deep-01 HFS treatment was conducted in July 2012 by AWE. The target zone was the Carynginia Shale over two intervals:

- Stage 1 - 2,370m to 2,425mMDRT, 273,973 lb (124.5 tonne) with 1,207 m3 fluid – slickwater/linear gel system
- Stage 2 – 2,283m to 2,330mMDRT, 313,514 lb (142.5 tonne) with 956 m3 fluid – slickwater/linear gel system

[43] Groundwater Monitoring Event Report for AWE Ltd Woodada Deep-01 Well Site, Gemec Environmental Consultants, January 2014

Gas flow was observed immediately after the composite plug between Stage 1 and Stage 2 was drilled out (Figure 18). The well flowed ~50,000scf/d under nitrogen lift and well head gas samples indicated methane presence. The low gas production was deemed sub-commercial.

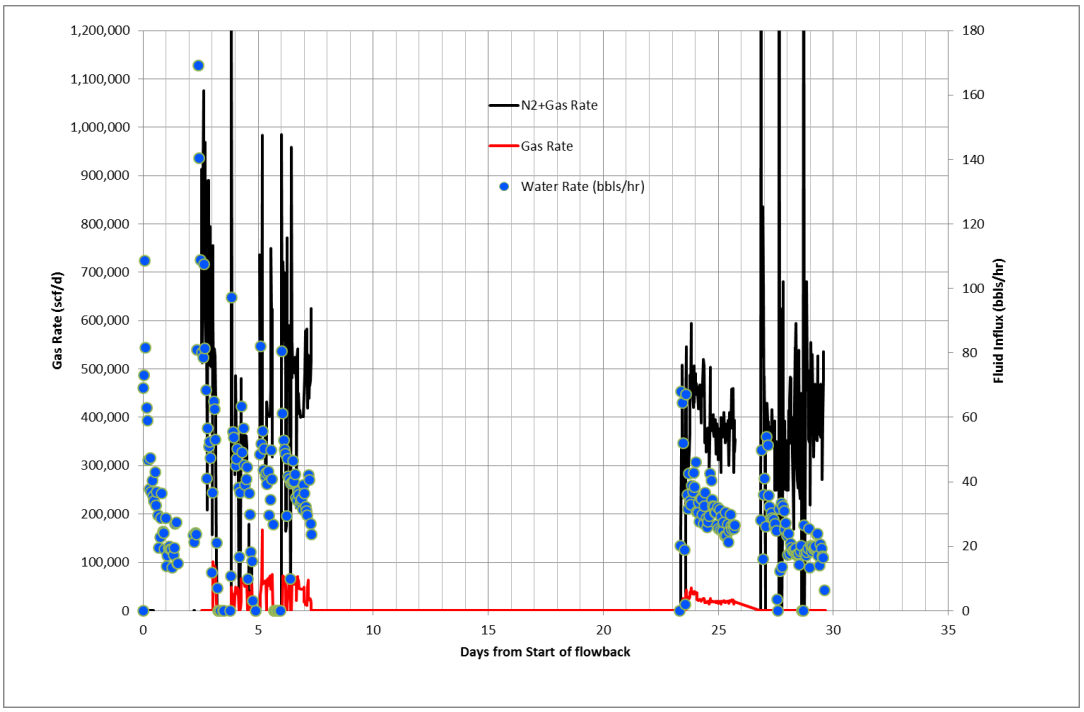

Figure 18. Woodada Deep-01 Well Test Results

3.2.1.8 Microseismic Testing Showing HFS Containment to Target Interval

AWE contracted Pinnacle, a leading provider of fracture mapping and reservoir monitoring services, to undertake microseismic testing during the HFS operation.

Pinnacle was primarily contracted by AWE to undertake HFS efficiency diagnostics to maximise completion efficiency and production economics for future HFS programs at Woodada Deep-1 and/or future wells.

The testing also provided valuable information on the scale and location of microseismic events from HFS which can be used to interpret the safety of HFS by providing evidence of containment to the target interval. Details of the mapping layout and equipment are shown in (Figure 19, Figure 20, Figure 21 and Figure 22).

Figure 19. Woodada Deep-01 microseismic Mapping Project Setup (aerial view)

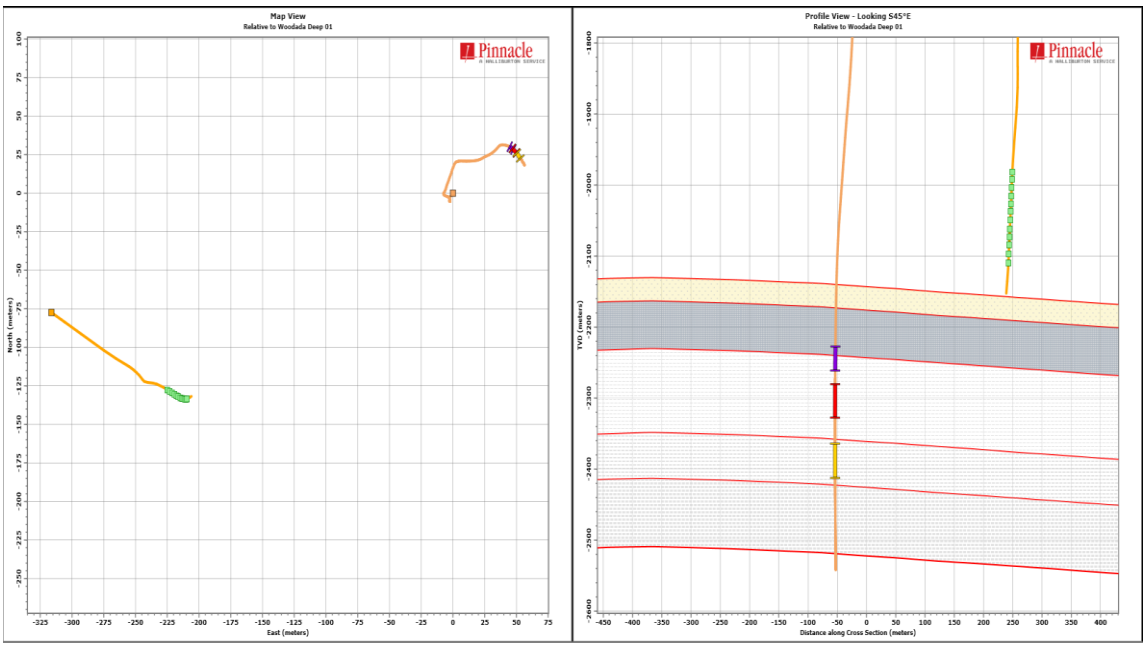

Figure 20. Mapping Project Setup

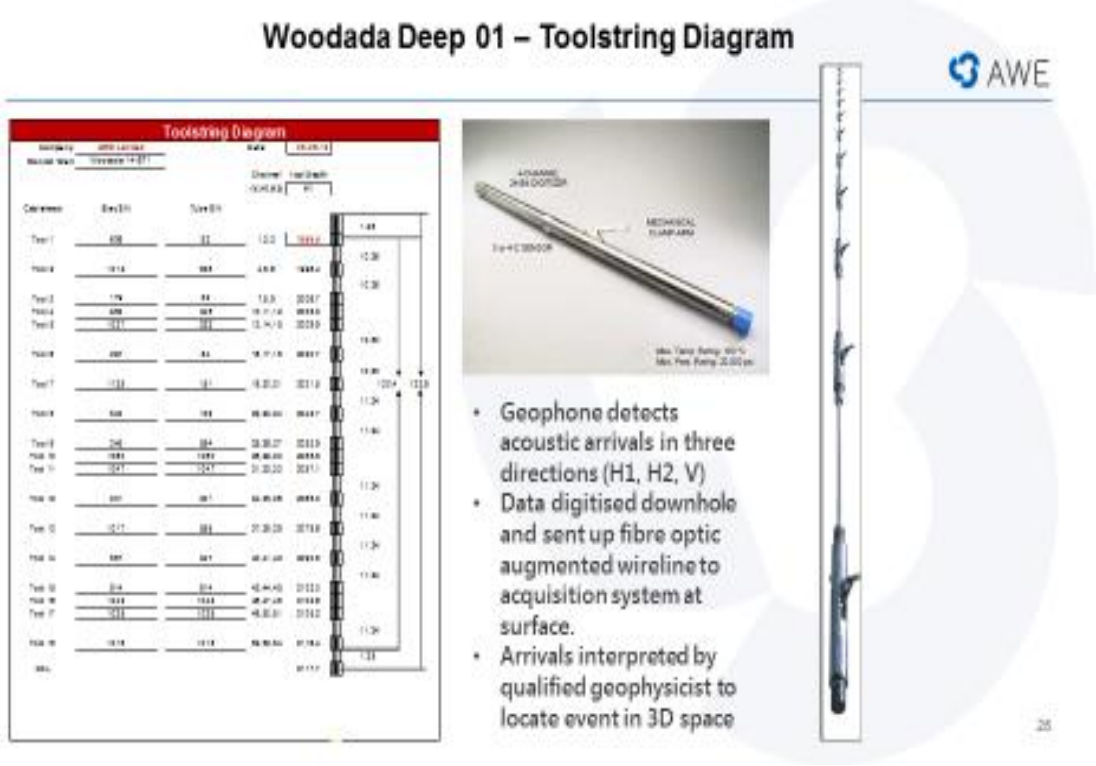

Figure 21. Microseismic Mapping - Toolstring Diagram

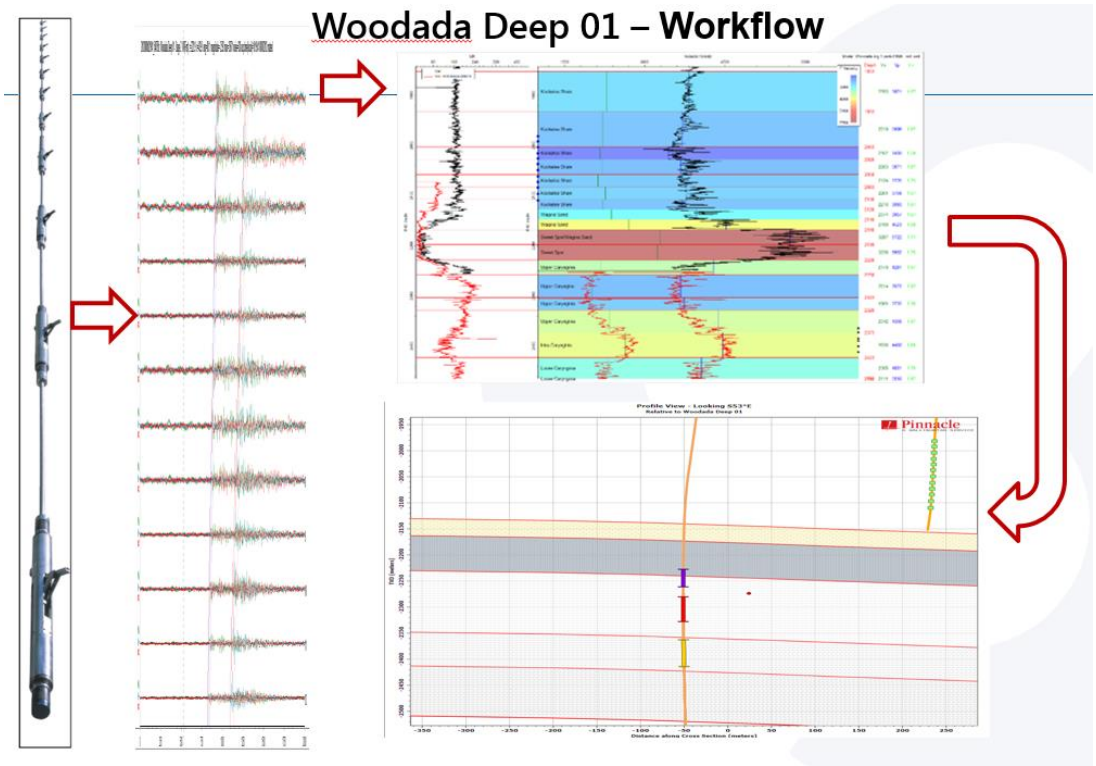

Figure 22. Woodada Deep 01 - Microseismic Mapping Workflow

Based on the results, Pinnacle reported three significant observations[44]:

- Contamination of the aquifer by HFS fluid is unlikely due to the significant distance between fracturing zone and the aquifer.
- The shallowest (closest to surface) mapped event was 700 metres in vertical distance away from the base of the closest known saline aquifer known as Lesueur Sandstone. The aquifer is 1,186 to 1,485 metres deep and due to its saline nature is not used for human or stock consumption.
- All events showed seismic moment magnitude between -3.0 and -1.9, which is typical for HFS treatments
- The smallest moment magnitude that can be felt by a person at surface is around 2.0 to 3.0. Each unit in moment magnitude is 30 times larger than the one before. Therefore, the largest events detected during the HFS at Woodada Deep-01 are ~27,000 times smaller than the smallest size of event that could be detected at surface. This is 729 million times smaller than the earthquake near Newcastle, NSW in 1989 which is the smallest known earthquake in Australia to have caused fatalities.
- In mapped events with abnormally high moment magnitude no linear "out of zone" features were recorded. Based on this analysis, it is likely that all events were contained within the targeted Carynginia section.

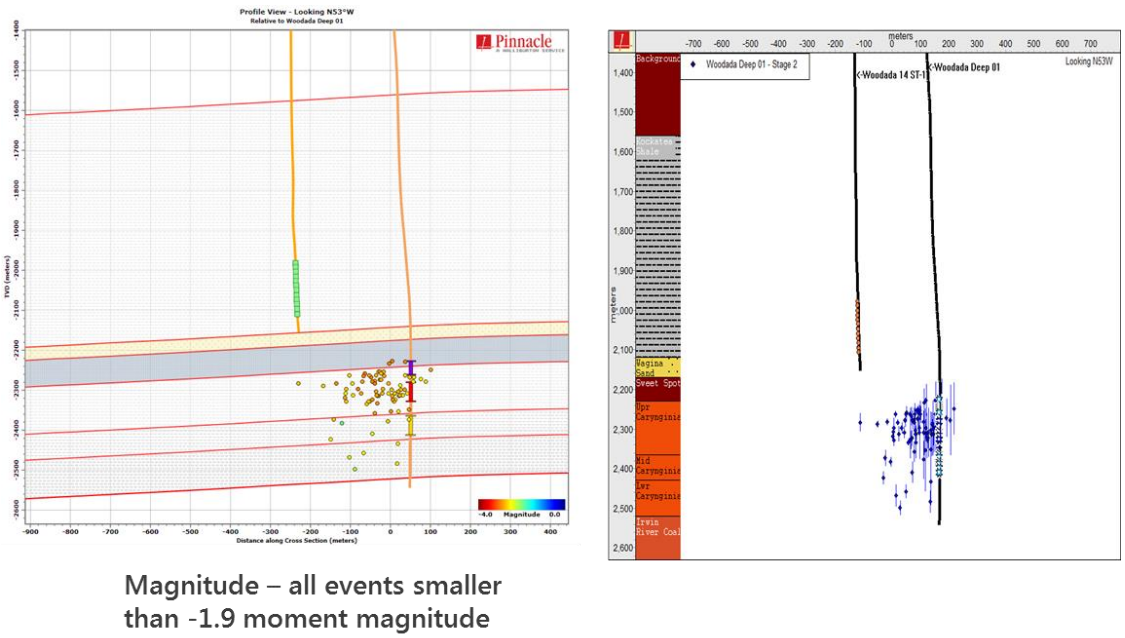

Figure 23. Microseismic mapping results

3.2.1.9 Amenity and Aesthetic Enjoyment

Lake Logue Nature Reserve continued to be available to the public for recreational amenities, aesthetic enjoyment and other activities during the petroleum activities, except for the specific area of activity. The footprint of the well site was only 0.8 ha and the duration of the activity was for forty days intermittently. Access tracks in the reserve continue to be available for use.

[44] Microseismic Fracture Mapping report Woodada Deep-01 2011, Pinnacle 2011

3.2.2 HFS - Senecio-02

AWE self-referred the proposed Senecio-02 HFS to the EPA on 26 September 2011. EPA set the level of assessment as 'Not assessed' on 24 October 2011. This decision was appealed in November 2012. The Minister for Environment dismissed the appeal on 2 March 2012.

Approvals continued under the DMIRS led approvals processes which were finalised 30 May 2012. The environmental management of all aspects of the Senecio-02 HFS activities were managed under the approved Onshore North Perth Basin Well Intervention Activities Environmental Management Plan [21/HSEQ/ENV/PL01] and Senecio-02 Hydraulic Fracture Stimulation Environmental Bridging Document [HSE-E-070].

Agency/Authority	Approval Required	Application lodged Yes / No
DMP, Petroleum Environment Branch	Approval of Well Intervention Activities Environmental Management Plan [21/HSEQ/ENV/PL01]	Lodged and approved
DMP, Petroleum Environment Branch	Environmental Bridging Document [HSE-E-070-Revision 1]	Lodged. DMP requested additional information.
DMP Environment Division	Approval of Works Program	To be lodged and approved
DoW, Midwest – Gascoyne Region	5C Licence to abstract groundwater	Obtained GWL173435(2) for abstraction of 10 ML of water
Environmental Protection Authority	Approval under Part IV of the EP Act	Lodged and approved.

3.2.2.1 Activity Overview

HFS was conducted in August 2012 by AWE. The target zone was the Dongara Sandstone over the interval 2800m to 2805mMDRT. A single HFS treatment was conducted (118,000 lb (53.63 tonne) 20/40 proppant pumped with a water based Hybor G crosslinked gel system).

Production improvement data indicates the HFS treatment has stayed within the target zone (Figure 24).

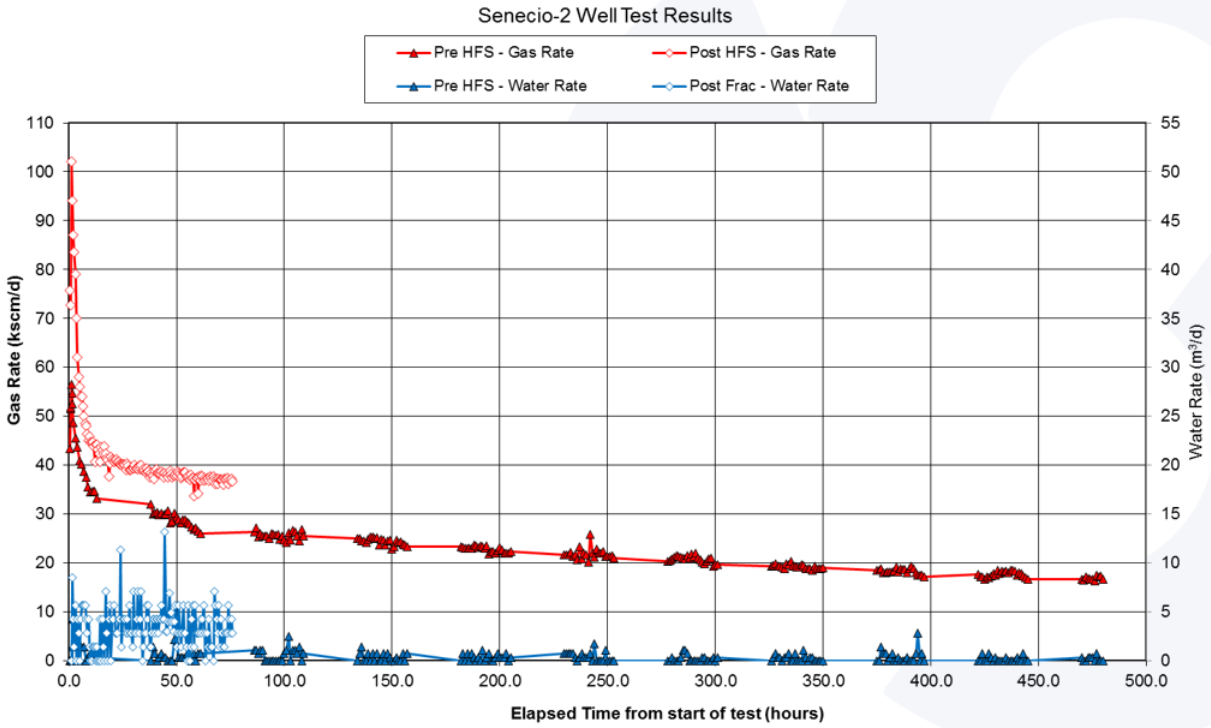

Figure 24. Senecio-02 Well Test Results

Pre and post HFS well tests were conducted on Senecio-02 well with no long term production test.

3.2.2.2 Land

From September 2012 to January 2013 Gemec was retained by AWE to provide independent analysis as to the chemical characteristics of the flow back fluid within the retention pond and provide advice on potential risks and disposal options of the retained fluid. It was found that the risk to human health, the environment or any environmental value from the flow back fluid remaining in the retention pond as of November 2012 was negligible and did not pose an unacceptable risk[45].It was recommended that the flow back fluid be allowed to evaporate over summer and any residual sludge remaining be disposed of at a licenced landfill facility. Removal and disposal of the residual flow back fluid sludge and the liner occurred in February 2013. No BTEX, TRH C10-C40 fractions, MTBE, PAHs or phenols were detected above the laboratory Limit of Reporting (LoR) in any of the soil validation samples collected from below the retention pond.[46]

3.2.2.3 Water

The Senecio-02 well site is located on private farm land in the Shire of Irwin. Prior to undertaking the HFS activity AWE engaged Gemec to complete baseline groundwater sampling. The three bores that the consultants collected samples from were the Senecio bore (located ~180m south), Milo Road bore (located ~1.4 km south east) and Hunts Road bore (located ~1.55 km west). The site setting and location of the monitoring bores (ie Senecio, Milo Road and Hunts Road) are presented in the attached (Figure 25).

[45] Retention Pond Water – Senecio-02 Well Site (Letter Report), Gemec, 2012,

[46] Flare Pit Decommissioning Soil Assessment Report for AWE Ltd Senecio-02 Well Site, Gemec Environmental Consultants, March 2015 – June 2017

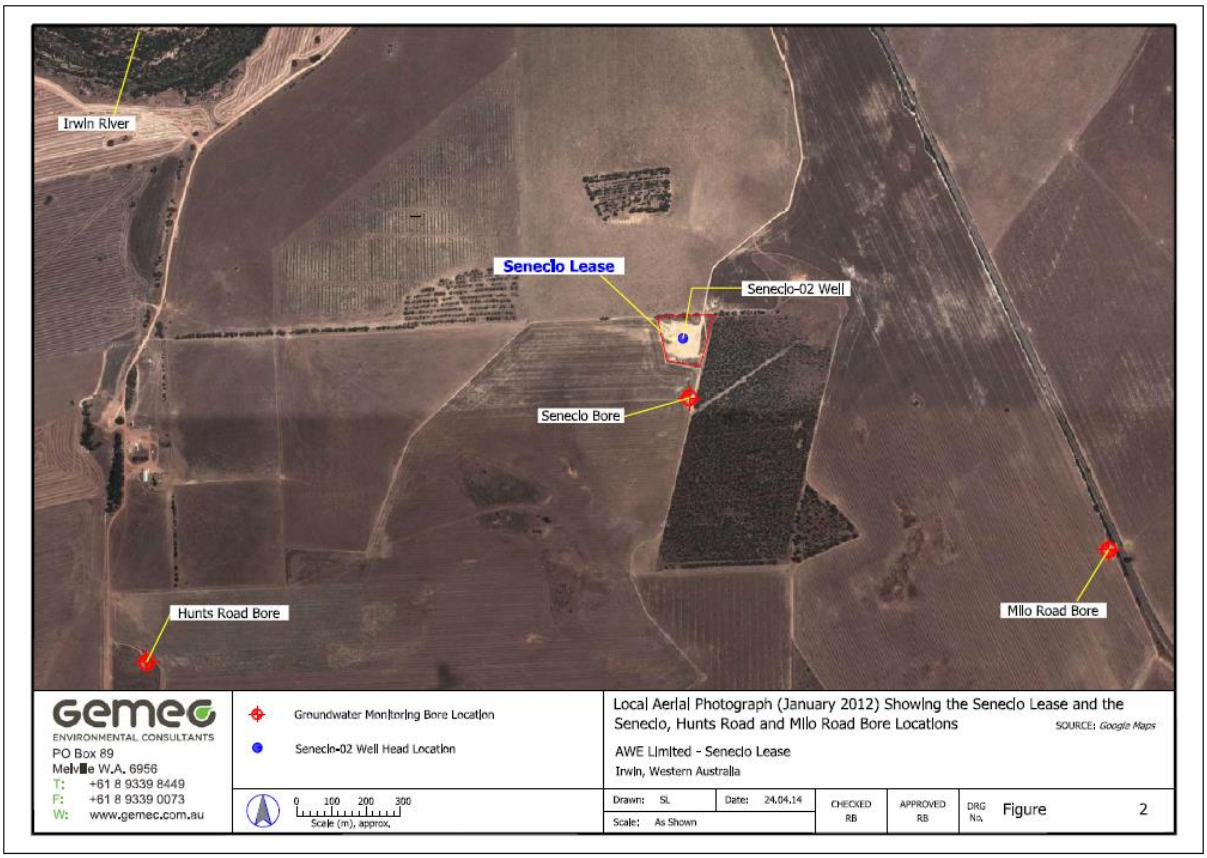

Figure 25. Senecio-02 Monitoring Bore Locations

Gemec monitored the three bores on a six-monthly basis for a period of two years post HFS.

Gemec concluded that a comparison of the data against pre and post HFS Groundwater Monitoring Events indicates that the Senecio-02 HFS activities have not adversely affected the unconfined superficial aquifer and that the groundwater analytical results obtained are generally considered to represent background conditions.[47]

3.2.2.4 Aboriginal Heritage

Heritage surveys and archaeological surveys were undertaken during Senecio-02 drilling planning stages of to avoid any identified sensitivities.

3.2.2.5 Amenity

The question of HFS impact on agricultural property price has been raised as a concern by some groups. AWE's experience is that the onshore activity, including HFS, has not negatively impacted local property prices. In 2014, two years after HFS at Senecio-02, the Irwin Park Farm, a well-established broad acre private farming business, was put on the market and sold promptly. AWE purchased the property and then leased it to another well-established local, family owned agricultural business. Since then AWE has received offers to purchase the property (comparable with the market pricing for equivalent properties in the region) and has regularly received enquiries from interested purchasers when the property has not been on the market. AWE has an excellent relationship with the tenant who is well recognised for successfully increasing farm

[47] Groundwater Monitoring Event Report for Senecio-02 Well Site, Gemec Environmental Consultants, January 2014

productivity. This is a good example that onshore development, including HFS, has not negatively impacted the property value.

3.2.2.6 Social Surrounds

The Senecio-02 site is located, in a paddock on Irwin Park Farm, which was then owned by a local, well established farmer. The landowner continued his agricultural activities without interruption while the drilling, HFS and flow test occurred. The well is shut-in under care and maintenance and the HFS has been removed and the pond site remediated.

The well site is approximately 2.3 km from the Irwin townsite. Despite the HFS pumps being a potential noise source, no complaints were received while HFS was underway and no complaints were received during the ensuing flow test which was conducted in September 2012.

The response to the Senecio-03 well flow test, which was conducted during July 2015 was markedly different. The well, which although approved for HFS was not treated, lies approximately 3.5 km from the Irwin townsite. Several Irwin townsite residents, although not the nearest neighbours, complained about noise, odour and vibrations from the flow test. Following the initial contact, AWE immediately halted the flow test and met with residents the following day. AWE then commissioned an independent assessment by Aurora Environmental, to better understand the issues raised and use for planning future well test activities. The investigation found that due to meteorological conditions, residents could have been disturbed during some nights of the flow-test and made recommendations for noise management improvements. However, the investigation found no scientific basis for reported vibrations or odour emissions. This result was consistent with reports from other nearby residents who said they had not experienced these impacts. A copy of the investigation is provided in Appendix C.

Baseline noise monitoring is now undertaken during well planning stages of drilling and flow-test and submitted with approvals requests for regulatory assessment. Noise mitigation measures are routinely factored into project design and during operations, hand-held noise monitoring equipment used during flow-test. Local residents are briefed prior to any flow-test occurring, and contact is maintained during flow testing activities. Since 2015, AWE has conducted four flow tests, noise levels were within acceptable regulated levels and AWE did not receive any complaints.

3.2.3 HFS – Drover-01

3.2.3.1 Activity Overview

The Drover-01 exploration well, located in cleared agricultural land adjacent to Lesueur National Park (Figure 26) approximately 220 km north of Perth. The well was spudded on 29 June 2014 and drilling reached a total measured depth of 2356 m on 22 July 2014. A Diagnostic Injection Fracture Test was conducted in July 2015. However, the test results indicated the gas resource was sub-economic and the approved HFS treatment did not proceed. The well was decommissioned during October 2015 and rehabilitated in May 2016.

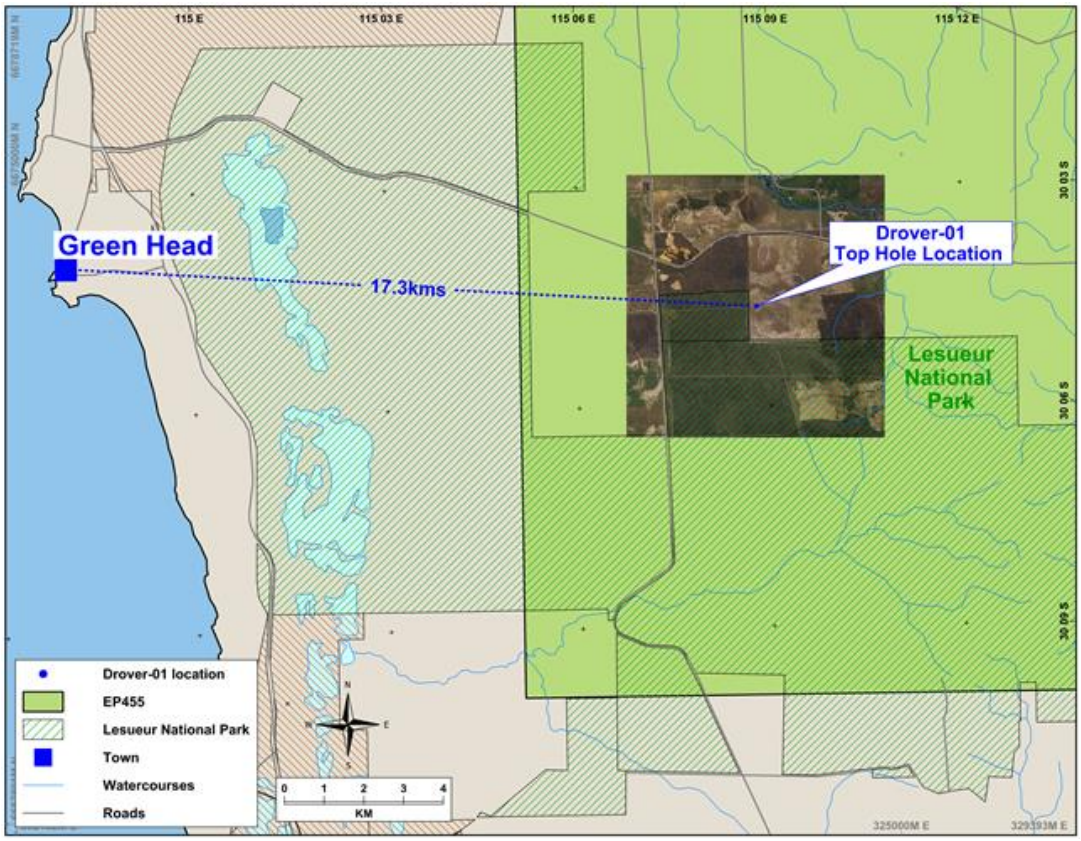

Figure 26. Map of Drover-01 location in relation to local sensitivities

3.2.3.2 Environmental Approvals

AWE referred the proposed Drover-01 drilling and HFS to the EPA on 24 September 2013. The EPA set the level of assessment as 'Not assessed' on 13 November 2013. An appeal was lodged against the proposal on 2 December 2013 with the final Ministerial Appeal Determination being issued 11 February 2014.

Approvals continued under the DMIRS led environmental approvals process which were finalised when the EP was approved on 16 April 2014. A summary of the key risks and management controls outlined in the EP is provided in Table 7 and a summary of the consultation undertaken during the planning and approvals process is provided in Table 8.

As shown in Table 7, the highest risk identified by AWE and Department of Water (DoW) was the potential impacts of surface spillage of chemicals or diesel fuel on water resources, including the two local water reserves. The Mountt Peron borefield, which provides drinking water to two coastal settlements is located approximately 4 km away from the well site. The Leeman (Midway) Water Reserve, now used as an emergency source as it is low yielding, has a lower water quality to the Mt Peron water reserve bore and greater risk from regional land use impacts[48], is approximately 14 km from the site.

Specialist advice from DoW as well as hydrogeological consultants, Rockwater, concurred that the key risk from the proposal was sub-surface water impacts from any spills at site. Both parties agreed the proposed

[48] Mount Peron Water Reserve and Leeman (Midway) Water Reserve Drinking Water Source Protection Plan, Water Resource Protection Series, Department of Water, Report No. 83, February 2008

control measures, including the groundwater monitoring program, would appropriately manage any potential sub-surface water impacts, especially any on either of the water reserves.

The EP identified that the depth to groundwater is 100 m. This would enable effective containment and clean-up of any surface spillage. In the EP, AWE committed to promptly implementing spill containment and clean up measures to prevent contamination, especially any offsite impacts on subsurface water if any surface spillage did occur.

DoW also advised that the depth of the drilling, combined with the presence of an aquitard would protect the water source from contamination. DoW advice reported in a local newspaper stated[49]:

> "The targets for hydraulic fracture stimulation at the Drover-01 site are deep, with the shallowest being about 1600 metres belowground level.
>
> Water at this depth travels in a west-north-westerly direction at a velocity that decreases with depth and would take thousands of (up to 6000) years to reach the distance to the Mt Peron Borefield.
>
> Therefore, the evaluation is the drinking water source for the supply to consumers in Green Head and Leeman is not at risk from Drover-01 exploration operations."

In its response to DMIRS and AWE about the EP, DoW recommended adoption of a monitoring program and a contingency plan to the EPA to further reduce the risk of potential impacts from any surface spillage. Details of the monitoring program are provided in Section3.2.3.4.

[49] Water 'not at risk': Department, Mid West Times Geraldton, August 2014

Table 7. Summary of Management Controls for Key Environmental Risks (Drover-01)

Risk	AWE Management Control Measures
1. Flora	• Flora study undertaken to assist project design and operational management • Hygiene equipment, inspection and procedure to minimise risk of introducing soil pathogens (eg dieback)
2. Fauna	• Fauna study undertaken to assist project design and operational management (eg lighting, fencing off operational areas, egress matting installed into ponds) • Retain mature trees where possible to conserve fauna habitat. • Establish speed limits around site to reduce potential for fauna interaction (ie vehicle collision).
3. Waste	• Segregate waste (hazardous, general and materials for recycling), cover waste receptacles • Collected and dispose of all waste offsite through licensed facilities and retain waste tracking records. • Drilling muds to be disposed of within a lined pit and collect soil samples to determine appropriate method of disposal.
4. Air Emissions	• Undertake any flaring only during limited stages of the project (Well Testing, Emergency while drilling in progress). • Maintain vehicles and machinery regularly to ensure efficient fuel use. • Apply water to areas prone to dust generation.
5. Noise	• Limit heavy equipment movements likely to generate noise to daylight hours only • Nearest sensitive noise receptor (landowner's house) is 4 km from the site. • In the event of large flare or high gas rates, suppress noise emissions by silencing control.
6. Light	• Direct lighting within operational areas only. • Nearest sensitive light receptor (landowner's house) is 4 km from the site. • The site is sufficiently set back from the Coorow-Greenhead road to reduce visibility from nearby road users.
7. Hygiene	• Inspection and wash down of all vehicles and equipment prior entering site as per hygiene procedure • Drover-01 site graded to fall away from Lesueur National Park, surface water run off contained within site.
8. Surface Water Management	• Mud sump and freshwater pond designed and constructed to ensure well integrity • Grade Site infrastructure: Access Road, Hygiene Station, Camp and Well Site to fall away from national park. • Establish 1.5m bund wall along western boundary of the Well Site to manage surface water run off away national park. • Hygiene station run to sump with overflow to capture run off water resulting from cleaning activities. • Drainage systems in place to reduce erosion and prevent run off from site.

Risk	AWE Management Control Measures
9. Groundwater Management	• Groundwater Study commissioned and prepared by Rockwater hydrogeological consulting. • Well Construction (triple casing and cement bond) and pressure monitoring of well annulus throughout operation. • Flowback retention and freshwater ponds are lined (infiltration rate 10^{-9} m/s. • Groundwater Monitoring Plan implemented 6-monthly groundwater samples collected for analysis. • Abstraction licence from DoW for production bore.
10. Fire	• Fire trucks on site & manned by trained firefighting crew. • Land & vegetation cleared around the flare pit as per DFES's total fire ban exemption requirements. • PTW to control ignition source(s) & all equipment are appropriately hazard zone rated. • Have gas detectors and remote and manual ESDs. • Position all fuel / hydrocarbon tank and onsite separator with a minimum separation distance. • Designate primary and secondary escape routes and muster points. • Fire response equipment be available to construction crews and all vehicles involved in pad construction to have a fire extinguisher in the vehicle.
11. Heritage Management	• Desktop search of the D.I.A Heritage Inquiry System indicated no registered sites in the proposed work area. • Two contracted monitors on site during initial earthworks.
12. Lesueur National Park	• Site location is within private land and has been moved further away from Lesueur National park to address concern. • The location is set back from the Coorow-Greenhead road to minimise impact to visual amenity. • Large truck movements will be restricted to daylight hours to reduce noise emissions from site. The nearest noise sensitive receiver is 4km away (landowners house) • Hygiene / vehicle wash procedure. • Imported materials (proppant, road and well pad base) from a local gravel source that had been interpreted as low risk by a dieback specialist. • Bottom hole location at least 350m east of Lesueur National Park boundary, previous studies by AWE at Woodada Deep have demonstrated that fractures are unlikely to propagate (vertically or horizontally) further than 260m. • The well pad and associated infrastructure such as the water storage ponds, flare and chemical bund will be located as far as possible away from the Lesueur National Park boundary.
13. Drilling activities	• Drilling manager accommodated onsite and other drilling personnel were housed in Green Head to reduce travel associated risks. Camp wastes disposed of within licenced facility or collected by licenced contractor for disposal (i.e. septic waste, food waste). • Drill pad setback 400m east of the Lesueur National Park boundary to provide additional buffer. Bund wall to be established on the western edge of the drill pad as a containment measure in the event of an unplanned spill.

Risk	AWE Management Control Measures
	• Volume of drilling mud use minimised by non-invasive mud design limiting fluid loss to surface formations protecting groundwater from contamination. • Blow out Preventer (BOP) in place once drilling operations reach a depth where hydrocarbons can be intersected. • Drilling muds to be contained within a HDPE lined (infiltration rate 10-9 m/s) pit, soil samples will be collected for analysis to determine appropriate method of disposal. • Recycling of mud limits the volume of water required to be taken from local ground water bores.

Table 8. Summary of engagement undertaken during planning and approvals phase (prior to establishment of the Community Reference Group)

Stakeholder	Issues and Resolution	Timing
Landowner	Access agreement and negotiations regarding site location and scope of project. The access compensation agreement has been signed and is in place.	Ongoing
DMP- Petroleum Branch.	Work Programs: Drilling application and programme.	Ongoing
DMP– Tenure and Land Access Branch	EP455 Permit extension application.	1 May 2013.
South West Aboriginal Land & Sea Council (SWALSC)	D.I.A Heritage Inquiry for Drover-01 Location- confirmation that there are no register sites in the proposed work area.	1 May 2013
DWER	Licence to construct a water bore and a licence to take water query submitted for Drover-01.	3 July 2013
	Briefing on Drover-01 project and discussions on potential groundwater monitoring programme and surface water protection measures.	5 July 2013
	DoW provided with Exploration Well Baseline Sampling Plan for review. DoW found the plan acceptable with regard to their requirements for the project.	1 October 2013
	Licence to Take Water (Section 5C) issued for Drover-01 (GWL177821).	9 December 2013
	Letter sent to the DoW outlining AWE's intention to not drill an additional monitoring bore to monitor surface contamination within the well pad as described within the EPA recommendation.	14 January 2014
	DoW responded to AWE's letter confirming their original position in that they recommend an additional monitoring bore is drilled and cited community concern and opposition to "Fracking" operations as key reasons.	14 February 2014
	AWE sent letter to DoW advising that a monitoring bore would be drilled to satisfy their EPA recommendation.	27 February 2014
	DoW provided feedback on the design; the feedback has been incorporated into the final design of the monitoring bore.	12 March 2014
Minister for Environment	Drover-01 project courtesy email outlining project and intention to submit EP and EPA referral to the respective Ministers.	23 August 2013
Minister for the Mines		

Stakeholder	Issues and Resolution	Timing
DMIRS- Petroleum Environment Branch	Briefing on Drover-01 exploration well location and proposed timeframes for submission of EPA referral and EP.	2 August 2013
	Confirmation of new Drover-01 surface and bottom-hole location. Bottom-hole location moved 350m away from Lesueur National Park to obviate need for s15a referral.	28 August 2013
Member for Moore	Briefed on Drover-01 proposal and likely EP and EPA submission timeframes.	5 August 2013
Various stakeholders including: DMP, Local community, Indigenous groups, Media, Interested NGO's, Industry groups	Distribution of Drover-01 project flyer to all identified stakeholders.	12 September 2013
Department of Health	Briefing on Drover-01 project	28 October 2013
Community Information Session: Leeman	Information session held to engage local community on Drover-01 project and allow a forum for the public to raise concerns Approximately 30 stakeholders attended and AWE representatives were able to answer a variety of questions on different topics. Information that could not be supplied on the day was subsequently provided within electronic or hardcopy form at a later date.	21 November 2013
Environmental Protection Authority	Briefing on Drover-01 exploration well location and plans to submit EPA referral and EP.	28 June 2013
	Site visit to Drover-01 location, discussed location and environmental sensitivities within the area.	23 October 2013
	'Roundtable meeting' involving representatives from DMP, EPA and DoW to discuss feedback from EPA referral public consultation.	31 October 2013
Department of Parks and Wildlife	Engaged to attend Drover-01 site visit to assess location, DPAW provided feedback on location and site design particularly in regard to surface water management.	23 October 2013
	Invite to attend 'Roundtable meeting' involving representatives from DMP, EPA and DoW to discuss feedback from EPA referral public consultation.	31 October 2013
	Engaged to provide advice on hygiene management procedure for Drover-01. DPAW Feedback received and incorporated into the Drover-01 Bio-security Procedure. [HSE-PR-050].	15 January 2014
Office of the Appeals Convenor	Received advice that one appeal was lodged against the EPA decision not to assess – Drover-01 Exploration Well.	3rd December 2013
	AWE submitted response to the Appeals convenor addressing the grounds of appeal.	19 December 2013
	Meeting to present Drover-01 project and address the grounds of appeal stated within the 'No Fracking Way' submission.	9 January 2014
	Office of the Appeals Convenor provide letter advising of Ministers appeal determination: The Minister dismissed the appeal.	12 February 2014
Shire of Coorow	Engagement on planned timeframe for Drover-01 activity.	TBA

The environmental management of all aspects of the Drover-01 drilling and HFS activities were managed under the approved EP, Drover-01 Exploration Well Environment Plan (HSE-E-077, Rev G).

3.2.3.3 Land

The Drover-01 well location was on cleared agricultural land adjacent to Lesueur National Park and management measures reflected minimising potential risks to the biodiversity of the park. For example, during the design phase of the project, the well site location was selected to lie within cleared agricultural land at a distance from the conservation reserve that minimised potential environmental risks.

Site rehabilitation activities commenced on 6 April 2016 and were completed on 26 May 2016, the following activities were undertaken as part of the rehabilitation of the Drover-01 lease area:

- Decommissioned mud sump and freshwater pond, removal of liner for offsite disposal
- Classified mud sump material, excavated and transported material to licensed offsite (Cataby remediation) facility for remediation
- Completed soil validation sampling within mud sump and well pad area
- Back filled excavations within lease area
- Re-contoured well pad area to be consistent with surrounding area
- Removed fencing as per landowner requirements
- Topsoil respread, remediate access and leave as per landowner requirements

The rehabilitation monitoring works involved the following:

- Collection of characterisation samples from the drilling mud retained within the LDPE lined retention pond on 31 March 2016
- Collection of validation samples from the drilling mud retention pond on 14 April 2016 following the decommissioning of the mud sump. Baseline soil chemical data was obtained from samples collected in May 2014 following excavation of the mud sump
- Collection of surface soil validation samples from the location of the former drill pad, flare pit and other site surfaces on 06 May 2016. Baseline soil chemical data was obtained from samples collected in May 2014 prior to the development of the well site area
- A Groundwater monitoring event involving the collection of representative groundwater samples from three locations on 26 and 27 July 2016 to compare groundwater chemical conditions with those reported pre- and post- drilling of the Drover-01 exploration well

The key findings from the works undertaken are summarised below:

- The drilling mud has been removed from the site and disposed of at a licenced remediation facility
- Soils at the site (ie drill pad surface soils, drilling mud sump soils, flare pit soils etc. have not been adversely impacted by the drilling of the Drover-01 exploration well and associated activities and therefore do not pose an unacceptable risk to human or ecological receptors
- Groundwater beneath the site and in the vicinity, of the site has not been adversely impacted by the drilling of the Drover-01 exploration well and associated activities. Groundwater beneath the site does not pose an unacceptable risk to human or ecological receptors

- A screening risk assessment based on the data gathered to-date indicates that no Contaminants of Potential Concern (CoPC) that could present, or have the potential to present, a risk of harm to human health, the environment or environmental values associated with the drilling of the Drover-01 exploration well were identified[50]

At the request of the landowner, a portion of the well pad was left in place for installation of sheep yards and a shed. The gravel access track was also left in place as a property improvement.

3.2.3.4 Water

As described in Section 3.2.3.2, during the approvals process, the potential impacts on surface water and groundwater were thoroughly considered given the distance of the proposed Drover-01 well to a drinking water supply area for two coastal settlements in the region, Green Head and Leeman, and the proposed use of HFS treatment.

In its response to DMIRS and AWE during the EP review, DoW noted the water resources were not at risk from proposed Drover-01 activities. It also recommended adoption of a monitoring program and a contingency plan to the EPA to further reduce the risk of potential impacts from any surface spillage which also addressed perceived risks that were expressed by some of the local residents.

Petroleum exploration activity has been occurring in the local region since the 1960s[51]. Data from previous drilling (shown in Figure 27) was used to assist planning for Drover-01 project design and also to help inform the groundwater monitoring program.

[50] Well Site Soil & Groundwater Decommissioning Report – AWE Limited – Drover-01 Location – Gemec Environmental Consultants - March – July 2016.

[51] WAPIMS database

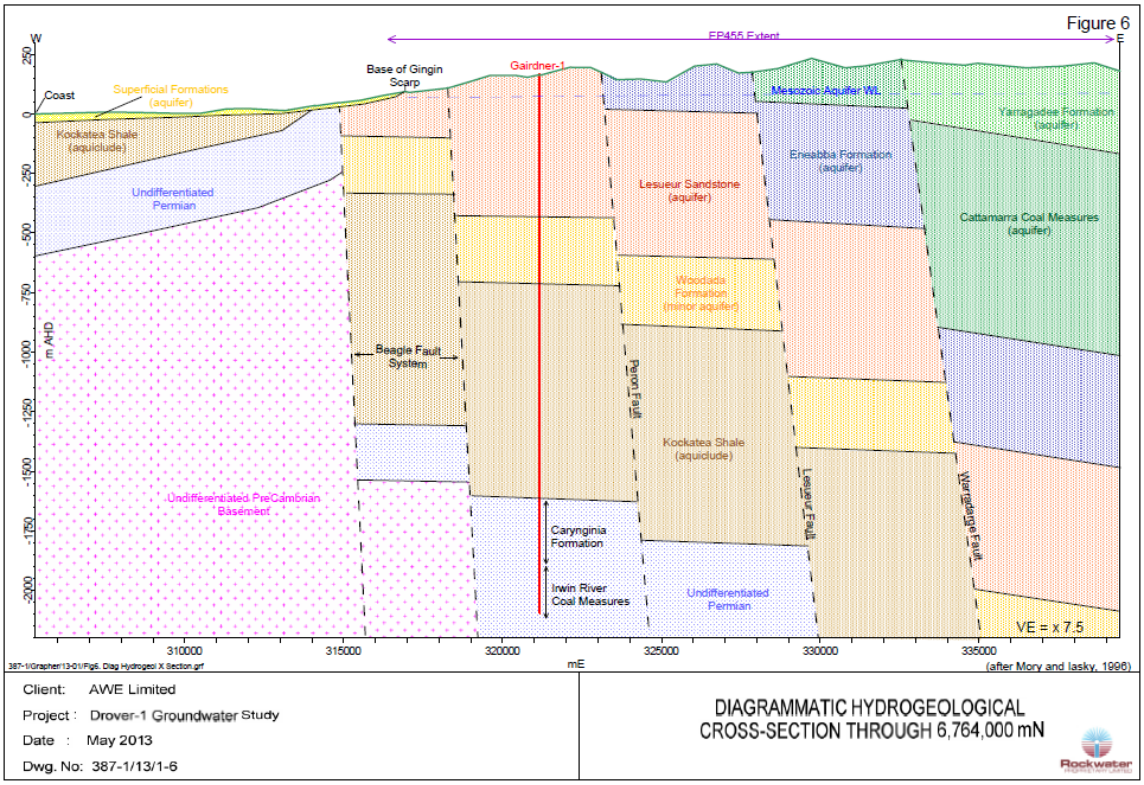

Figure 27. Hydrogeological assessment undertaken during Drover-01 planning phase drew upon data from previous nearby exploration activity

The program was designed by an independent hydrogeological consultant, Rockwater[52] and reviewed by DoW (Appendix D). DoW recommended the program included installation of an additional monitoring bore downstream of the well site. The approved bore location and design was based on site-specific groundwater depth and flow. The bore was installed by a licensed water driller and the monitoring was conducted on a six-monthly basis by independent consultant, Gemec (Figure 28 and Figure 29).

[52] Drover-1 Groundwater Study, Report No. 387-1/13/01, Rockwater, May 2013

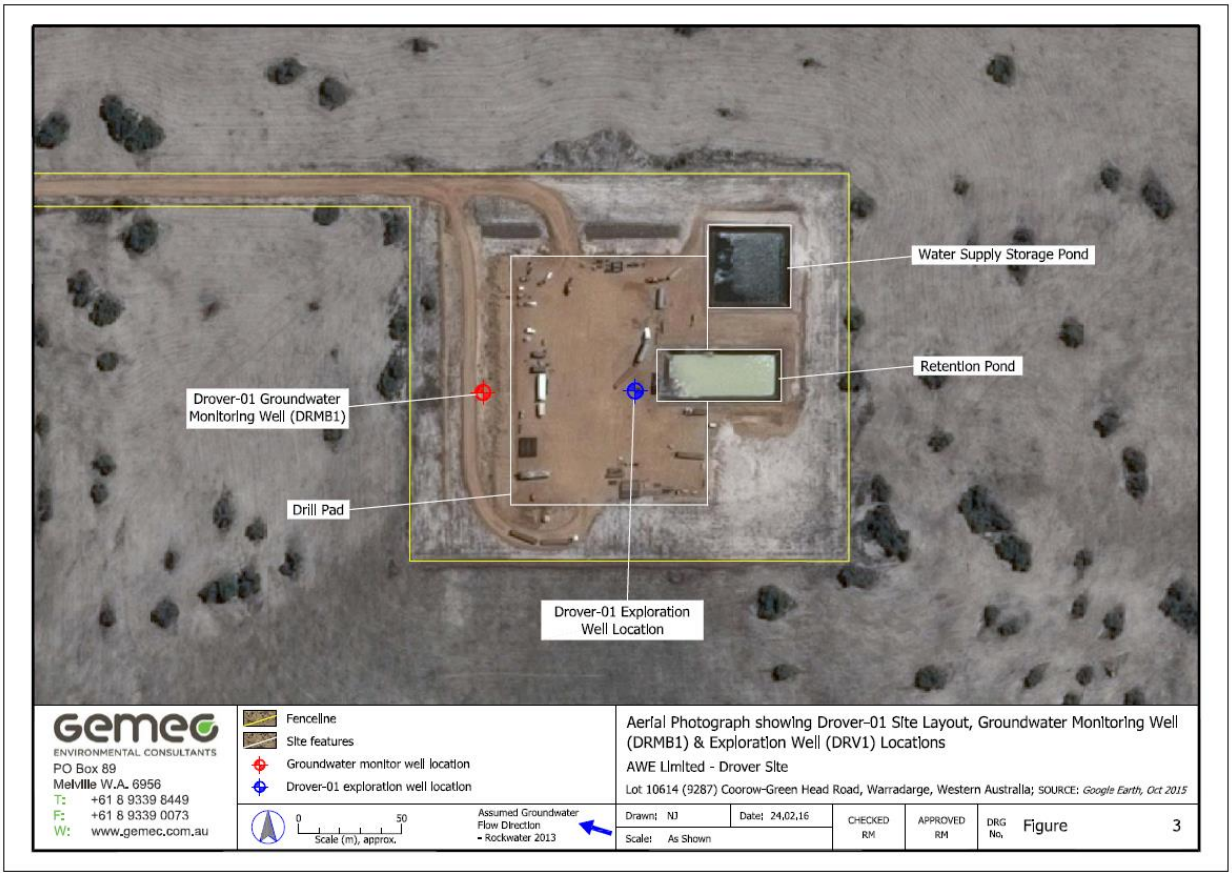

Figure 28. Drover-01 Groundwater Monitoring Bore Layout

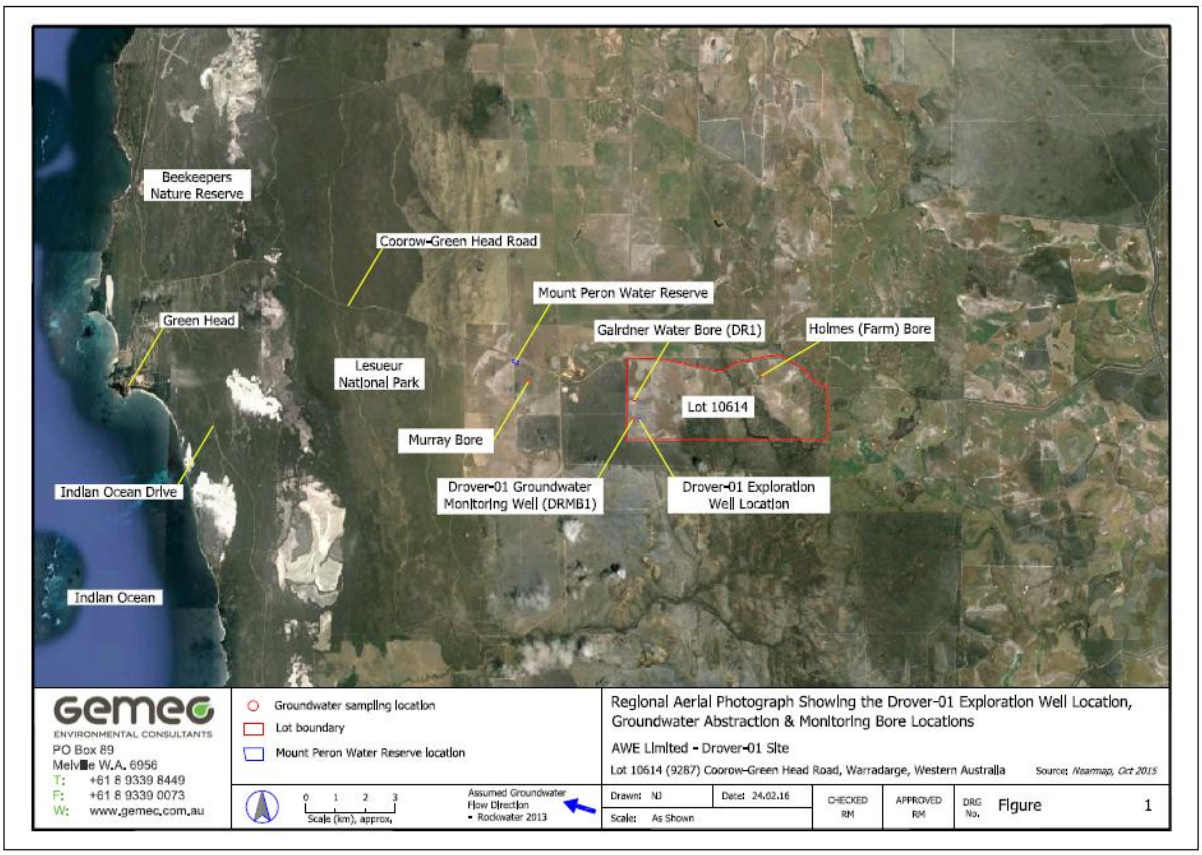

Figure 29 Drover-01 Monitoring Bore Locations

The initial phase of AWE's groundwater monitoring program at Drover-01 involved testing for 86 analytes, sourced from four different locations. Results showed no irregularities from 342 of those 344 tests. The results of the July 2015 monitoring event showed Irregular readings for methane measurements at two locations, DR1 (4 mg/L) and DRMB1 (0.5 mg/L) that extensive analysis found to be most likely the result of a difference in sampling methodology between the tests. Methane is non-toxic and non-poisonous and there are no screening or threshold levels to apply to the results.

These initial monitoring results, whilst not harmful, were immediately reported to the regulatory authorities. The DoW subsequently confirmed that the levels of recorded methane posed no environmental or safety risk.

Following analysis to better understand the reasons for the elevated readings, independent environmental consultancy, Gemec, concluded that the presence of hydrocarbons was not a result of AWE activities in relation to the drilling of the Drover-01 exploration well[53]. Gemec confirmed that the methane was microbial and was not from shale gas or naturally occurring reservoir gas and that the source of the methane in the two wells was different.

AWE consequently organised further sampling to be conducted. In addition, AWE advised the landowner of both the initial monitoring result, the plan to undertake another sampling.

AWE then commissioned further testing and independent analysis of the results by the University of Queensland. Further analysis used isotope testing to determine the origin of the elevated methane in the two monitoring locations. The isotope testing helped determine that the elevated methane reading at the first location, DRMB1, reflected the normal application of materials used to construct a new water bore, consistent with the construction of a typical agricultural water bore.

Ongoing monitoring in all three bores showed methane concentrations had decreased in each of the bores since the July 2015 monitoring event that had triggered further investigation by University of Queensland concluding it was not due to inorganic sources such as the deeper shale formations beneath the well site location[54]. Additional monitoring following the University of Queensland investigation showed methane concentrations were observed to be attenuating and reconfirmed the discrepancy at the Gairdner water bore (DR1) location thus confirming further that the result was not related to AWE activities.

In response to the level of community interest in potential impacts from the Drover-01 exploration well, AWE made a presentation to the Shire of Coorow Drover-01 Community Reference Group about the groundwater monitoring results. The purpose was to ensure local residents were aware of and understood the monitoring results and were able to raise any questions they had and get prompt responses. A copy of the presentation is attached (Appendix E).

The Drover-01 site has been decommissioned and rehabilitated. The site has returned to the landowner for its previous use of cereal cropping and low intensity stock grazing. At the request of the landowner, the

[53] Groundwater Monitoring Event Report for AWE Ltd Drover-01 Location, Gemec Environmental Consultants, December 2015

54 Well Site Soil and Groundwater Decommissioning Report for AWE Ltd, Drover-02 Location, March-July 2016, Gemec Environmental Consultants

gravel access track, part of the gravel well pad and fencing were left as they provided improvements to the agricultural property.

3.2.3.5 Social Surrounds

To increase the level of engagement between AWE and residents of the Shire of Coorow even further, the company sponsored the formation of an independently facilitated Community Reference group for the Drover-01 exploration well. This reference group operated independently of AWE, although AWE provided information specifically requested by the reference group participants and, like a number of other stakeholders including regulators and subject matter experts, participated in the group by invitation.

Based on the positive feedback about the engagement process, the group jointly entered the inaugural Community Partnerships Award sponsored by the then DMP (Appendix F).

3.3 Production

3.3.1 Corybas Gas Field Production Well

Corybas-01 well was drilled in January 2005. Following a successful HFS treatment in May 2009, the well was connected via flowline to the DPF in April 2010. It produced gas from the Corybas gas field that was processed at the nearby DPF until October 2016 when the DPF was temporarily shut-in.

3.3.1.1 Corybas-01

HFS treatment at Corybas-01 was conducted in May 2009 by AWE. The target zone was the Irwin River Coal Measures (IRCM) over the interval 2514m to 2536 mMDRT (mMDRT = metres measured depth referenced to the rotary table on the drill rig)

A single HFS treatment was conducted incorporating a (158,000 lb (71.8 tonne) 20/40 proppant pumped with a water based Borate crosslinked gel system. Following HFS, the well head was replaced with a production well head.

Pre and post HFS well tests were conducted showing a 218% improvement in gas rate (Figure 30). The production improvement is indicative of a HFS treatment that has stayed within the target zone. Long term water production is indicative of water of condensation from reservoir interval, and as such it is reasonable to conclude containment is achieved (ref section 3.1). Gas at high pressure and temperature in the reservoir rock has water vapour in it. This water is from the water that exists in the rock itself. When the gas is produced and de-pressures and cools as it travels to surface, the water condenses out of the gas. This is known as water of condensation – much like the water vapour from air condensing into rain when the air cools. Water of condensation generally has low total dissolved solids which we measure as a check.

Corybas-01 production well has been raised on occasion in the media. Background to this matter follows. In June 2012, during routine maintenance inspections, required by regulation, a minor seep on the production wellhead (not HFS wellhead) was detected by AWE facility operators and promptly repaired. As evidenced by incidents reported to DMIRS. It is not unusual for a valve to leak. Operators develop and use maintenance and inspection schedules to minimise any impacts from potential emission sources like this. All incidents are reported to DMIRS in accordance with regulatory requirements.

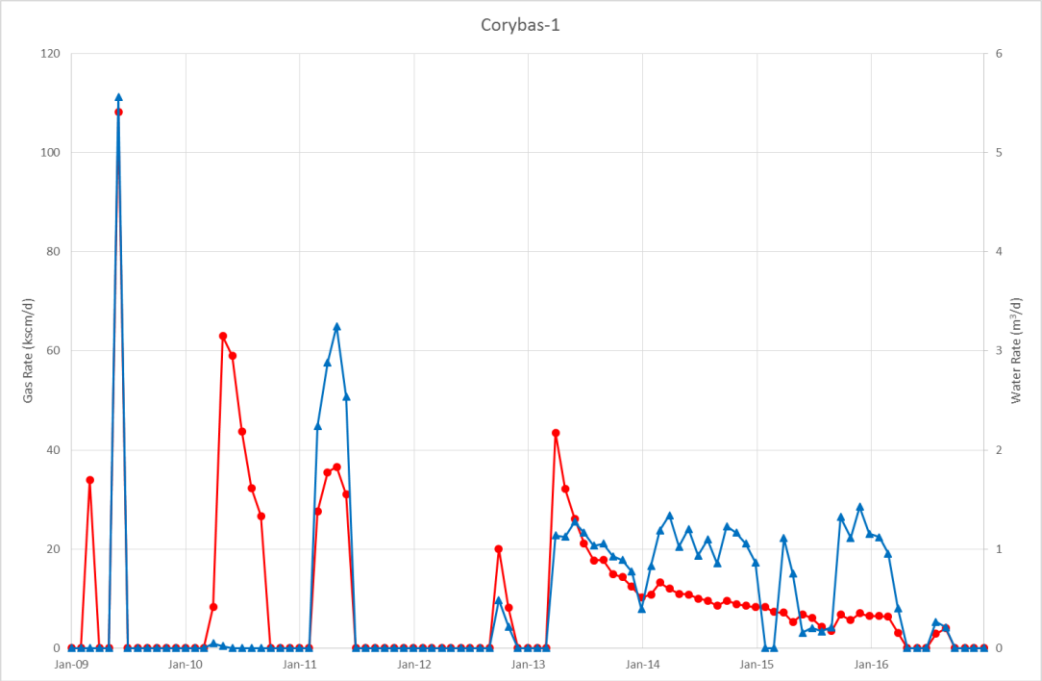

Figure 30. Corybas-1 Production History (blue =water rate, red= gas rate)

3.3.2 Dongara Gas Field Production Wells

HFS was used as a Well Intervention Activity to help improve production at seven producing wells from 1974 through to Dongara 21 and Dongara 24 in 1981 and 1985 respectively.

3.3.2.1 Dongara-03L

HFS was conducted at Dongara-03 in March 1974 by WAPET over the interval 1638 to 1639.9mMDRT. The target zone was the Lower Carynginia Formation.

A MY-T gelled water system was used with a maximum proppant concentration of 2.5 lb per gallon. No details of volumes of fluid or proppant pumped are on file but were likely to be similar to Dongara 9L HFS which was 30,000lb (13.6 tonnes).

Production history shows normal production decline indicative of a HFS treatment that has stayed within the target zone (Figure 31). No real productivity enhancement noted due to the HFS process. Water production is at rates typical of water of condensation from the reservoir interval ~0.03 m^3 water/kscm gas.

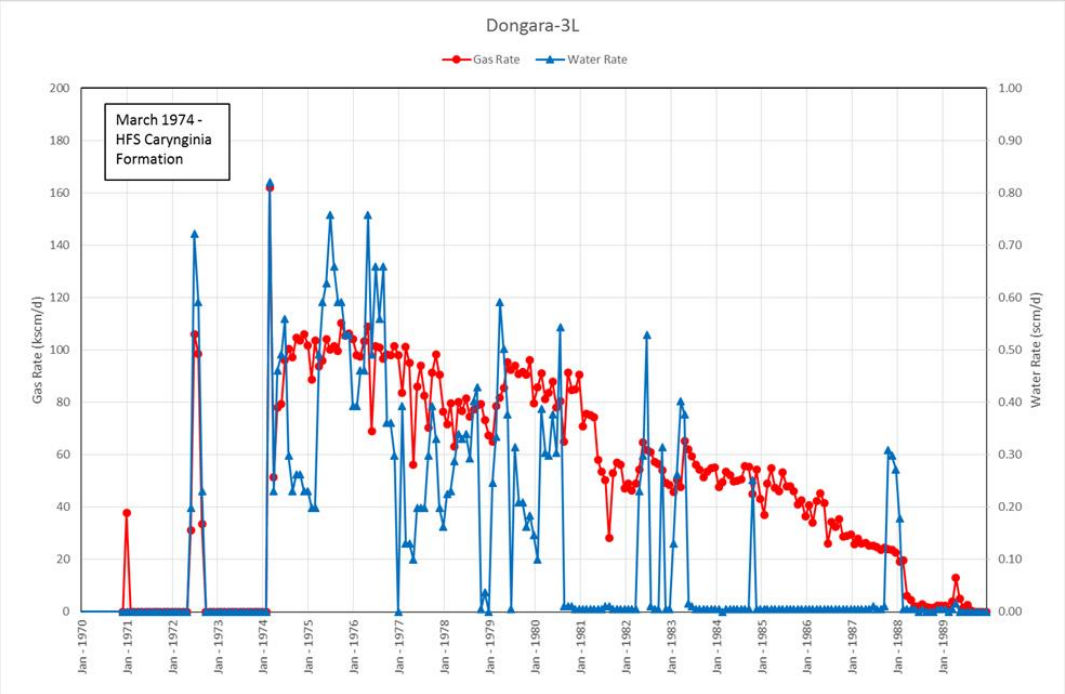

Figure 31 Dongara-3L Production History

3.3.2.2 Dongara-09L

Dongara-09 was treated with HFS in April 1974 by WAPET over the intervals 1707.2 to 1710.2mMDRT and 1714.8 to 1726.7mMDRT. The target zone was the Irwin River Coal Measures (IRCM). A maximum proppant concentration of 3 lb per gallon was used with a total of 30,000 lbs (13.6 tonnes) of proppant pumped. The HFS was not optimal as proppant was over displaced, resulting in poor proppant connection to the wellbore. No details of gel type, but likely the MY-T Gelled water system (based on similar timing to Dongara-3 HFS).

Prior to the HFS the well was completed over the Dongara/Wagina. After the HFS a dual completion was put in place and the IRCM (HFS target) was produced in isolation.

Production history shows normal production decline and is indicative of a HFS treatment that has stayed within the target zone (Figure 33). Water production was indicative of water of condensation from reservoir interval.

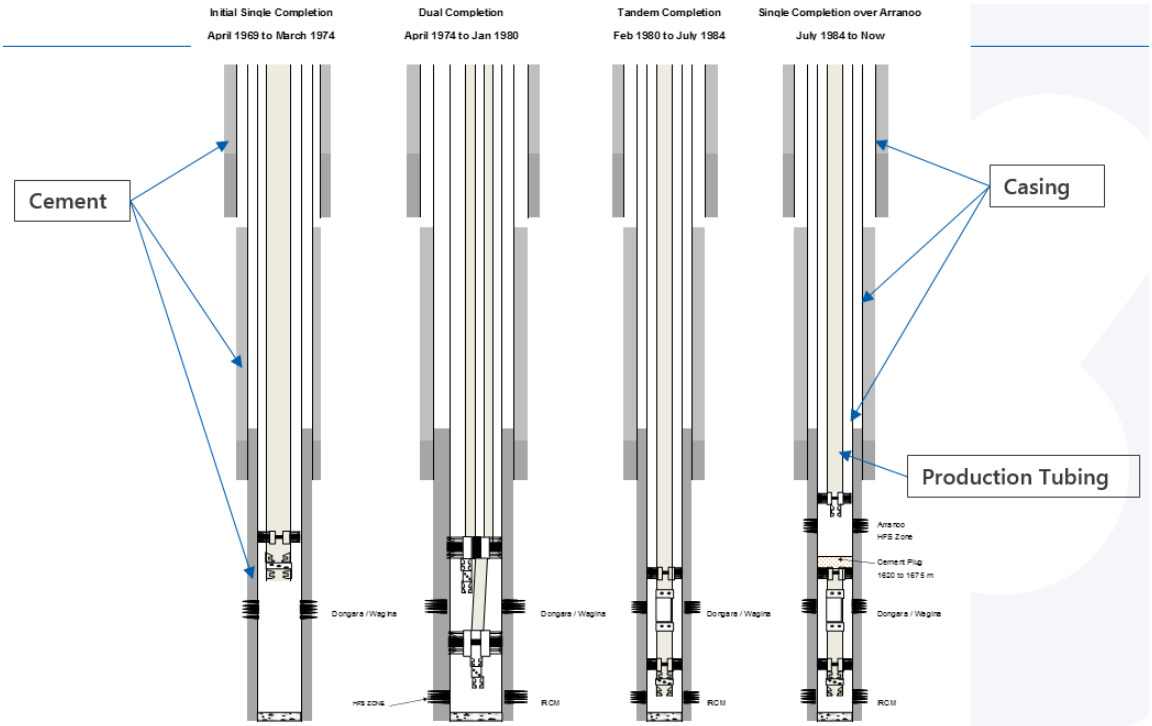

Figure 32. Dongara-9 Completion History

In January to February 1980, the well was recompleted to enable commingling of all productive intervals (Figure 32). A high gas rate from Dongara/Wagina was observed and an increase in water production due to reservoir water breakthrough in Dongara/Wagina. Reservoir water is formation water down-dip of the gas zone and typically is of high salinity.

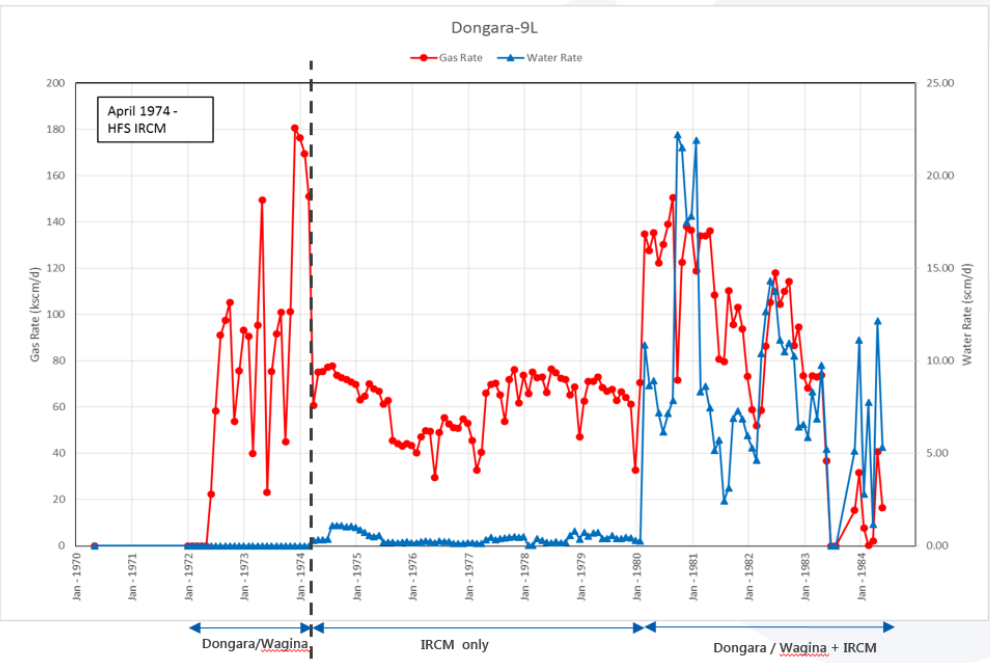

Figure 33. Dongara-9L Production History

3.3.2.3 Dongara-9A

HFS was conducted at Dongara-9A in July 1984 by WAPET over the intervals 1500 to 1506mMDRT and 1530 to 1537mMDRT. The target zone was the Arranoo member of the Kockatea Shale. The HFS was conducted

using a dedicated fracture string with a maximum proppant concentration of 6 lb per gallon. A total of 70,000 lbs (31.8 tonnes) of 20/40 mesh proppant was pumped. 920 bbl (99 m^3) cross-linked nitrified gel was used.

Production history shows normal production decline for a low permeability reservoir and is indicative of a HFS treatment that has stayed within the target zone (Figure 34). Water production was indicative of water of condensation from reservoir interval.

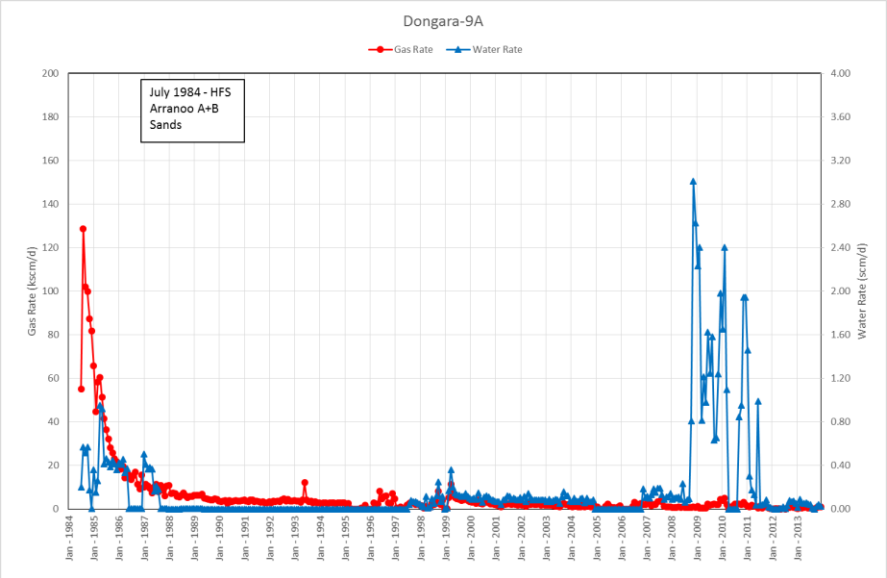

Figure 34. Dongara-9A Production History

3.3.2.1 Dongara-15L

HFS was conducted at Dongara-15 in March 1974 by WAPET. Two separate HFS treatments were undertaken. The first over the IRCM and the second over the Carynginia Formation. The IRCM HFS intervals were 1684.3m to 1717.9mMDRT. The program was a 30,000lb (13.6 tonne) 12/30 mesh proppant to 3 lb/gal using MY-T gelled water system. The Carynginia HFS intervals were 1647.7m to 1672.7mMDRT. The program was a 30,000lb (13.6 tonne) 12/30 mesh proppant to 3 lb/gal using MY-T gelled water system.

Production history shows benefit of HFS with the gas rate increased by 200% post-HFS (Figure 35). This is indicative of a HFS treatment that has stayed within the target zone. Water production indicative of water of condensation from reservoir interval.

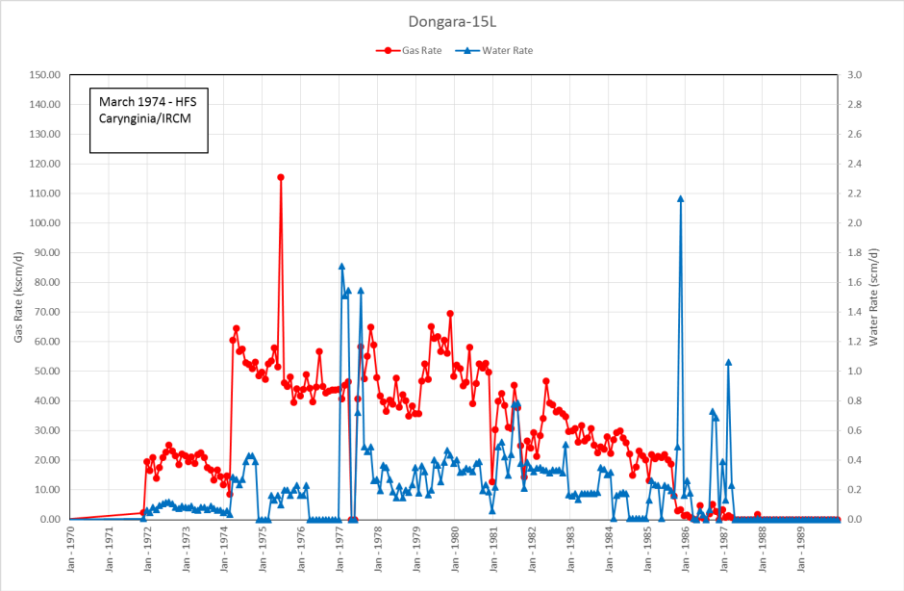

Figure 35. Dongara-15L Production History

3.3.2.2 Dongara-21A

HFS was conducted at Dongara-21A in December 1981 by WAPET. The target zone was the Arranoo "B" reservoir over the interval 1589.5 to 1601.2mMDRT. A single HFS treatment was conducted. The program used 60,000 lb (27.3 tonne) 20/40 mesh proppant to 4 lb/gal and a cross linked water-based gel system was used. The job terminated prematurely due to poor proppant feed from the proppant silos.

Dongara Arranoo reservoir is a gas cap - oil reservoir with water drive. Dongara 21A targeted the oil. Although HFS treatment improved oil rates the job was not a success in terms of total production volumes recovered (Figure 36). The water produced with the oil is formation water from the target reservoir.

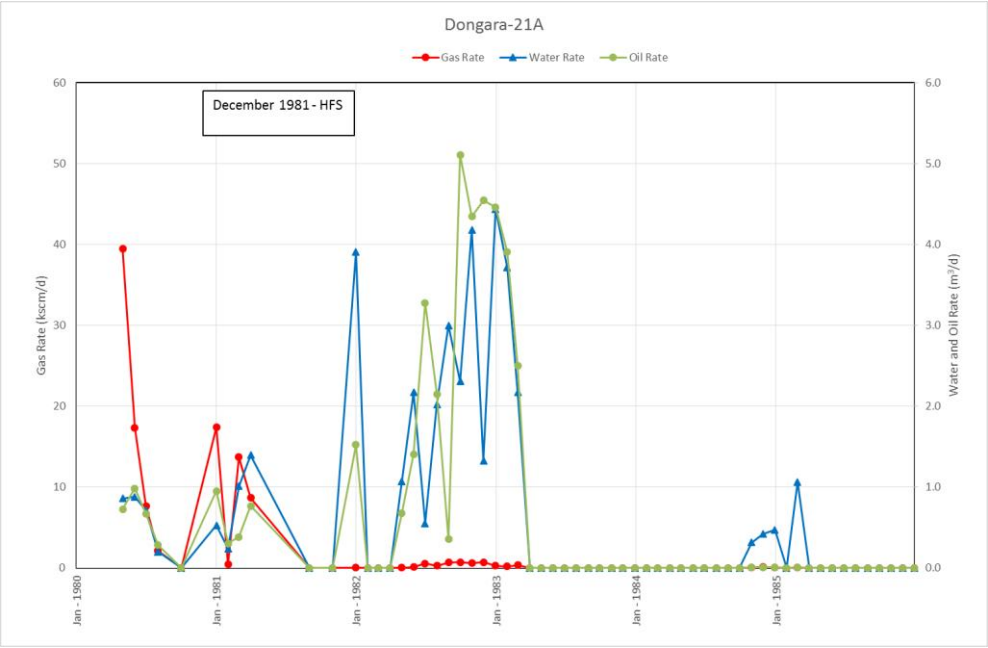

Figure 36. Dongara-21A production history

3.3.2.3 Dongara-24A

HFS was conducted at Dongara-24A in July 1985 by WAPET. The target zone was the Arranoo "A"+"B" reservoirs over the interval 1451m to 1508mMDRT. A single HFS treatment was conducted. The program used 133,000 lb (27.3 tonne) proppant pumped with 144m^3 gel.

The Dongara Arranoo reservoir is a gas cap - oil reservoir with water drive. Dongara 24A targeted the oil. The HFS treatment improved oil rates and recovery (Figure 37). The water produced with the oil is from the target reservoir. HFS was confined to the target zone as if the fracture had migrated out of the zone into aquifers, subsequent oil production would have fallen to zero, particularly after shut-in periods.

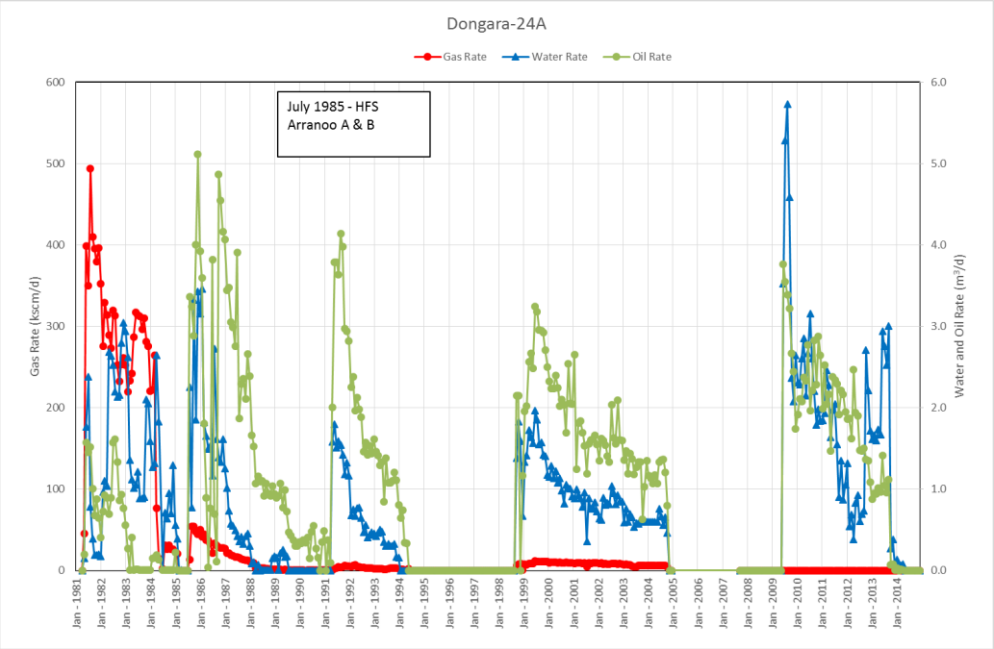

Figure 37. Dongara-24A production history

4.0 BASELINE REGIONAL STUDIES

4.1 Seismology Research Centre – North Perth Basin Seismic Monitoring Network

AWE contributes to a Mid West regional seismic monitoring project. The North Perth Basin Seismic Monitoring Network installed by the Seismology Research Centre (SRC) comprises three seismic monitoring stations which were all installed in mid-September 2014 throughout the northern Perth Basin (ie Senecio-2 well , Arrowsmith and Warro Field site) [55] (Figure 38).

Baseline monitoring data captured since 2014 shows that the northern Perth Basin is a low risk area regarding earthquakes. The Perth Basin is a stable area with inactive faults as seen by the lack of natural seismic events. This means earthquakes are not a significant hazard for onshore operations in the region. Therefore, potential HFS activity impacts from microseismicity would be negligible in this area.

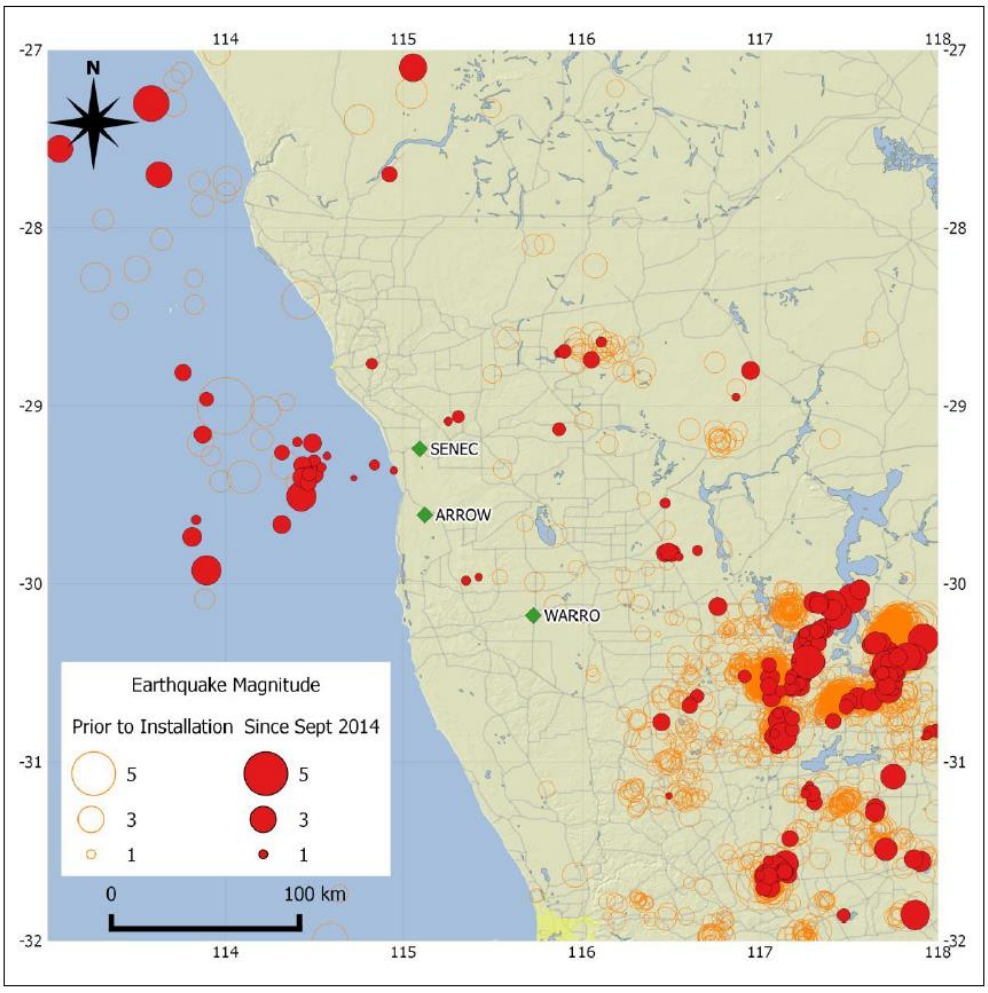

Figure 38. Monitoring locations and baseline earthquake monitoring data

Nevertheless, AWE addresses the issue of seismic events during its project planning and impact assessment phases. The assessment uses results of AWE's seismic monitoring which provides valuable information on the site-specific characteristics and ensures well design and water management are conducted safely.

[55] North Perth Basin Seismic Monitoring Network Annual Report 2017, Seismology Research Centre

4.2 CSIRO - Perth Basin Baseline Monitoring Study

AWE co-funded and participated in a CSIRO/University of Western Australia baseline monitoring project, including capturing additional baseline groundwater, from the northern Perth Basin. Monitoring of groundwater, air quality emissions and seismicity are subjects often raised by Mid West community members who are interested in the onshore sector and this study was undertaken to help ensure Australia's onshore gas industry uses and implements the best environmental monitoring standards available.

CSIRO/UWA, in collaboration with Latent Petroleum, AWE, Origin Energy, Norwest Energy and DMIRS established a research program into methods of calculating baseline values of environmental indicators and monitoring techniques during development of tight gas resources in the northern Perth Basin.

As part of the project, a desktop review of available groundwater monitoring data around the project sponsors' permit areas was conducted, along with measurements of ambient methane concentrations.

The groundwater study indicated a lack of monitoring wells within the permit areas, apart from those being monitored by explorers, and provides a valuable update to the regional groundwater models built by the DWER. The mobile methane survey measured ambient levels of methane across the northern Perth Basin and found that methane concentrations were close to those measured at the Cape Grim atmospheric research station (Tasmania). The soil-gas flux survey measured very low or negative methane flux, closely associated with carbon dioxide levels, indicating the flux rate was controlled by microbial action (ie not due to onshore drilling activities)[56]. A copy of the report is provided (Appendix G).

The outcomes of the project are assisting operators to address community assurance, adhere to or surpass regulatory requirements and establish industry best practice standards.

Further research has recently been proposed to help build on the findings from Phase 1 of the study.

[56] Baseline Characterisation and Monitoring Protocols for Development of Shale and tight Gas Resources, Northern Perth Basin, CSIRO Energy, University of Western Australia, Report Number: EP167555, 10 May 2017

5.0 STAKEHOLDER SURROUNDS

Since the 1960s, more than 200 oil and gas wells have been drilled in the Perth Basin with oil and gas produced from multiple fields, while agriculture and tourism have flourished, demonstrating these industries can coexist.

5.1 Local businesses

AWE has a significant positive impact on local business and economies. In a purely financial sense AWE contributed around $16 million in 2016 to the Mid West economy through wages, supply and service contracts with local businesses and community partnerships. This direct spend does not take into account the multiplier effect of investment in the local economy.

AWE is an active member of the Mid West Chamber of Commerce and Industry (MWCCI). This organisation represents local Mid West businesses, many of which are involved with the agricultural as well as the resources sector.

In March 2015 AWE, in conjunction with the MWCCI, held a procurement workshop in Dongara to provide local suppliers and operators with the opportunity to ask questions about AWE's forward plans, procurement processes and provide feedback. The workshop was attended by more than 80 representatives from local Mid West businesses, some of which were since awarded service contracts.

As AWE's flagship Mid West project, the Waitsia Gas Project, began to take shape, the company awarded more than $6 million in service contracts to local Mid West contractors. This figure it anticipated to rise as the company progresses Waitsia through development to its production operation. Four local service contracts were awarded for Waitsia Stage 1A including pipeline construction, earthworks, concreting and electrical and instrumental construction. These initial contracts built on AWE's long-stated preference to award contracts to local operators wherever practical, supporting the regional community and economy.

5.2 Agricultural sector

The Mid West region produces a significant proportion of Western Australian fresh fruit, vegetables and agricultural produce and the oil and gas sector has coexisted alongside horticulture and agriculture for well over half a century.

The former State Government included AWE's property, Irwin Park Farm, in their Water for Food program. The initiative sought to help significantly increase irrigated agriculture state-wide by identifying water and land resources, as well as irrigation technologies, that could enable Western Australia's fresh food and animal protein production to increase its contribution to regional economies[57]. Irwin Park Farm, which has gas wells drilled on the property, including one that has been HFS treated, was selected under the Midlands Project location as a focus area[58]. This demonstrates a high level of comfort with the safety of oil and gas operations and its ability to operate alongside important agricultural regions without negatively impacting on the surface or sub-surface environment.

[57] http://www.waterforfood.wa.gov.au/About

[58] http://www.waterforfood.wa.gov.au/Projects/Midlands-Groundwater-And-Land-Assessment

AWE is a member of the Mingenew Irwin Group (MIG), an internationally recognised research and development organisation promoting and developing economic and environmentally sustainable agriculture. MIG covers approximately 320,000 hectares within the Shires of Mingenew and Irwin and is made up of almost 200 farm businesses. This equates to approximately 95 per cent of farmers in the Mingenew area. AWE is liaising with MIG how it can provide strategic rehabilitation advice to AWE as it decommissions unused wells and facilities.

AWE is also a regular participant at the Mingenew Expo, the largest agricultural field day in Western Australia's Mid West and an active member of the Mid West Chamber of Commerce and Industry. This organisation represents local Mid West businesses, many of which are involved with the agricultural as well as the resources sector.

5.3 Tourism Sector

The tourism industry in the area surrounding AWE's activities is centred in the twin towns of Dongara – Port Denison which largely provides traditional family holidays in a safe and modestly priced location. It is an extremely popular destination during school holidays and peak times such as Easter will see 100 per cent occupancy for most accommodation providers.

The Shire of Irwin created the Tourism Development Plan 2013-2018[59] which identified low awareness and infrastructure issues as the industry's main weaknesses and competition from other towns and international destinations as key threats. Proximity to oil and gas related activities was not referenced in the plan however companies like AWE provide a steady source of business visitors to the area sustaining the local tourism sector in their traditionally slower periods.

Dongara – Port Denison was awarded the GWN7 Top Tourism Award in the Community Relations Category in 2013 and 2014. The Shire of Irwin also received the Local Government award for Tourism in the Perth Airport WA Tourism awards, the Bronze award in 2013, then the Silver award in 2014.

In 2016, Dongara Tourist Park was a Perth Airport Tourism Award finalist and a winner of two MWCCI business excellence awards in 2016.

The local tourism sector centred on Dongara – Port Denison is modest but has successfully existed alongside and is supported by the oil and gas industry.

[59] Tourism Development Plan, Shire of Irwin

6.0 CONCLUSION

AWE's key focus in Western Australia is the development of the Waitsia Gas Project, one of the largest onshore conventional gas discoveries in Australia for the last 40 years. HFS is not required in order to produce the Waitsia field's estimated 820 PJ of gross 2P Reserves.

In the past AWE projects have safely utilised HFS on specific wells under highly regulated conditions. AWE's experience as a long term onshore operator in Western Australia with HFS expertise is that:

- Western Australia has a comprehensive and robust regulatory framework;
- There have been no observable environmental impacts from AWE's HFS activities; and
- Effective stakeholder engagement is key to onshore regulatory and operational success.

Western Australia's comprehensive regulatory framework has evolved to meet the needs of community and emerging technologies and is a robust, effective regulatory scheme ensuring HFS operations meet appropriately high safety and environmental standards.

The 'whole of government' leadership of DMIRS has delivered effective and transparent management and mitigation of the environmental impacts of the onshore oil and gas industry.

AWE routinely participates in regulatory reviews and readily shares experiences gained from our various exploration, production and decommissioning activities conducted in the northern Perth Basin.

Rigorous, independent studies have been commissioned into HFS in Australia and have consistently concluded that the risks associated with HFS are manageable if industry best practice and regulations are implemented and enforced.

AWE's experience of exploring for and producing gas, through utilising HFS techniques in Western Australia, demonstrates that observable environmental impacts have been avoided, mitigated and managed through the existing robust regulatory scheme.

As an active member of the Mid West community, AWE is keenly aware of the local interest in HFS and how it has and will be used in the region. Stakeholder engagement and a solid commitment to effectively communicating with our neighbours and interested parties has been critical to successfully advancing AWE's suite of developments in the Mid West.

AWE generates significant economic benefit for the Mid West region and Western Australia, is a significant local employer and through the shared resource of Western Australia's gas, helps meet the energy needs of households, businesses and industries.

AWE appreciates the opportunity to contribute to the next evolution of Western Australia's regulatory environment and trusts that the *Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia 2017* leads to increased public understanding and confidence in the system.

Snapshot: Shire of Irwin Onshore Energy Industry (2017)

Meet2Create.com

World around us

1. Cleaner energy push worldwide and within Australia
2. Energy supply concerns on the east coast of Australia is refocussing WA public attention to the importance of local energy supplies. This appears favourable for the WA onshore energy industry
3. Perceived poor environmental records from energy industries in the USA and eastern Australia continue to negatively impact on attitudes to the industry in WA – but to a lesser degree over the past 12 months
4. WA continues to be in a significant economic downturn, low oil price is pressuring industry – many businesses in the Mid West are struggling
5. Industry and government continue to struggle to find ways to address the 10 common questions raised by stakeholders (see reverse side)
6. There has been an increased sensitivity within industry and government to use the term "Fracking" (or similar terminology). This word is now owned by interest groups
7. *Consultant's observation: Despite a number of government enquiries across Australia and continued negative media articles about the industry, there now appears to be less concern about the risks associated with the industry with most stakeholders.*

Industry

10. Many good success stories (jobs, energy security, successful safe decommissioning, environmental record) but these are not well communicated
11. Language used by industry and proponents to communicated with stakeholders continues to be too technical and confusing (Tcf, Xmas tree, conventional vs unconventional gas, aquifers). Diagrams explaining the industry are generally poor
12. There are inconsistent approaches by industry to "how" community engagement is undertaken in the Mid West. Lack of guidelines around how this should be done
13. Representative bodies of industry are seen as combative to interest groups which has put some of the community off-side
14. Concerns some companies are "fly-by-the-night" – drill and sell.

AWE

20. AWE has the best stakeholder relations program for the industry in WA – positive landowner interactions, community roundtables, community open days, coordinating Expos, 1on1 discussions and interviews, bus tours and local employment
21. AWE stakeholder representatives are highly respected and trusted by all stakeholders and are a critical linchpin for the company in stakeholder relations
22. Many locals benefit both directly and indirectly from AWE's existing operations – but these benefits (i.e. stories) could be better told in more easily digestible, modern mediums (e.g. video, audio, interactive education)
23. There are high expectations that AWE's future procurement policy for Waitsia will favour local Shire of Irwin businesses. Such policy being measurable with clear targets
24. Community Roundtable has been very well received by all Stakeholders.

Green Interest Groups

30. Value protection of water quality, well integrity, surface pollution, chemicals usage
31. Very vocal and well organised in Mid West, do not like fossil fuels
32. Emotive video documentaries initially very successful but loosing effectiveness. Still no industry equivalent despite numerous recommendations to do so
33. Tactics of bullying, passive aggressive behaviour and release of continual doomsday information have started to work against these groups. Community are now starting to use the terminology "fake news" to apply to information released by these groups.

Community

40. The community believe that face-to-face interactions from industry and government have been far more successful in building trust and openness than traditional communication strategies such as media releases, websites and handouts
41. Information complexity continues to be passed to the community – most company and government websites are hard to navigate, language used is inconsistent or complex, There is no one centrally designed portal where the community can source information
42. Community is very vulnerable to slick marketing campaigns by interest groups using modern mediums of communication. Industry and government are a long way behind in using modern mediums as effectively as interest groups
43. In the Shire of Irwin, anecdotal evidence suggests that the majority of people are supportive of the energy industry. This assumption should be tested quantitatively
44. Some landowners who aren't directly involved in projects and don't have land access agreements, feel they're missing out on benefits. What about farms around those areas that miss out from compensation?
45. There is a desire from community to have independent people outside of government, industry and interest groups to run good engagement and present the facts.

Government

50. Government departments have embraced stakeholder engagement as a core function for enabling the onshore energy industry to work effectively in communities
51. Involvement in community roundtable forums, expos and open days has dramatically improved the trust and respect with those communities receiving this attention
52. Uncertainty over State Govt. policy direction relating to the onshore energy industry poses a risk to the industry
53. Desire from key stakeholders for Government to show leadership in developing a definitive integrated energy strategy (i.e. coal, gas, renewables, uranium)
54. Government approval processes difficult to follow or understand by stakeholders
55. Unclear to stakeholders which government department is responsible for what - approval, regulation and promotion of the industry (i.e. DMIRS, DPIRD, DWER)
56. Community is unclear of the role of three tiers of Governments (i.e. Commonwealth, State and local government) in developing and implementing key policy in this industry (e.g. council bans on industry, energy security policy at state level, carbon tax)
57. Perception with some stakeholders that the cumulative effects from the onshore industry are not well understood or focussed on by regulators
58. Government departments recommending industry to undertake more stakeholder engagement. However, the key issue of "how" good stakeholder engagement should be implemented (e.g. face-to-face, workshops) is rarely discussed or valued
59. Rights of landusers vs industry continues to be area of concern for sections of the community.

All stakeholders: Environmental and Social

60. Value protection of water quality – e.g. from well integrity (long term), chemicals used and volumes of water used in the process
61. Very limited stakeholder concern about conventional gas extraction
62. Clean-up and rehabilitation process are considered very important
63. Industry needs to show leadership in being good corporate citizens.

Positive feedback √

Top 5 most significant issues – Kris Barnes opinion 1

Updated Dec 8th 2017

Mid West Key Stakeholder Questions

Meet2Create.com

1. What are the potential benefits of the industry to me? E.g. direct and indirect jobs, family employment, sponsorship, infrastructure?
2. When will projects come into production and will industry commit to using local people and local businesses?
3. Relative to other landuses in the region (i.e. agriculture, mining, light industry), how do the impacts to the environment from the onshore energy industry compare?
4. What does a full production field look like? Is it 10,000 wells?
5. What is fracking, what are the risks and how are these controlled?
6. What's the difference between fracking in WA vs other parts of the world where there is a perception of considerable environmental damage and health impacts?
7. What wells in the Mid West region will require fracking in either the exploration or production phase?
8. When has there been a problem in WA with well integrity and what has been done to ensure that similar problems don't happen again?
9. What formal, written guarantees will the company and government provide to the local community to ensure that local drinking water supplies are not affected by the industry?
10. Why should local residents accept the risks associated with the onshore energy industry when there is already plenty of gas in other parts of the state?

Meet2Create

Shire of Irwin Community Roundtable

Q&A Tracking Table

This document tracks progress of questions and answers raised by the community during the Shire of Irwin Community Roundtable Workshops. This document was prepared as a request from the community at the 7/12/2016 workshop. Please contact Kris Barnes (Independent Facilitator) for any further information (0411 700 259, krisbarnes@iinet.net.au).

Updated 1/12/2017

Purpose of Workshop

- Further encourage two way conversations between stakeholders and AWE regarding onshore energy projects in the Shire of Irwin, particularly those associated with the proposed Waitsia Gas Project development
- Answer key priority questions that were identified by the community
- Get a project update from AWE
- Discuss nominations for community roundtable membership
- Focus on clarifying what the community wants and how to best help deliver benefits from AWE's ongoing presence in the region

Questions yet to be 100% answered

Questions answered or actions complete

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Questions Raised By Community	Page	Status
Question 1: Does our attendance here (Community Roundtable) give blanket approval for a social licence?	5	Completed
Question 2: What is the specific process and chemicals to be used particular to each well to be fracked in this region? How much of a risk is it to human health and the environment. How is this risk managed?	5	Completed
Question 3: How do land access agreements work in practice?	6	Completed
Question 4: What is the project schedules for AWE: when, start-up time, notice to community?	9	Completed
Question 5: What monitoring is in place.- Baseline, Air and Water. CSIRO Project?	10	10%
Question 6: What are the potential benefits of the industry to each stakeholder? E.g. jobs, sponsorship, infrastructure, subcontracting opportunities?	11	50%
Question 7: What are the chemicals used in the fracking process and how much of a risk are they to the environment and human health should they get into the water supply?	11	Completed
Question 8: What are the processes and procedures used to ensure well integrity – especially in the long term? When has there been a problem in WA with well integrity and what has been done to ensure that similar problems don't happen again?	11	20%
Question 9: What is the approvals process?	11	20%
Question 10: Is it possible to get more public information on the DMP website relating to audits of company performance (e.g. what checks have been done, when?)	12	Completed
Question 11: What is the relevance/significant of toxicity of the chemicals used in the industry compared to other industries (e.g. farms and Roundup)?	12	Completed
Question 12: What soil and water testing is done? Who does it and when?	13	Completed
Question 13: If a tailings dam wall breaks – how is it managed? Does it go into the soil and how is this cleaned?	14	Completed
Question 14: How are chemicals managed at the end of their life of use?	14	Completed
Question 15: How advanced is the science on the chemicals used and what is the confidence level that they are safe (e.g. we thought asbestos was safe)? (raised 7/12/2016 as supplemental question to DMP brief)	14	Completed
Question 16: If there is a well integrity issue, how are chemicals managed?	15	Completed
Question 17: What information is available for historic wells and can we access this?	16	Completed
Question 18: What is the Water for Food program?	17	Completed

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Questions Raised By Community	Page	Status
Question 19: How will the Water for Food program work if there are existing/future resource leases over the same area?	17	Completed
Question 20: How does Water for Food fit with Irwin Park Farm?	18	Completed
Question 21: Where does Dongara gas go?	18	Completed
Question 22: If we cut of gas in Mid West what impact would it have to the state?	18	Completed
Question 23: Does decommissioning of wells include full rehabilitation?	18	Completed
Question 24: Will local services be used?	19	Completed
Question 25: What is the cost (of the Rehabilitation)?	19	Completed
Question 26: What does rehabilitation (of decommissioned wells) involve?	19	Completed
Question 27: What is landowner wants full rehabilitation (from decommissioning activities)?	19	Completed
Question 28: Who is responsible for clean-up at Jingemia and compliance (referring to whistleblower case)?	20	20%
Question 29: Is the mineral sands company going to mine?	20	Completed
Question 30: What percentage is conventional vs unconventional?	20	Completed
Question 31: CSIRIO: Offered to speak about the work that they have been doing in Mid West relating to the oil and gas industry	20	0%
Question 32: Is Beach Energy about to be onsold?	21	Completed
Question 33: How many more wells are coming in the area?	21	Completed
Question 34: How big is the area to be consumed by the activity? Can this be put into perspective with other activities in the area?	21	Completed
Question 35: How many people in the community will receive training so that they can apply for some of the potential jobs?	22	Completed
Question 36: Can we get a breakdown of the $16m in FY16 and $10m in FY17 into the Mid West economy? Who are the top 10 beneficiaries?	22	50%
Question 37: What does the local community get long term?	23	Completed
Question 38: Has AWE modelled how money is tracked and used in the community?	23	Completed
Question 39: How much land has AWE brought up and is there a plan to buy up more land for future activities?	23	Completed
Question 40: How many wells are we going to get close to the townsite?	23	Completed

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Questions Raised By Community	Page	Status
Question 41: How many employees since 2014 has AWE employed?	**23**	**Completed**
Question 42: What is the acreage of the Irwin Farm?	**24**	**Completed**
Question 43: Has any consideration been given to use some of the land at Irwin Farm by community organisations to raise money for their cause?	**24**	**Completed**
Question 44: Can industry continue to use horizontal drilling?	**24**	**Completed**
Question 45: How many slick water practices have been used in WA?	**24**	**Completed**
Question 46: How can problems in Pennsylvania be prevented from coming here?	**24**	**Completed**
Question 47: How much water is used in the fracking process and how does this compare to other industries?	**25**	**Completed**
Question 48: Only 60% of water is returned to the surface. Is this right? There is a general concern on bringing water from other areas and depositing it to new areas.	**25**	**Completed**
Question 49: Is the scientific enquiry any different to the one in 2014?	**25**	**Completed**

Q&A: Progress Status

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 1: Does our attendance here (Community Roundtable) give blanket approval for a social licence? (raised 26/10/2016)						
AWE	AWE answered on 26/10/2016.	Jane Aberdeen	26/10/2016	This question was answered at the 26/10/2016 workshop.	M	**Completed**
ANSWER	AWE Answer No, participation in the workshop does not indicate social licence approval. The roundtable is in response to stakeholder feedback and the intention is to provide a mechanism for discussion of issues of interest from a range of stakeholders.					
Question 2: What is the specific process and chemicals to be used particular to each well to be fracked in this region? How much of a risk is it to human health and the environment. How is this risk managed? (raised 26/10/2016)						
Department Mines and Petroleum	DMP to prepare to answer these questions at 7th December 2016 workshop.	DMP	7/12/2016	This question was answered at the 7/12/2016 workshop. Link: Additional questions were also raised and are contained in Supplemental Questions and then tracked from Questions 10-17.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP Answer: <u>What is the specific process and chemicals to be used particular to each well to be fracked in this region?</u> • All chemicals used by the industry must be disclosed in a transparent process as required by regulation • Chemicals used in all wells are available on the DMP website https://ace.dmp.wa.gov.au/ACE/Public/PetroleumProposals • During the workshop the community visited the DMP website to confirm this process <u>How much of a risk is it to human health and the environment? How is the risk managed?</u> • Fracking fluid is made up of 90% water, 9.5% sand, 0.5% chemicals. Chemicals are added for different reasons (e.g. breakers) • Brad provided an analogy of the chemicals used in the onshore energy industry. He used the example of fracking fluid having similar toxicity to a backyard swimming pool. Risk to human health was minimal • There is a specific process to assess chemical risk AS/NZS ISO 31000:2009 Risk Management Standard • Brad explained that there are 3 key aspects – chemical hazard source, pathway and exposure receptor. All three of these are needed for a risk to be realised.					
Question 3: How do land access agreements work in practice? (raised 26/10/2016)						
Sally O'Brien (Landowner)	Sally to provide her personal experience on how the land access agreements have worked from her perspective.	Sally O'Brien	7/12/2016	This question was answered at the 10/5/2017 workshop. Further questions were also raised and are captured as subsets below.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	Early Days • Sally's family came to the area in the 1930's • There had been some "cowboy" oil and gas companies come through the region in the past and undertook seismic surveys. Companies approached farmers individually. • In the early days, Sally felt that there wasn't much that her family could do about oil and gas companies coming onto their land. This had caused her concern because she felt the integrity of her products and family was important • Sally expressed to the workshop that her family cared deeply for the land and wanted to hand it over to the next generation in even a better condition than how they received it. 2011 • Origin, with AWE as a minor shareholder, approached Irwin landholders regarding conducting bar far the most intensive seismic survey ever to be conducted in the region • All landholders initially worried about what work they wanted to do • Sally was also concerned that companies were approaching farmers individually rather than as a collective. Local landholders joined together to collectively negotiate access agreement and compensation rates. Successful outcome. 2014 - today • AWE sought regulatory approval for Irwin-1 appraisal well and approached our business to negotiate an access and compensation agreement • We had a family discussion on what this meant to us. We believe that we are consumers of energy and that it would be hypocritical of us if we didn't do it. Having it on our land gives us the opportunity to influence how the process is conducted and managed for all. Developed what we felt was a fair access and compensation agreement with AWE representatives over a period of nearly 12 months • The families experiences from many years of dealing with oil and gas companies assisted in the development of a land user access agreement template, a joint initiative of farming groups and industry • We had good input into appropriate site access (i.e. avoiding direct access in some circumstances and getting a good new road where we wanted it) • We will get a new agreement it the company chooses to go into production phase. We feel our agreements give us some control • We are always looking out for new technology with oil and gas so that things can be done better • It is always best to keep communicating and trying to find common ground and agreement; all the while getting you the best outcome. This was a key theme of Sally's conversation.					

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
	Questions Do you have a sunset clause? ANS: Yes Does AWE have a right to purchase the farm if gas comes in? Ans: No What happens to compensation if something happens onsite or offsite? Ans: AWE is responsible for operating within the approvals granted and would have to clean-up any contamination caused as a result of its activities (i.e. on or off-site). If I don't have a baseline study am I protected? Ans: Yes, however, baseline studies help to show cause and effect. Have you had any abandoned wells on your property? Ans: Yes. Two exploration wells but these have been rehabilitated. Comment: Jane Aberdeen. When you take on exploration you take on decommissioning. Has your family had baseline health checks as there could be health issues associated with this industry? Ans: No Facilitator comments: There were also some Q&A related to the commercial interests of Sally O'Brien. The facilitator does not believe that it is appropriate that these conversations are recorded in these notes. It is recommended to contact Sally directly on these questions and answers as they are of a personal nature.					
DMP	DMP provided a brief overview of the process at the 16/2/2017 workshop and contributed to the discussions at the 10/5/2017 workshop.	DMP	10/5/2017		M	100%

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP ANSWER The DMP provided a short overview of the land access working group. Key points included: • A Land Access Working Group has been established to review the statutory framework for land access by the resources industry • The move is a direct response to recommendations from the Standing Committee on Environment and Public Affairs report on 'Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas'. • The Land Access Working Group comprises representatives from industry and farmer bodies, local government (WALGA), NGO's and various State Government agencies • The working group is chaired by DMP's Director General • Community consultation will occur in the mid west of Western Australia in the coming months • The first stage of the group is looking at access to free hold land for petroleum activities • The group will provide a report and recommendations no later than 30 June 2018 for consideration by the State Government in relation to resources land access issues.					
AWE	Provide perspective on their land access agreements.	Jane Aberdeen	7/12/2016	Made comment at 10/5/2017 workshop.	M	100%
Question 4: What is the project schedules for AWE: when, start-up time, notice to community? (raised 26/10/2016)						
AWE	Provide update on project schedules.	Jane Aberdeen	7/12/2016	This question was answered at the 7/12/2016 workshop.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	AWE Answer <u>Waitsia Gas Project - to date</u> • Senecio-3 well discovered the Waitsia Gas Field in September 2014 • Appraisal wells, Waitsia-1 and Irwin, drilled in 2015 • Diagnostic Fracture Injection Tests conducted in July 2016 at Waitsia-1 and Irwin-1 • Stage 1A - Extended Production Test • Involved installing infrastructure to allow gas to flow from two wells through a newly constructed 7km pipeline to the existing Xyris Production Facility • Mid West businesses contracted to help (~$12 m of contracts to local service providers) • The Extended Production Test results will help plan for further development (e.g. Stage 2) • Commissioned in August 2016 and community launch held, including a site tour. <u>Waitsia Gas Project - Next steps</u> • Waitsia Gas Project Stage 2 – planning is underway • Exploration/appraisal • Two wells planned in April-June 2017 • Waitsia-3 – will be on private land near the Yardanogo Nature Reserve. and on the same block as the Mondarra-2 well. • Waitsia-4 will be on private, cleared agricultural land near the Xyris Production Facility • Required approvals are nearing completion • Results will help Waitsia Gas Project field development planning • Stage 2 production will be from free flowing gas (i.e. does not involve hydraulic fracture (fracking) stimulation) • Gas production • A new gas production facility is in early stages of planning. It will be located somewhere east of the Xyris Production Facility on private, cleared agricultural land and provide up to 100 TJ of gas a day when it is operating • Following further internal approvals, construction will commence in 2018 with gas being produced in 2020 • Procurement process will again include local service providers, similar to Stage 1A process					
Question 5: What monitoring is in place.- Baseline, Air and Water. CSIRO Project? (raised 26/10/2016)						
AWE	Provide an outline at the next workshop.	Jane Aberdeen	10/5/2017	In development for 10/5/2017 workshop.	H	10%

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 6: What are the potential benefits of the industry to each stakeholder? E.g. jobs, sponsorship, infrastructure, subcontracting opportunities? (raised (26/10/2016)						
TBA	TBA	TBA	TBA	TBA	H	10%
Question 7: What are the chemicals used in the fracking process and how much of a risk are they to the environment and human health should they get into the water supply? (raised 26/10/2016)						
DMP	DMP to prepare to answer this question at the next Community Roundtable.	DMP	7/12/2016	This question was answered at the 7/12/2016 workshop. Refer also Question 2 above. Link: Additional questions were also raised and are contained in Supplemental Questions and then tracked from Questions 10-17.	H	**Completed**
ANSWER	DMP Answer Refer question 2 above.					
Question 8: What are the processes and procedures used to ensure well integrity – especially in the long term? When has there been a problem in WA with well integrity and what has been done to ensure that similar problems don't happen again? (raised 26/10/2016)						
DMP	TBA	TBA	TBA	This question overlaps with Question 16.	M	20%
Question 9: What is the approvals process? (raised 26/10/2016)						
TBA	TBA	TBA	TBA	TBA	M	0%

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 10: Is it possible to get more public information on the DMP website relating to audits of company performance (e.g. what checks have been done, when?) (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Link: Written answers provided by in supplementation Q&A document.	H	**Completed**
ANSWER	DMP Answer Answer: In response to stakeholder interest, DMP has developed a Transparency Policy and has several transparency improvement initiatives underway that respond to key issues of interest. An example is DMP's introduction of the down-hole chemical disclosure in 2012, which includes monitoring and reporting. From a regulatory perspective, there are some associated legal issues with publicly releasing site inspection results and data if it may be used at some point as evidence in a prosecution case. Notwithstanding, DMP is investigating ways of presenting a succinct summary of compliance inspections on the DMP website to help improve confidence in operational performance.					
Question 11: What is the relevance/significant of toxicity of the chemicals used in the industry compared to other industries (e.g. farms and Roundup)? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP Answer Chemicals used in the resources sector are comprehensively assessed prior to use and carefully monitored during use for each specific activity. As mentioned, the chemical disclosure requirements are rigorously applied. Environment Plans approved for each activity include information about the specific chemical products approved for use. These are available on the DMP website. Use of similar chemicals in other sectors (e.g. broad acre farming, intensive horticulture) are not as closely regulated. The Department of Agriculture and Food (DoAF) is the lead agency for regulating chemical use in agricultural sector. DoAF does not require activity specific assessment, monitoring or reporting. There is lots of information available on the internet for the relative toxicity of various chemicals used by agriculture, mining, medicines, petroleum, etc. The DMP Environmental Risk Assessment for Chemicals provides a good overview: http://www.dmp.wa.gov.au/Documents/Environment/ENV-PEB-165.pdf					
Question 12: What soil and water testing is done? Who does it and when (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**
ANSWER	DMP Answer Answer: Soil and water quality are key factors assessed and regulated for each activity. Baseline monitoring is required so once activities are underway and completed, any significant changes in monitoring results can be detected and acted upon promptly to mitigate any impacts. DMP assesses and approves proposed monitoring protocols that have been developed by technical specialists prior to the activities starting. Monitoring protocols focus on the potential contamination source, the pathway and any potential receptor. Ongoing non-specific water monitoring within sumps for chemicals is extremely expensive and not a good use of tax payer resources – instead DMP inspects the chemicals being stored on site against what has been approved for use. Sumps may contain a mixture of drilling, cementing, fraccing and waste fluids – so concentrations of chemicals would not be identical to what is in the chemical disclosure information. Water testing of sumps is not undertaken as this water is contained in a lined sump and not released to the environment. If any leaks or spills occur to the environment, then DMP requires companies to undertake soil and water testing as part of their clean up (to ensure that the environment is returned to a non-polluted state). Water quality monitoring is generally undertaken by independent consultants. Baseline groundwater monitoring is also best practice for any drilling activities to get an understanding of water quality pre and post drilling. Monitoring continues throughout the activity and afterwards too.					

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 13: If a tailings dam wall breaks – how is it managed? Does it go into the soil and how is this cleaned? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document	H	**Completed**
ANSWER	DMP Answer Answer: Sumps are required to be constructed to overflow rather than break. DMP requires companies to have freeboard (extra) volume in their sumps to cater for exceptional rainfall events. Spill contingency plans must also be approved by DMP to deal with any type of spill (large or small). Overflows / breaches must be reported to DMP, investigated and cleaned up.					
Question 14: How are chemicals managed at the end of their life of use? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**
ANSWER	DMP Answer All chemicals are disposed of at an appropriate DER licensed waste facility. Chemicals contained within evaporation ponds are tested after drilling activities have ceased. If these chemicals are found to be above guideline levels they are removed and disposed of at an appropriate DER licensed waste facility.					
Question 15: How advanced is the science on the chemicals used and what is the confidence level that they are safe (e.g. we thought asbestos was safe)? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP Answer Answer: Chemicals are a part of everyday life – and we are exposed to a larger number of chemicals every day. The body of scientific knowledge on approved chemicals is significant and is the foundation for the assessment of risk. If this body of knowledge changes, then we apply that to our new understanding of risks and controls. This is exactly the same for any industry and medical science too. At DMP all chemicals proposed for use by a petroleum company are risk assessed according to WA environment and safety regulations before they are approved or rejected. DMP uses the most current scientific knowledge to assess the toxicity and biodegradability of chemicals. Petroleum companies must demonstrate that the chemicals used do not pose significant risk to human health, the environment or groundwater resources. If a significant risk or potential impact is identified then the proposal is referred to the EPA for an independent environmental assessment.					
Question 16: If there is a well integrity issue, how are chemicals managed? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP Answer There are many classifications of well integrity issues (see Petroleum in Western Australia magazine, April 2015, pp 24—25, available at http://www.dmp.wa.gov.au/Petroleum/Publications-1601.aspx). The majority of well integrity issues do not allow interaction between the internal contents of the well and the groundwater or surface environment. In circumstances where external well casing may be compromised, if the integrity issue cannot be remediated, the well will be decommissioned. Decommissioning involves installing a series of cement plugs that provide isolation internally between different vertical zones in the well and also provides isolation from the external rock formation. If repair is possible, a steel casing patch (a sort of internal sleeve) may be installed, or a seal can be created by squeezing cement through holes usually involves the application of a patch onto the interior of the casing. To enable patching, the well is filled with fluid containing chemicals including biocides, corrosion inhibitors, and pH adjustors. These chemicals degrade into inactive versions over time. In some cases, fluid density is increased with the use of salts. After the well is patched and normal operations re-commence, the fluid is retrieved to surface from inside the well casing. Loss of the fluid into the rock formation is minimised. Once the repair is completed, the fluid is replaced by a clean water-based fluid which also contains small amounts of corrosion inhibitors, biocides and pH adjustors. This fluid stays within the casing to protect it from internal corrosion. In line with other chemical usage in petroleum wells, the highest risk of using chemicals during well integrity operations occurs at the ground surface. Mitigation measures are kept in place to minimise the risk of such events. A DMP speaker on well management may be available to further answer this question at a later date.					
Question 17: What information is available for historic wells and can we access this? (raised 7/12/2016 as supplemental question to DMP brief)						
DMP	DMP to provide written answer and if necessary talk about this at the next workshop.	Lyn Reid	1/2/2017 (written) 16/2/2016 (talk)	Some informal discussions took place on this question at the 7/12/2016 workshop. Written answers provided by DMP in supplementation Q&A document.	H	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMP Answer Answer: Information about historical wells is available online through the Department of Mines and Petroleum WAPIMS system (information and free access at http://www.dmp.wa.gov.au/Petroleum-and-Geothermal-1497.aspx). To learn about a particular well, select the Wells tab at top and type in the well name and press Search. In the next screen, click on the well name until the row turns blue. Press View Details for Selected Rows and all the publically available information about the well will be displayed in multiple tabs. In general, detailed information becomes publically available two years after the well activity is completed. The Well Completion Report contains significant amounts of information about how the well was constructed, chemicals used during drilling, and the surrounding geology. The report, although highly technical, is often clear enough to be understood by members of the public. For specific questions about available information, please contact the DMP.					
Question 18: What is the Water for Food program? (raised 7/12/2016)						
Department of Water	DoW to provide written answer and if necessary talk about this at the next workshop.	Darryl Abbot	1/2/2017 (written) 16/2/2016 (talk if necessary)	Some informal discussions took place on this question at the 7/12/2016 workshop. Documentation and presentation provided at 16/2/2017 workshop. Written answers provided by DoW in supplementation Q&A document.	H	**Complete**
ANSWER	DOW Answer The following links are two brochures that summarise the program and provide detail on the midlands projects. (Link)					
Question 19: How will the Water for Food program work if there are existing/future resource leases over the same area? (raised 7/12/2016)						
Department of Water	DoW to provide written answer and if necessary talk about this at the next workshop.	Mark Canny	1/2/2017 (written) 16/2/2016 (talk if necessary)	Some informal discussions took place on this question at the 7/12/2016 workshop. Documentation and presentation provided at 16/2/2017 workshop. Written answers provided by DoW in supplementation Q&A document.	M	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DoW Answer Agriculture, including irrigated agriculture, and mining/petroleum activities have co-existed in the Midlands region for a considerable period. Additionally, the government has a clear policy position supporting multiple land use, including petroleum activities and irrigated agriculture, to make the best use of land and water resources. Water for food is about providing updated information to existing landowners to assist them make investment decisions underpinning a move into, or expanding, irrigated agriculture. The program will not impact on existing or future "onshore petroleum" petroleum resource leases, and any future investment decisions by the landowner, and associated approval processes, will not change. Existing regulatory procedures will still apply.					
Question 20: How does Water for Food fit with Irwin Park Farm? (raised 7/12/2016)						
AWE	Answered verbally during the workshop (7/12/2016) and captured in notes.	Jane Aberdeen	7/12/2016	This question was answered at the 7/12/2016 workshop.	M	**Completed**
ANSWER	AWE Answer Jane explained that the Minister for Water announced the initiative on Christmas Eve 2015. Water for Food staff subsequently met with AWE as Irwin Park Farm had been included in the Water for Food Midlands project area. The project helps provide another example of agriculture and gas sectors coexisting. AWE agreed to assist the project by allowing DoW to install shallow groundwater monitoring bores on Irwin Park Farm					
Question 21: Where does Dongara gas go? (raised 7/12/2016)						
AWE	Answered verbally during the workshop (7/12/2016) and captured in notes.	Jane Aberdeen	7/12/2016	This question was answered at the 7/12/2016 workshop.	M	**Completed**
ANSWER	AWE Answer Transported via pipeline to Perth for domestic and industrial consumer consumption					
Question 22: If we cut of gas in Mid West what impact would it have to the state? (raised 7/12/2016)						
DMP	Answered verbally during the workshop (7/12/2016) and captured in notes.	Brad Jakowyna	7/12/2016	This question was answered at the 7/12/2016 workshop.	M	**Completed**
ANSWER	DMP Answer Security of supply impact, cost/price of gas impact					
Question 23: Does decommissioning of wells include full rehabilitation? (raised 7/12/2016)						
AWE	Answered verbally during the workshop (7/12/2016) and captured in notes.	Jane Aberdeen	7/12/2016	This question was answered at the 7/12/2016 workshop.	M	**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	AWE Answer Yes					
Question 24: Will local services be used?						
AWE	AWE answered on 16/2/2017.	Jane Aberdeen	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer AWE will continue using as many local business services as possible in the project, although decommissioning the actual well requires specialist services. The procurement process includes local service providers for general activities required during site rehabilitation like earthworks. AWE is using similar procurement approach to the Stage 1A process.					
Question 25: What is the cost (of the Rehabilitation)?						
AWE	AWE answered on 16/2/2017.	David Guise	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer This year project costs will be about $7 million.					
Question 26: What does rehabilitation (of decommissioned wells) involve?						
AWE	AWE answered on 16/2/2017.	David Guise	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer Decommissioning involves installing plugs within the well to isolate it from any aquifers, then cutting the wellhead below ground and backfilling to restore the soil profile. Rehabilitation then depends on the landowner's preference for final land use and what area is to be rehabilitated. Usually the land is returned for broad acre cropping or pasture. Need to also be mindful of weeds and soil hygiene especially if working in a conservation area. (Consultant's note: This issue might be worth exploring in a separate workshop agenda item).					
Question 27: What is landowner wants full rehabilitation (from decommissioning activities)?						
AWE	AWE answered on 16/2/2017.	David Guise	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer Our agreements with landowners require us to restore the land to its previous land use and in negotiation with the landowner. Specific details are negotiated with each landowner as some prefer keeping infrastructure such as gravel roads and fences as they are seen as improvements. For example, the Drover-1 well took six months to complete decommissioning and rehabilitation.					

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 28: Who is responsible for clean-up at Jingemia and compliance (referring to whistleblower case)?						
Origin	Answered verbally during the workshop (16/2/2017) and captured in notes. However, AWE cannot speak on behalf of Origin. Action: Rod to send list of questions to Jane Aberdeen for passing onto Origin. Origin to be asked if they would present at a future workshop.	Rod Copeland/ Jane Aberdeen	10/5/2017	Waiting on questions. Origin potentially available to speak at future workshop.		20%
Question 29: Is the mineral sands company going to mine?						
AWE	Answered verbally during the workshop (16/2/2017) and captured in notes.	Jane Aberdeen	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer Tronox has environmental approvals to proceed with the minerals sands mine although they said they have no immediate plans to do so. This reflects the low global demand for mineral sands and low market prices.					
Question 30: What percentage is conventional vs unconventional?						
AWE	Answered verbally during the workshop (16/2/2017) and captured in notes.	Jane Aberdeen	16/2/2017	This question was answered at the 16/2/2017 workshop.		**Completed**
ANSWER	AWE Answer Stage 2 gas is free flowing (conventional). Future appraisal well results may show tight sands present.					
Question 31: CSIRIO: Offered to speak about the work that they have been doing in Mid West relating to the oil and gas industry						

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
CSIRO	CSIRIO: Present at the next workshop about the work that they have been doing in Mid West relating to the oil and gas industry			The community agreed at 16/2/2017 to have CSIRO speak at 10/5/2017. However, two factors prevented this. First, the CSIRO representative was not available on 10/5/2017. Also, the priority of this item needs to be discussed against other previous high priorities (see above). Kris Barnes to raise this at 10/5/2017 meeting.		0%
Question 32: Is Beach Energy about to be onsold?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Steve McCracken	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**
ANSWER	AWE Answer Beach Energy is buying the Lattice Energy assets. No participant knew of any other sales plans. Beach Energy is best placed to answer this question.					
Question 33: Question: How many more wells are coming in the area?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Steve McCracken	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**
ANSWER	AWE Answer About 17 or 18 planned, less than number of wells used for Dongara field. Some will be from same well pad. No need to frack for Stage 2. May be less wells over life of the project depending on appraisal results.					
Question 34: How big is the area to be consumed by the activity? Can this be put into perspective with other activities in the area?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Steve McCracken	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	AWE Answer Proposed new facility will have smaller footprint than the Hovea Production Facility area. Refer to Dongara gas field area, producing since 1971, which looks like farm land (e.g. existing wells and infrastructure are not noticed by many people now and new development will be similar in appearance). Decommissioning project means overall number of wells will decrease despite Stage 2 development.					
Question 35: How many people in the community will receive training so that they can apply for some of the potential jobs?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**
ANSWER	AWE Answer Facilities operators live locally and are employed through a contracting firm who trains them for the job. Most of the jobs will be through contractors during construction phase. Noted after the meeting: AWE sponsors a STEM scholarship at Geraldton TAFE and people interested are welcome to apply. Participant Jenny Devereux (Community/MidWest Labour Pool) – provided an example of an 18 year old who was employed for two weeks work experience by a contractor to AWE. (In addition, please refer to Question 24).					
Question 36: Can we get a breakdown of the $16m in FY16 and $10m in FY17 into the Mid West economy? Who are the top 10 beneficiaries?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was partially answered at the 8/11/2017 workshop. Action: Jane offered to provide a breakdown of expenditure into local economy once the update is available.	M	50%
ANSWER	AWE Answer The amount for FY 16 reflects local spend increased as a result of the Stage 1A development. Some of the top ten local companies included Dongara Skip Bins, Mitre 10, MidWest Labour Pool, Dongara Drilling and Dongara IGA. Estimated FY 17 amount provided is based on rates, sponsorships, local wages and work contracted in the Shire. An updated local spend analysis is underway and will be made available.					

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 37: What does the local community get long term?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	AWE Answer Refer to question 24 and 36.					
Question 38: Has AWE modelled how money is tracked and used in the community?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	AWE Answer To a degree. We track sponsorships and partnerships and some of our local expenditure. We are starting a more complete analysis.					
Question 39: How much land has AWE brought up and is there a plan to buy up more land for future activities?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**
ANSWER	AWE Answer AWE owns Irwin Park Farm and Locksley Farm. No plans to buy more land for AWE.					
Question 40: How many wells are we going to get close to the townsite?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	AWE Answer Senecio-3, drilled in 2014, is the closest well to the Irwin town site (Refer to project map presented at workshop 6: www.meet2create.com). No wells are planned for drilling next year and no additional wells will be required for Stage 2 of the development.					
Question 41: How many employees since 2014 has AWE employed?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		**Completed**
ANSWER	AWE Answer Depending on activity levels, AWE engages 12-14 full-time contracted operators at the facilities. These employees live locally. Other companies use fly-in/fly-out and drive-in/drive-out contractors.					

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
Question 42: What is the acreage of the Irwin Farm?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	AWE Answer Unsure. Think about 12,000 acres.					
Question 43: Has any consideration been given to use some of the land at Irwin Farm by community organisations to raise money for their cause?						
AWE	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jane Aberdeen	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	AWE Answer This suggestion had been mentioned and briefly discussed. No proposal to AWE presented and not yet considered.					
Question 44: Can industry continue to use horizontal drilling?						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	DMIRS Answer Yes, this practice is part of conventional drilling.					
Question 45: How many slick water practices have been used in WA?						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	DMIRS Answer Two. In addition, over 600 wells fracked in WA with no reported incidents. Post workshop, DMIRS provided a link for the community on stimulated wells in WA. http://www.dmp.wa.gov.au/Documents/Petroleum/PD-SBD-NST-126D.pdf					
Question 46: How can problems in Pennsylvania be prevented from coming here?						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed

Stakeholder to Answer	Action	Who	When	Notes on Progress	Priority (H,M,L)	% Complete
ANSWER	DMIRS Answer USA EPA report said that there has been no systemic contamination of water by fracking. Western Australia has a strict regulatory framework for this industry.					
Question 47: How much water is used in the fracking process and how does this compare to other industries?						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	DMIRS Answer Approximately 10 million litres of water (10,000KL) are required for a 10 stage deep shale hydraulic fracture stimulation program of which anywhere from 40 to 60% returns to the surface. This is the equivalent to the annual usage of 15-20 households and much lower than irrigated agriculture. (NB during the workshop the group also agreed that 10 commercial mango trees would use this amount of water in one year). In terms of sustainability of the groundwater resource, the Department of Water and Environmental Regulation would generally consider this a low volume and have a low risk of impacts on the environment or other users.					
Question 48: Only 60% of water is returned to the surface. Is this right? There is a general concern on bringing water from other areas and depositing it to new areas.						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	DMIRS Answer Use of water volume is low compared to other uses. The value of the end use of water is not assessed by the Department of Water and Environmental Regulation, and unless it is clearly wasteful, the Department of Water and Environmental Regulation would not make a value judgement on the best end use for water taken. (NB Please also refer to Q&A questions 10, 12, 18 and 19 relating to water. The Q&A document can be found on the website hosting the community roundtable information: www.meet2create.com)					
Question 49: Is the scientific enquiry any different to the one in 2014?						
DMIRS	Answered verbally during the workshop (8/11/2017) and captured in notes.	Jeff Haworth	8/11/2017	This question was answered at the 8/11/2017 workshop.		Completed
ANSWER	DMIRS Answer It is different because it is a scientific inquiry focused on environmental issues whereas the previous inquiry was a parliamentary inquiry.					

Commitments: Progress Status

Organisation	Action	Who	When	Notes on Progress	% Complete
Commitment 1: AWE to provide continued support for an independently-facilitated and resourced Community Roundtable					
AWE	Funding obtained from AWE.	AWE	August 2016	Funding obtained for independently facilitated process. However, any person or organization may contribute to these costs if there is concern over conflict of interest of the facilitator.	**Completed**
Commitment 2: Shire of Irwin to provide Community Roundtable with a workshop venue to use at no cost – Aug 2016					
Shire of Irwin	Shire of Irwin to provide a workshop venue at no cost for the Community Roundtable.	Shire of Irwin	August 2016	Shire of Irwin agreed to provide a workshop location at no cost.	**Completed**
Commitment Sought Number 3:					
Commitment Sought Number 4:					

Rockwater
PROPRIETARY LIMITED

DROVER-1
GROUNDWATER STUDY

May 2013

REPORT FOR
AWE LIMITED

(Report No. 387-1/13/01)

[redacted]

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1 INTRODUCTION

AWE Limited (AWE) is planning to drill and core a well on their exploration permit, EP455, 16.5 km east of Greenhead. If the results are favourable, a hydraulic fracturing programme will be undertaken. The preferred location of the site, to be known as Drover-1, is on cleared land adjacent to abandoned well Gairdner-1 (Fig. 1). The target reservoirs are in the basal Kockatea Shale, Carynginia Shale, Irwin River Coal Measures and High Cliff Sandstone; at depths of greater than 1,600 m.

As part of the environmental assessment of the project, AWE has commissioned Rockwater to undertake a study of the groundwater system at the site. Groundwater use for the project is estimated to be 6 ML for the drilling operation and up to 4 ML for the hydraulic fracturing programme (assuming 4 stimulations). As anticipated groundwater use is expected to be minimal and the target reservoirs are at significant depths below aquifers, the hydraulic fracturing programme is anticipated to be of negligible risk to the groundwater system. Nevertheless, as the Drover-1 site is located adjacent to Lesueur National Park and has a minor component of surface infrastructure and potential contaminants, AWE is aiming have a thorough hydrogeological understanding of the site so any potential risks can be minimised.

2 GEOLOGY

2.1 STRATIGRAPHY

The stratigraphic sequence beneath EP455 is summarised in Table 1 and incorporates interpretations by AWE, Lipski (1991), Mory and Iasky (1996) and Kern (1997).

Gairdner-1 intersected sedimentary rocks of Permian to Late Triassic age over a total depth of 2,172 m as illustrated in Figure 2. Although not noted in the Gairdner-1 lithological descriptions, the surface geology over the majority of the study area is mapped as Tertiary laterite and associated sand (Fig. 3). A sequence of Jurassic strata is mapped at the surface east of the Drover-1 site.

Table 1: Strata within EP455

Formation	Age	Regional Lithology
Laterite and associated sand	Tertiary	Leached quartz sand over pisolitic to massive ferruginous laterite
Yarragadee Formation	Mid to Late Jurassic	Sandstone with siltstone and claystone beds; up to 2000 – 4000 m thick
Cadda Formation	Mid Jurassic	Shale, siltstone, and sandstone, locally limestone
Cattamarra Coal Measures	Early to Mid Jurassic	Sandstone, carbonaceous siltstone; minor coal
Eneabba Formation	Early Jurassic	Sandstone, multicoloured siltstone and claystone; minor coal
Lesueur Sandstone	Mid to Late Triassic	Sandstone, coarse-grained, pebbly; minor siltstone and conglomerate
Woodada Formation	Early to Mid Triassic	Sandstone, fine-grained, and carbonaceous siltstone
Kockatea Shale	Early Triassic	Shale, dark, siltstone, and minor sandstone and limestone
Carynginia Limestone	Late Permian	Probably equivalent to the Beekeeper Formation (Hall and Kneale 1992) – sandstone, skeletal limestone, and shale
Carynginia Shale	Early Permian	Siltstone, micaceous and carbonaceous, lesser sandstone and conglomerate
Irwin River Coal Measures	Early Permian	Alternating sandstone, siltstone, carbonaceous shale, and coal.

The stratigraphic sequence is described below, from oldest to youngest and a Tertiary subcrop geology map is presented as Figure 4.

2.1.1 Permian

The Permian section consists of the Irwin River Coal Measures and the Carynginia Formation. Although not intersected by Gairdner-1, the High Cliff Sandstone, which comprises interbedded sandstone, conglomerate and minor siltstone, is interpreted to underlie the Irwin River Coal Measures at this location.

The Irwin River Coal Measures, comprising coal and carbonaceous shale interbedded with sandstone and siltstone was intersected over the lowermost 138 m of Gaindner-1 and was not fully penetrated. It has a maximum known thickness of 307 m in Arrowsmith-1, about 25 km to the north (Fig. 3, Mory and Iasky 1996).

The overlying Carynginia Formation is informally divided by AWE and Lipski (1991) into a lower shale member and an upper limestone member (Fig. 2). However, Mory and Iasky (1996) interpret the limestone in this part of the stratigraphic section to correlate with the Beekeeper Formation, which they indicate sits unconformably on the Carynginia Formation. The Carynginia shale member, capping the Irwin River Coal Measures, is 259 m thick in Gairdner-1 and the overlying Carynginia limestone member is 35 m thick.

The High Cliff Sandstone, Irwin Rover Coal Measures and the Carynginia Shale are potential targets of the drilling and hydraulic fracturing investigation.

2.1.2 Triassic

Three formations comprise the Triassic-age strata in Gairdner-1: Kockatea Shale, Woodada Formation and Lesueur Sandstone. Based on the data from Gairdner-1 the base of the Triassic is at 1,740 m below rotary table (brt) and strata of that age continue to the surface.

The lowest unit, the Early Triassic Kockatea Shale, is 852 m thick in Gairdner-1. The geophysical logs indicate consistently shaley strata (Fig. 2). The basal 100 m of this shale is another potential target of the hydraulic fracturing investigation.

The Mid Triassic Woodada Formation, which consists predominantly of sandstone and siltstone, is 311 m thick in Gairdner-1. Geophysical logs from Gairdner-1 suggest that the formation is a thinly-bedded, fine-grained unit (Fig. 2).

The Late Triassic Lesueur Sandstone is predominantly a coarse-grained sandstone with traces of claystone and siltstone. The unit is 577 m thick in Gairdner-1 (Fig.2) and has been logged from the surface where it outcrops in places (Fig. 3 and 4).

2.1.3 Jurassic

Although not intersected by Gairdner-1, four Jurassic-age formations are recognised in the eastern part of EP455: Eneabba Formation, Cattamarra Coal Measures, Cadda Formation and Yarragadee Formation (Fig. 4).

The lowest unit, the Early Jurassic Eneabba Formation, is characterised by multicoloured siltstone and claystone with sandstone interbeds and is known to be up to 854 m thick.

The Early to Mid Jurassic Cattamarra Coal Measures is up to 1,500 thick and consist of fine- to coarse- grained sandstone interbedded with carbonaceous siltstone and claystone, with coal seams of up to 11 m thickness.

The Mid Jurassic Cadda Formation has a maximum known thickness of 290 m (Mory and Iasky 1996) and consists of shale, siltstone and medium to very coarse grained sandstone grading to a shelly limestone at some locations.

The Yarragadee Formation is of Mid to Late Jurassic age and consists of fine to coarse grained feldspathic sandstone, siltstone and claystone with minor conglomerate and coal. It is known to be between 2,000 m to 4,000 m thick, thickening to the east.

2.1.4 Tertiary

Laterite and associated sand are widespread across the Arrowsmith Region, which occurs east of the Gingin Fault where Drover-1 is to be located (Fig. 3). This unit was not noted in the lithological log for Gairdner-1.

2.2 GEOLOGICAL STRUCTURE

The Mesozoic strata of the Perth Basin in the Drover-1 environs dip at very low angles, generally downwards to the east and north. They are cut by regional faults that trend mainly northerly: the Beagle and Coomallo Faults, that delineate the Cadda Terrace (on which Drover-1 is located), and several lesser faults that produce negligible displacement and trend to the north-west and east (Figs 3 and 4). The strata are essentially continuous over the Cadda Terrace, which is about 25 km wide (E-W) and more than 100 km long (N-S).

The faults within the Drover-1 prospect are indicated in Figure 5. The map shows that the proposed Drover-1 is at least 4 km distance from the closest regional fault, the Beagle Fault to the west, and 3.3 km from the High Cliff Sandstone Marker Faults (part of the Peron Fault system) to the north-east.

3 HYDROGEOLOGY

3.1 SETTING

The Drover-1 site is in the Eneabba Plain Sub-Area of the Arrowsmith Groundwater Area, for Department of Water (DoW) management purposes (DoW 2010). The aquifers that are recognised in this subarea are listed in Table 2 (in order from shallowest to deepest).

Table 2: Aquifers in the Eneabba Plains and Twin Hills Sub-Areas

Aquifer	Formation	Typical Bore Yield (kL/day)	Groundwater Quality*	Distribution
Superficial	Bassendean Sand Tamala Limestone	small to moderate	marginal to brackish	Not present in study area –occurs west of Gingin Scarp
Yarragadee	Yarragadee Formation	large >1000	fresh to brackish	Not present at Gairdner-1 but occur beneath the eastern portion of EP455 (Fig. 4), within the Twin Hills Sub-Area
Cattamarra	Cattamarra Coal Measures	moderate >500	brackish to saline	
Eneabba	Eneabba Formation	moderate 500-1000	fresh to brackish	
Lesueur	Lesueur Sandstone	Large up to 2000	fresh to marginal	Occurs from surface in study area

Modified after DoW (2010)
*Fresh = <500 mg/L TDS; Marginal = 501-1500 mg/L TDS; Brackish = 1,501-5000 mg/L TDS; Saline = 5,001-50,000 mg/L TDS; Hypersaline = >50,000 mg/L TDS.

Of these recognised aquifers, the only one that is present at the Drover-1 site is the Lesueur aquifer, which is discussed in detail in Section 3.2. The underlying Woodada Formation is

noted by Kern (1997) to be a minor multilayered aquifer, with confining argillaceous beds, which is in hydraulic connection with the overlying Lesueur aquifer. At one test site (WL12 5 km east of Jurien) it contained relatively fresh groundwater but the salinity is more marginal elsewhere where the formation comprises thicker beds of fine-grained sandstone and siltstone.

The Eneabba, Cattamarra and Yarragadee aquifers occur to the east of the study site within the EP455 boundary (Fig. 4) but are within the adjacent Twin Hills Groundwater Sub-Area.

The relationships between the aquifers in the vicinity of EP455 are depicted in Figure 6.

3.2 LESUEUR AQUIFER

3.2.1 Groundwater Levels and Flow

Accurate groundwater level data in the vicinity of the study area are limited and data from the DoW's WIN database near the site include numerous irregularities (Fig. 7). For example, two bores (WIN ID 20007603 and 20007604) located 900 m and 150 m north-west of the proposed Drover-1 site have recorded water levels of 36 m AHD and 144 m AHD, respectively. Other data to the east of the site (e.g. WIN ID 20007589 and 20007602) indicate that some bores may access perched groundwater resulting in relatively elevated groundwater levels.

Isopotential data for the top of the Mesozoic Formations, recorded in May 1993 and presented by Kern (1997), are considered to provide a better estimate of groundwater heads in the Lesueur aquifer at the site (Fig. 7). These data, which include four measurement points within a 13 km radius of the site, indicate heads in the Lesueur aquifer decline from an elevation of about 76 m AHD, just west of the Peron Fault (2 km east of Drover-1), to about 63 m AHD, 6.4 km to the west where the Kockatea Shale/Carynginia Formation subcrops. The data imply that groundwater flow is towards the west to north-west. However, these 1993 groundwater level data are dated. Hydrographs for the shallower Leeman Shallow Project bores on the WIN database indicate that water levels have risen by between 0.8 and 2.5 m since 1993. WIN data for the Water Corporation's Leeman 1-91 bore, however, appears to include only pumping water levels (which are drawn down below the standing water level due to the pumping), with the level reported by Kern (1997) the only standing water level that is readily available.

The isopotentials from Figure 7 were used to estimate depth to groundwater at the site (Fig. 8). The derived data indicate that the depth to groundwater in the vicinity of Drover-1 and in the areas of Lesueur National Park, directly to the west and south of the site, is considerable (>100 m below ground level). To the west, near the boundary of the impermeable Kockatea Shale, the data suggest that the groundwater heads may approach

artesian. To the east, the plotted depth to groundwater and the WIN database data again do not correlate well, and the actual depth to groundwater is uncertain as discussed previously.

Surface water flow at the site is expected to follow topographic gradients, which generally slopes downwards towards the west to north-west.

3.2.2 Groundwater Recharge and Discharge

Groundwater recharge to the Lesueur aquifer in this area is derived predominantly from rainfall where the aquifer occurs at the surface or beneath thin surficial deposits. The aquifer outcrops within the Lesueur National Park, to the south, and sub-crops beneath a thin cover of Tertiary laterite and sand over the remainder of the area between the Beagle and Peron Faults. Therefore, there is a considerable area over which there is potential for rainfall recharge to occur. Some groundwater flow into the Lesueur aquifer, from the Eneabba Formation and Cattamarra Coal Measures, is likely to occur from the east across faults.

The water level data presented in Figures 7 and 8 suggest that groundwater discharge from the Lesueur aquifer occurs near the edge of the Beagle Fault system, along the eastern boundary of the Kockatea Shale. Upwards hydraulic head gradients in the Lesueur aquifer near this boundary result in discharge into the Superficial aquifer, which is present west of the Gingin Scarp (Fig. 8). Several springs occur close to this boundary (Section 4.2).

3.2.3 Groundwater Quality

Groundwater in the Lesueur aquifer typically has fresh to marginal salinity which most likely increases with depth. Salinities of water sampled from bores within the study area screened in the upper portion of the aquifer range from 450 mg/L to 1,435 mg/L Total Dissolved Solids (TDS) (Fig. 9). However, one bore, Amax Greenhead No.1 (WIN ID 20007614) which is constructed deeper in the aquifer (680 m bgl), has a reported salinity of 3,620 mg/L TDS. It is likely that the groundwater salinity in the Lesueur aquifer is slightly higher close the contact with the Eneabba Formation, which is known to contain more brackish groundwater; however, there are limited data within the study area to support this.

3.2.4 Aquifer Connectivity

The major regional confining layer between the hydrocarbon exploration targets (the basal 100 m of the Kockatea Shale, Carynginia Formation, Irwin River Coal Measures and the High Cliff Sandstone) and the overlying aquifers is the Kockatea Shale. The formation is 852 m thick in Gairdner-1 and geophysical logs indicate consistently shaley strata (Fig. 2). Elsewhere in the area the Kockatea Shale may be more than 1,100 m thick (in Eneabba-1 oil well; Mory 1994). The Kockatea Shale is recognised as a primary regional seal for

hydrocarbon plays in the northern Perth Basin (D'Ercole 2003) and, as such, would also form a major hydraulic confining layer.

The major aquifer, the Lesueur aquifer, and the underlying minor aquifer, the Woodada Formation, are likely to have some degree of hydraulic connection. However, they, both contain minor confining layers, which may impede or restrict vertical groundwater movement.

The hydraulic properties along faults in the area are difficult to assess without specific investigations, which have not been undertaken. There could be groundwater flow between adjacent aquifers where permeable strata are juxtaposed across a fault, such as the contact between the Lesueur aquifer and Eneabba Formation across the Peron Fault (Fig. 6). Additionally, faults that cut the strata are potential conduits for vertical movement of fluids. No significant faults have been identified in the vicinity of the hydraulic fracturing operations.

4 EXISTING GROUNDWATER USE

4.1 GROUNDWATER USERS

Groundwater extraction is licensed by the DoW and the available resources are managed for allocation purposes within defined areas. The Drover-1 site is located within the Eneabba Plain Sub-Area of the Arrowsmith Groundwater Area, although EP455 also intersects the Twin Hills Sub-Area of the Arrowsmith Groundwater Area, to the east, and the Cervantes, Nambung and Bagingarra Sub-Areas of the Jurien Groundwater Area, to the south (Fig. 10).

Active DoW licences to extract groundwater (GWLs) near Drover-1 are shown in Figure 10 and are summarised in Table 3. Only shallow domestic and stock watering bores are exempt from licensing. Such bores provide only small supplies, generally from the Superficial aquifer, and are the most numerous water-supply bores in the area.

Table 3: DoW GWLs Held Near Drover-1

GWL	GW Area Name	GW Subarea Name	Aquifer Name	Allocation (kL/a)
65700	Arrowsmith	Eneabba Plains	Lesueur	470,000
57960		Twin Hills	Yarragadee	70,000
171512		Twin Hills		24,000
167278		Dongara	Superficial	3,000
111221	Jurien	Cervantes	Superficial	55,000
175401				400,000

The data show that there is limited licensed groundwater use in the area directly surrounding Drover-1. The closest licence, GWL 65700 held by the Water Corporation (Leeman 1-91)

allowing 470,000 kL/a of groundwater to be extracted from the Lesueur aquifer, is located 4.2 km north-west of the proposed Drover-1 site. This is the only current GWL in the Lesueur aquifer within this sub-area and represents 26% of the allocation limit of 1,800,000 kL; with 1,330,000 kL/a currently available for allocation. The proposed 10 ML to be used by AWE in the drilling and hydraulic fracturing testing at Drover-1 would represent only 0.5% of the total annual allocation of the Lesueur aquifer.

The Yarragadee aquifer in the Eneabba Plains and Twin Hills Sub-Areas is the major groundwater resource, with the largest available allocation and currently allocated resources (Table 4). Most of the extraction from this aquifer occurs in the north-eastern parts of these sub-area where this aquifer outcrops or occurs at shallow depth.

Table 4: Groundwater Allocation Summary for Eneabba Plains and Twin Hills Groundwater Sub-Areas

Sub-Area	Aquifer	Allocation Limit (kL/a)	Licensed Allocation (kL/a)	Total Allocated, Committed and Requested (kL/a)	Allocated Resources (%)
Eneabba Plains	Cattamarra Coal Measures	100,000	0	0	0%
	Lesueur	1,800,000	470,000	0	26%
	Eneabba	2,000,000	800,000	1,400,000	70%
	Superficial	14,470,000	281,300	1,281,300	9%
	Surficial	0	0	0	0%
	Yarragadee	20,440,000	15,510,711	20,400,711	100%
Twin Hills	Cattamarra Coal Measures	500,000	0	0	0%
	Lesueur	200,000	0	0	0%
	Parmelia	3,400,000	46,000	46,000	1%
	Superficial	0	0	0	0%
	Surficial	490,000	0	0	0%
	Yarragadee	42,830,000	18,138,250	19,138,250	45%

Data from the DoW - dated 25 March 2013

4.2 GROUNDWATER DEPENDENT ECOSYSTEMS

The depth to groundwater at the Drover-1 site is estimated to be in excess of 100 m based on isopotentials published by Kern (1997), with the closest expression of groundwater of less than 20 m depth being 4 km to the west (Fig. 8). It appears unlikely that the Lesueur National Park within (at least) a 2 km radius of Drover-1 contains groundwater dependent vegetation considering the comparatively deep water table.

The DoW WIN database contains contradictory information; the depth to groundwater at WIN site 20007604, located 150 m northwest of the proposed Drover-1 site, is recorded to be 24 m bgl, whereas the depth to groundwater at WIN site 20007603, located approximately

900 m north-north-west of the site is recorded as 146 m. The exact depth to groundwater at the site needs to be ascertained but given the relatively high topographic elevation of the site (approximately 170 m AHD), it would be unlikely that the depth to groundwater is shallow (<20 m bgl). Therefore, there is minimal likelihood of GDE in the vicinity of the site.

The study undertaken by Rutherford *et. al* (2005) identifying groundwater dependent ecosystems (GDE) in the Northern Perth Basin, considered only sites that had a depth to groundwater of less than 20 m to be potentially reliant on groundwater. The closest GDE identified by the study is a natural spring, named "Diamond of the Desert", located 7 km to the southwest (Fig. 8). Here the impermeable Carynginia Shale is juxtaposed against the Lesueur Sandstone along the Beagle Fault causing upward discharge of groundwater into the Superficial formations. This GDE is well outside the area of influence expected for the operations at Drover-1.

5 RECOMMENDED MONITORING

There are three existing bores near the proposed Drover-1 site that may be useful for groundwater monitoring (Fig. 8); the details of which are summarised in Table 5 and locations shown in Figure 8. The condition and availability of these bores needs to ascertained but, if deemed suitable, they could be used for groundwater level and quality monitoring.

If the existing bores are unsuitable or unavailable, at least two monitoring bores would be required to be installed; ideally one as close as practical to the Drover-1 hole (say offset 150 m) and one downgradient (say 0.5 to 1.0 km west-north-west depending on access). This would allow the depth to groundwater and the hydraulic gradient to be confirmed. Note that if the existing bores are suitable and available for monitoring these additional bores would not be required.

To establish whether operations have any effect on the groundwater system, bores should be installed with groundwater loggers which record the groundwater level, electrical conductivity, pH and temperature. These should be installed as soon as possible to establish baseline trends prior to operations. Data should be downloaded and manual groundwater level measurements taken at least quarterly.

Comprehensive water analyses should be undertaken on groundwater samples collected from each of the available monitoring bores prior to commencement of operations and at say 6-monthly intervals thereafter. The exact timing will depend on the duration of operations. Sampling and monitoring should continue for at least 2 years following the completion of operations. The comprehensive analysis suite should be supplemented with hydrocarbons and any other additives specific to the hydraulic fracturing operations.

Table 5: Summary of Lesueur Aquifer Bores for Potential Monitoring Use

WIN Site ID	AWRC Name	MGA mE	MGA mN	Drilled Depth m bgl	Slotted Interval m bgl	Year Constructed	Elevation* m AHD	Water Level m bgl	Water Level m AHD	TDS from WIN	Distance and direction from Drover-1
20007603	BORE	321,282	6,672,132	220	192-198	?	182	146	36	500	150 m NE
20007604	BORE	321,287	6,671,297	91.64	54-60	1990	168	24	144	930	900 m NNE
20007613	FARM NO 1	318,330	6,671,559	51.82	?	1974	108	40	68	1,570	2,900 WNW
* Elevation estimated from Google Earth											

A rainfall and barometric gauge should be set-up at the site to allow climatic influences to be incorporated in the analysis of data.

Bores used for monitoring will need to be surveyed so groundwater levels can be compared accurately.

6 SUMMARY AND CONCLUSIONS

A groundwater study has been undertaken for the area surrounding the proposed Drover-1 site (16.5 km east of Greenhead), where AWE is considering a hydraulic fracturing programme. Although groundwater use is expected to be minimal, totalling 10 ML for the entire project, and adverse risks to the groundwater system are expected to be minimal, AWE is aiming have a thorough hydrogeological understanding of the site so that any potential risks can be minimised.

The target reservoirs for the hydraulic fracturing stimulations are expected to be at depths of greater than 1.6 km, far below the 580 m bgl base of the Lesueur sandstone, the main aquifer in the area. The hydraulic fracturing targets include the basal 100 m of the Kockatea Shale, at about 1.6 km depth, to the Irwin River Coal Measures at about 2.1 km depth. The Kockatea Shale is expected to be around 850 m thick at Drover-1 and, excluding the basal 100 m, provides a thickness of 750 m of impermeable shale between the planned targets and the overlying aquifer. Therefore, providing that the integrity of the well casing and annular cement grout at the proposed Drover-1 site are not compromised and there are no unforeseen connections of strata, the hydraulic fracturing should not affect overlying aquifers.

The main aquifer which sub-crops beneath the site is the Lesueur aquifer, which is composed of 580 m of sandstone and siltstone. Groundwater levels at the site need to be confirmed but are expected to be in excess of 100 m bgl. Groundwater salinity in the Lesueur aquifer is typically fresh to marginal and most likely increases with depth. Given the expected considerable depth to groundwater, it appears unlikely that vegetation within the adjacent Lesueur National Park is groundwater dependent.

There is limited groundwater use in the area. Within the Eneabba Plains groundwater management sub-area, only 26% of the Lesueur aquifer allocation limit of 1,800,000 kL is currently utilised. The closest groundwater user, the Water Corporation, is located 4.2 km north-west of the proposed Drover-1 site, well outside the area of influence expected for the operations at Drover-1.

Existing bores need to be visited to determine if they would be suitable or available for groundwater level and quality monitoring. If they are not, at least two monitoring bores will be required to be installed to determine the groundwater level, hydraulic gradient and

groundwater quality at the site. On-going groundwater level and quality monitoring is recommended before, during and after the operations to ensure the groundwater system is not impacted.

Dated: 10 May 2013

Rockwater Pty Ltd

M J Taylor
Senior Hydrogeologist

J S Moncrieff
Principal Hydrogeologist

REFERENCES

Department of Water, 2010, Arrowsmith groundwater allocation plan: Department of Water, Water Resource Allocation Planning Series, Report No. 28.

D'Ercole, C.D., 2003, The rejuvenation of the northern Perth Basin: Western Australia Geological Survey, Extended Abstracts, Article 2003/5, p. 5-7.

Hall, P.B. and Kneale, R.L., 1992, Perth Basin rejuvenated: APEA Journal, v. 32, pt. 1, p. 33–43.

Kern, A.M., 1997, Hydrogeology of the coastal plain between Cervantes and Leeman, Perth Basin: Water and Rivers Commission Hydrogeology Record Series No. HG 3.

Lipski, P. 1991. Well Completion Report Gairdner No. 1 EP-100, Perth Basin, WA. Unpublished report prepared by Arrow Petroleum Limited.

Mory, A.J., 1995, Geology of the Arrowsmith-Beagle Islands 1:100 000 sheet: Western Australia Geological Survey, Explanatory Notes, 26 pp.

Mory, A.J. and IASKY, R.P., 1996, Stratigraphy and structure of the onshore northern Perth Basin, Western Australia: Western Australia Geological Survey, Report 46, 102 pp.

Rockwater, 2011. Woodada Deep-01 Well. Aquifer connectivity report. Unpubl. Report for AWE Limited. March 2011 (387-0/11/01).

Rutherford, J., Roy, V. and Johnson, S.L., 2005, The hydrogeology of groundwater dependent ecosystems in the Northern Perth Basin. Dept. of Environment Hydrogeological Record Series, HG11.

Perth
[redacted]

12 June 2015

David Guise
[redacted]

RE: Investigation of Noise and Odour Complaint from Senecio-03 Well Intervention and Production Testing

Dear David,

Aurora Environmental provide this letter of advice detailing the findings of the environmental investigation in response to a written complaint received by the Department of Environment Regulation (DER) regarding flaring associated with well testing of the Senecio-03 well.

BACKGROUND

The Senecio-3 well site is located within Permit L1, approximately 14.5 kilometres (km) east of Dongara and 367 km north of Perth, Western Australia. The Senecio-03 well in the Senecio Gas Field was spudded on 4 August 2014, and allows access to gas within the Dongara/Wagina formation located greater than 2,600m below ground level and additionally allowed for the exploration of deeper formations (Carynginia, Irwin River Coal Measures and High Cliff Formations). The exploration and testing of the deeper formations identified a significant gas discovery in the deeper sands, which has the potential to contain more gas that than the shallower Dongara/Wagina formation.

In order to accurately evaluate and test the two separate reservoirs AWE Limited (AWE) conducted well intervention and production testing on Senecio-03 between 18–21 February and 8-15 March 2015 which involved intermittent flaring of gas from the well over a total of 10 days.

In accordance with the requirements of the *Petroleum and Geothermal Energy Resources (Environment) Regulations 2012* (the 'Petroleum (Environment) Regulations'), the environmental risks and potential impacts of the activity (including noise from flaring) and management measures to mitigate the risks identified were presented in the *Senecio-03 Well Intervention and Production Testing Environment Plan Bridging Document* which was lodged with the Department of Mines and Petroleum on 7 November 2014 and subsequently approved.

A detailed stakeholder consultation program was undertaken by AWE during the preparation of the Environment Plan Bridging Document as required by Regulation 17(1)(b) of the Petroleum (Environment) Regulations). The consultation began in July 2014 and included a number of local residences (within 3 km of the well site) and the Shire of Irwin via various methods including mail outs, community information sessions, emails, phone calls and face-to-face meetings. AWE liaised closely with nearest residents to Senecio-3 and the Shire about the flaring plans and limited the consultation to those likely to be impacted based on previous experience with the Senecio-02 well.

No complaints regarding noise or odour were received during the four days of well testing of the Senecio-02 well in September 2012, located closer to the Irwin township, approximately 2.1km south of the town and 1.8 km northeast of Senecio-03 well. On this basis, noise mitigation measures implemented during flaring at the Senecio-02 well were considered successful.

As no noise or odour concerns were raised by stakeholders, and no complaints were received during flaring of the Senecio-02 well, AWE considered the enhanced noise management measures (diffuser and raised bund walls on the flare pit) to reduce noise emissions at Senecio-03 well site would be adequate. To confirm the adequacy of the management measures implemented, AWE also conducted noise monitoring at the well site during flaring.

Flaring at the Senecio-03 well commenced on 18 February 2015 and anecdotal information was received that the flare had initially been noticed by the nearest residents and their animals, and said they had not been unduly disturbed. On 10 March AWE personnel heard reports of local residents' concerns being made via social media and promptly followed this up with one of the neighbouring landowners asking them to help AWE contact the concerned resident. Based on this report via social media, AWE then decided to delay restarting the flare until daylight hours. AWE was able to contact the complainant, discuss their concerns and possible solutions including providing alternative temporary accommodation.

On 11 March, the AWE Regional Manager (Mr David Guise) met with Mr Rod Copeland to continue discussions regarding an unrelated matter on his property, and both Mr Guise and Mr Copeland observed the sound from the direction of the flaring. Aurora has been informed that Mr Guise and Mr Copeland have had previous conversations and both parties had contact phone numbers for each other.

On 15 March 2015 a complaint about noise emissions from the flare was received via phone from a local resident. In the hour following the complaint, AWE Limited (AWE) suspended the flow testing and shut-down the flare. AWE organised a meeting with concerned and available community members for the following evening (16 March 2015).

On 17 March 2015, Mr Copeland, resident at 26926 Midlands Road, Irwin WA, distributed a letter dated 13 March 2015 signed by 34 people from 20 residences in Irwin. The letter was distributed by email to; AWE, the Shire of Irwin and councillors, Hon Terry Redman MLA, Shane Love MLA, Hon Paul Brown MLC, Hon Mia Davies MLA, Hon Brendon Grylls MLA, Hon Martin Aldridge MLC, Vincent Catania MLA, Hon Dave Grills MLC, Hon Colin Holt MLC, Hon Jacqui Boydell MLC, Premier of WA, Minister for Mines and Petroleum, Mark McGowan MLA, Hon Gary Gray MP, Department of Mines and Petroleum (Phil Gorey, Mr Brad Jakowyna and Laura McCarthy), APPEA, CEO of WA Farmers, CEO of Shire of Carnamah, CEO of Shire of Three Springs, CEO of Shire of Coorow, CEO of Shire of Mingenew, CEO of City of Greater Geraldton, CEO of Shire of Northampton, Central Greenough Frack Free Zone, Conservation Council of WA, Peter Robertson, Jaime Yallup, Jo Franklin, Frack Free Geraldton, Claire Moodie, Geraldton ABC Radio Morning Show, Melissa Price Federal member for Durack, Jane Hammond Lock the Gate Media co-ordinator and Mr Ian Blayney MLA for Geraldton. The letter and email is provided in Attachment 1.

AWE (Jane Aberdeen, Regulatory and Community Affairs Manager) received a phone call from the Department of Environment Regulation (DER) (Mark Brand) on 18 March 2015 whom was investigating Mr Copeland's complaint. Ms Aberdeen explained the actions that had been taken and that the flare had been shut-down. Aurora has been informed that once he was aware of this, Mr

Brand requested additional information regarding the flaring schedule, the Environment Plan Bridging Document and the notification letters sent to stakeholders for his reporting requirements to the DER Executive.

AWE responded to Rod Copeland's email with a letter dated 20 March 2015. This letter is provided in Attachment 2. The letter was also sent to the concerned residents whom attended the meeting on 15 March, the Shire and local Irwin residents.

AWE has subsequently commissioned Aurora Environmental (Aurora) to assess the impacts from noise and odour emissions on the residences of Irwin during the flaring. Aurora provide this letter to respond to the DER's queries and outline the results of the investigation into the validity of the claims regarding noise and odour impacts from the flaring.

FLARING ACTIVITY

Flaring or burning of gas, was undertaken within the flare pit at the Senecio-03 well on the dates and times listed in Table A. The wind direction and speed data from the Bureau of Meteorology's (BoM) Geraldton Airport station (ID: 008315), which is the nearest weather station to the well site with available data, has been correlated with the flaring periods (Table A).

TABLE A: FLARING AT SENECIO-03 WELL

Date of Flaring	Time of Flaring	Duration of Flaring	Wind direction (degrees true)*	Average wind speed (range)* (km/h)
18 February 2015	11:00am to 5:15pm	6 hours 15 mins	SSE – S (160° – 190°)	36 (24 – 46)
20 February 2015	2:45pm to midnight	9 hours 45 mins	SSE – SSW (170° – 220°)	30 (22 – 37)
21 February 2015	Midnight to 1:45pm	13 hours 45 mins	SE – SSW (130° – 200°)	27 (17 – 41)
8 March 2015	10:45am to midnight	1 hour 45 mins	E – S (80° – 190°)	26.5 (11 – 42)
9 March 2015	Midnight to 8:30am	8 hours 30 mins	NNE – SSW (30° – 210°)	13 (5 – 21)
11 March 2015	6:00am to midnight	18 hours	N – SW (0° – 230°)	16 (0 – 28)
12 March 2015	Midnight to midnight	24 hours	N – W (0° – 270°)	12 (0 – 24)
13 March 2015	Midnight to midnight	24 hours	NNE – N (30° – 360°)	16 (5 – 35)
14 March 2015	Midnight to midnight	24 hours	N – NNW (0° – 340°)	28 (0 – 52)
15 March 2015	Midnight to 8:30pm	20 hours 30 mins	SSW – NW (210° – 320°)	17 (8 – 24)

*Data sourced from BoM at half–hourly intervals for the period 18 February 2015 to 15 March 2015.

INVESTIGATION OF NOISE EMISSIONS

Whilst the oil and gas activity of well evaluation and production testing is regulated under the Petroleum (Environment) Regulations, causing pollution (including noise pollution) is an offence under the *Environmental Protection Act 1986*. The key piece of legislation for setting noise limits and determining if noise is unreasonable is the *Environmental Protection (Noise) Regulations 1997* (the 'Noise Regulations').

The nearest residences to the well site are located approximately 3.3 km to the northwest (26825 Midlands Road) and 3.4 km to the north (40 Morgan Lane). The wind conditions under which impacts to the nearest residences may occur are under calm to light south-easterly to south winds.

Calm (0km/h) to light (< 19 km/h) (Beaufort Wind Scale 0-3) south to south-easterly wind conditions prevailed on:

- 21 February for 3 hrs;
- 8 March for 1.5 hrs;
- 9 March for 5.5 hrs;
- 11 March for 6.5 hrs;
- 12 March for 4.5 hrs;
- 13 March for 8.5 hrs; and
- 14 March for 1.5 hrs.

Based on the data recorded at the Geraldton Airport weather station (Table A). Under these conditions it is likely that sound from the flare could be heard at these residences during flaring.

To understand the intensity of the sound on the nearest residences, the maximum noise that could be produced from the source (i.e. flare pit) was established. The sound power level of the flare can be estimated to be 135 dB(A) based on monitored data. This can be used to accurately model noise levels during flare operation. Based on the outputs of this modelling it is estimated that noise levels at premises 3-4 km away from the flare pit could have been 45 dB(A). Based on this modelling, the level of noise is likely to have been audible to residences and could have exceeded the assigned noise levels allowable under the *Environmental Protection (Noise) Regulations 1997* (Table B) during evenings and night-time (1900 to 0700 hours). However as data on noise levels was not collected an exceedance of the assigned levels cannot be confirmed.

TABLE B: ASSIGNED NOISE LEVELS FOR NOISE SENSITIVE PREMISES

Type of premises receiving noise	Time of Day	Assigned Level (dB)		
		$L_{A\ 10}$[1]	$L_{A\ 1}$[2]	$L_{A\ max}$[3]
Noise sensitive premise: highly sensitive area[4]	0700 – 1900 hours Monday to Saturday (Day)	45	55	65
	0900 – 1900 hours Sunday and Public Holidays (Sunday / Public Holiday Day)	40	50	65
	1900 – 2200 hours all days (Evening)	40	50	55
	2200 hours on any day to 0700 hours Monday to Saturday and 0900 hours Sunday and Public Holidays (Night)	35	45	55

AWE used qualitative data, previous experience and additional controls to ensure that the operation of the flare at Senecio-03 would not contravene the allowable noise levels specified in the Noise Regulations. This view was formed on the following basis:

- Flaring conducted at Senecio-02 well had not resulted in any complaints or exceedance of the Noise Regulations and this well site was located in a more sensitive location closer to residences;
- In view of the fact that gas production rates at Senecio-03 were expected to be higher than at Senecio-02, AWE adopted enhanced noise controls including fitting a diffuser to the flare and installing raised bund walls around the flare pit; and
- The design and control measures had been endorsed by the regulator.

However based on the meteorological data presented above, during the hours of which the prevailing winds were optimal for disturbing residents, it appears that noise levels may have exceeded the allowable criteria although no actual measurements exist to confirm this.

[1] $L_{A\ 10}$ assigned level means an assigned level which, measured as an $L_{A\ Slow}$ value, is not to be exceeded for more than 10% of the representative assessment period.
[2] $L_{A\ 1}$ assigned level means an assigned level which, measured as an $L_{A\ Slow}$ value, is not to be exceeded for more than 1% of the representative assessment period.
[3] $L_{A\ max}$ assigned level means an assigned level which, measured as an $L_{A\ Slow}$ value, is not to be exceeded at any time.
[4] Highly sensitive area means that area (if any) of noise sensitive premises comprising —
(a) a building, or a part of a building, on the premises that is used for a noise sensitive purpose; and
(b) any other part of the premises within 15 m of that building or that part of the building.

Aurora considers AWE's immediate responsive action to the initial complaint, including shutting down the flare within an hour of the noise complaint and organising a public meeting to openly discuss the issue were appropriate.

In order to prevent a recurrence of this situation, Aurora recommends that for future well evaluation and production testing, a Noise Management Plan is developed and approved by DER.

It is understood that some residents suggested that the noise emissions from the flare caused vibration which rattled windows. Advice from a recognised acoustical consultant (Herring Storer Acoustics, Tim Reynolds) indicated that such vibrations could typically only occur in very close proximity to a noise source such as a flare (i.e. within the boundaries of the well site).

ODOUR EMISSIONS

Impacts from odour emissions are regulated under the *Environmental Protection Act 1986* by the DER.

The assessment of odour impacts is a difficult process as it is highly subjective in nature with some individuals finding odours offensive that others consider part of their daily life. An example of this is that farmers who work day in day out with farm animals and experience the odour of animal manures and urine without being significantly offended while a person from an urban environment going to a farm is likely to find such odours offensive. In addition, the measurement of odours is difficult as there are currently no proven instruments for odour measurements (although some are being developed). This means that odour assessment is generally conducted using the human nose and that the odour assessor needs to be trained to characterise odours effectively and also needs to be present on site at the time an impact occurs.

In the case of the Senecio-03 well, the gas in question is a sweet, dry gas. This means the gas is primarily methane (measurements show the composition is in excess of 93% v/v methane) with minimal sulfur compounds (H_2S concentrations were measured to be typically in the range of 1-2 parts per million (ppm) and no measurement exceeded 3.8 ppm) and contains minimal condensate (liquid or long chain hydrocarbons). Accordingly, the gas would not be highly odourous in nature but as with all raw natural gases it will contain at least some trace levels of organic compounds other than methane that could give it a characteristic hydrocarbon odour. It should be noted that methane does not have a detectable odour which is why stenching agents such as mercaptans are added to reticulated natural gas supplies so gas leaks can be readily detected.

Aurora is familiar with gas production well sites and can only identify three potential odour sources that may contribute to odours at the time of the well commissioning:

1. Odours derived from any liquids that are separated from the gas after it exits the wellhead (usually a mixture of condensate and possibly some water);
2. Incomplete combustion of gas in the flare; and
3. Fugitive leakages of gas from flanges, valves and seals.

As gas is flammable/explosive and a valuable commodity, the oil and gas industry takes great care to minimise fugitive loss of hydrocarbons for commercial safety and environmental reasons. The design and maintenance of equipment is of the highest standard to minimise the release of flammable products to the maximum extent possible. In addition, flammable gas meters are placed

in the vicinity of the wellhead to provide early warning of any gas release that may represent a safety hazard in which case production would immediately be shut down.

Advice from AWE indicates there have been no gas alarms, from gas detection at the Senecio-03 well and in addition, measurements of ambient levels of hydrocarbon gases conducted by an independent consultant (Gemec) detected only very low trace levels of a hydrocarbons (See data in Attachment 3) which could not have contributed to off-site odour complaints outside the well site. Finally workers working in the vicinity of the well head did not detect any offensive odours.

As a result it is considered extremely unlikely that fugitive gas releases could have contributed to off-site odour impacts.

With regard to liquids, the well and flare system incorporated a closed condensate capture system to prevent the release of hydrocarbons to atmosphere. AWE has advised that only a few litres of hydrocarbon liquids were collected in this sealed system during the operation of the flare and as a result the condensate system is considered unlikely to be an odour source. This view is confirmed by the fact that AWE staff did not detect any significant hydrocarbon odours in the vicinity of the well site.

The final possible odour source is the flare. The flare is designed to ensure virtually complete combustion of any gas and liquids. The effective performance of the flare in this regard is shown by the fact that there was no dark smoke and extremely limited visible grey or white smoke emissions on an occasional basis during the flaring. This is confirmed by AWE workers including contractors and videos of the flare in operation viewed by Aurora staff.

The gas directed to the flare consisted of short chain organic compounds i.e. primarily C_1- C_4 compounds with the majority (>93%) being odourless methane and minimal long chain organic compounds with only trace levels of H_2S which would have been converted to SO_2 (which is not odourous at low concentrations like H_2S) in the combustion process. It is difficult to see how the flare could have represented a significant off-site odour source. It is however noted that the intense heat released during flaring, gives rise to a substantial thermal plume rise for burnt gas from the flare which means that it is conceivable that if odourous emissions were released from the flare, they may not be detected locally but could be detected a distance downwind when the plume re-intersected with the ground.

AWE staff indicated that they did not personally detect offensive odours either on or off-site during the operation of the flare.

RECOMMENDATIONS

Aurora understands no more flaring is expected at the Senecio-03 well.

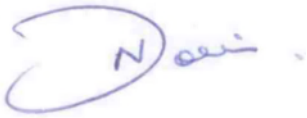
AWE intends to continue exploration in the Perth Basin, within the Dongara region and will need to responsibly manage future flaring activities to reduce the potential impacts to the local community to as low as reasonably practicable (ALARP).

In order to achieve management to ALARP Aurora recommend implementing the following noise management strategies for future flaring:

1. Prior to future well evaluation and production testing, the Shire of Irwin, local residents and the DER is notified of the flaring schedule and provided with an opportunity and the details of the AWE contact person to liaise with during the flaring period.

2. Review the design of the flare pit for each new well site, and have the design verified in terms of noise emissions on nearest residences via noise modelling. Modify the flare pit design by either:
    a. Increasing the height and improving the design of noise bunds.
    b. Incorporating more diffusion area.
    c. Review selection and option of inline noise diffuser to assist in minimising noise from the flare.
3. If construction activities (including flaring) are carried out between 0700 and 1900 hours Monday to Saturday and noise emissions are controlled by using all reasonable measures then the noise emissions are exempted from meeting the Assigned Noise Levels in the Noise Regulations. If construction works are undertaken outside these hours and AWE believe it is possible that the relevant assigned noise levels at nearby premises may be exceeded, then a Noise Management Plan must be prepared and submitted to the CEO of the DER for approval prior to the commencement of flaring.
4. For future well sites, an allowable noise limit measured at set distance from the flare should be established by noise modelling studies that will ensure that noise levels at the nearest sensitive premises is in compliance with the relevant assigned noise levels. When flaring commences, AWE should perform check measurements at the set distance from the flare to verify that the flare is operating as designed and is unlikely result in exceedances of allowable noise limits.
5. Noise monitors should be set up at the nearest noise sensitive premise to log noise emissions during flaring, with an alarm system (via sms to mobile phones) that is triggered if noise exceeds allowable limits. The logged data should be compared with noise modelling predictions to assess which residences may have been impacted and implement adaptive management.
6. If necessary, cease flaring during light prevailing winds in the direction of noise sensitive premises.

For and on behalf of Aurora Environmental



Noel Davies
Principal

Attachments:

1. Rod Copeland Email dated 17 March 2015 with letter attached dated 13 March 2015
2. AWE letter dated 20 March 2015
3. Gemec Monitoring Data

ATTACHMENT 1

Rod Copeland Email dated 17 March 2015 with letter attached dated 13 March 2015

Caitlin Dorrington

From: [redacted]
Sent: Wednesday, 27 May 2015 4:27 PM
To: [redacted]
Subject: FW: AWE - additional information - confidential
Attachments: Concerned Members of the Irwin Community 16-03-15.pdf

From: [redacted]
Sent: Tuesday, 17 March 2015 1:11 AM
To: [redacted]
Cc: 'AWE Perth Pty Ltd'; 'Mr David Guise'; 'President of Shire of Irwin'; 'Cr I F West'; 'Cr K J Hepworth'; 'Cr D R Kennedy'; 'Cr M Leonard'; 'Cr J A R Porteus'; 'Cr B Scott'; 'Cr M T Smith'; 'Hon Terry Redman MLA'; 'Mr Shane Love MLA'; 'Hon Paul Brown MLC'; 'Hon Mia Davies MLA'; 'Hon Brendon Grylls MLA'; 'Hon Martin Aldridge MLC'; 'Mr Vincent Catania MLA'; 'Hon Dave Grills MLC'; 'Hon Colin Holt MLC'; 'Hon Jacqui Boydell MLC'; 'Premier of WA'; 'Minister for Mines and Petroleum'; 'Mr Mark McGowan MLA WA Leader of the Opposition'; 'Hon Gary Gray AO MP Federal Shadow Minister for Resources'; Webmaster; GOREY, Phil; 'DMP Environment Operations-Petroleum Team Mr Brad Jakowyna'; MCCARTHY, Laura; 'APPEA'; 'APPEA'; 'CEO of WA Farmers'; 'CEO Shire of Carnamah'; 'CEO Shire of Three Springs'; 'CEO of Shire of Coorow'; 'CEO Shire of Mingenew'; 'CEO of City of Greater Geraldton'; 'Ceo of Shire of Northampton'; 'Central Greenough Frack Free Zone'; 'Conservation Council of WA'; 'Conservation Council of WA'; 'Peter Robertson'; 'Jaime Yallup'; 'Jo Franklin'; 'Frack Free Geraldton (frack.free'; 'Claire Moodie'; 'Geraldton ABC Radio Morning Show'; 'Melissa Price Federal member for Durack'; 'Jane Hammond Lock the Gate Media co-ordinator'; 'Mr Ian Blayney MLA for Geraldton'; ': AWE Ltd'
Subject: CONTINUOUS NOISE AND ACRID SMELL EMISSIONS FROM WAITSIA WELL @ IRWIN W.A.

To all of the individuals, government representatives or instrumentalities (Local, State and Federal), Action Groups, Farming Representative Bodies, and Oil and Gas Industry representatives, to which the attachment has been forwarded, this email is to inform you of the list of other entities that have also been sent this correspondence, and why.

THE SHIRE OF IRWIN and COUNCILLORS
It should be noted that the Shire, by its own declaration and we quote from ENVIRONMENTAL HEALTH section on the webpage that “Active involvement by local authorities in Environmental and Public health issues has achieved massive improvements in the quality of life and longevity of most Australians. However new health hazards have emerged in recent years—for example bird-flu, chemical sensitivity or noise exposure—that might have the potential to affect the health of residents.”
It was with the references to chemical sensitivity and noise exposure that we as a community felt obliged to make this complaint.
We believe that the current noise and acrid smell emitting from Waitsia comes within these parameters.
We therefore insist that the Health representatives from the Shire are immediately reactive to our complaint and act on our behalf as ratepayers.

As this is a letter of complaint to our local government representatives, it is anticipated that it will be listed on the next meeting agenda and be discussed at the next meeting.

TO ALL OTHER LOCAL GOVERNMENT BODIES THAT WE HAVE CONTACTED,
Please be advised to what we, as a community, are now having to endure and this is only the beginning of what may happen within your own Shire.

THE HEALTH DEPARTMENT,
You are included because the problems that we are enduring are of vital importance to the current well-being of us and our children, and the long term health of the community and environment.

TO ALL POLITICIANS WHETHER STATE OR FEDERAL,

We, as voters in all levels of government, have contacted you so that you may be aware of what we are having to put up with, after some of your decision-making is foisted upon us,
You should be aware that some are your decisions are not made with the wishes of a majority of voters and those decisions have major impacts on peoples' lives during implementation of those ill-informed decisions and for a long time after.

FARMING REPRESENTATIVE BODIES,
You have been included on our list of contacts because you represent a large number of complainants that are now being currently impacted and in the future, your members will be more greatly affected, by what is happening right across the State of WA.

ACTION GROUPS,
You have been included because some of the problems inherent with O and G developments have already begun to surface in our region and we need your ongoing support to combat those problems.

THE OIL AND GAS INDUSTRY,
You have been included on our list simply because of your title.
You are the companies that want to make gross profits from the Oil and Gas underneath the land and the sea with little or no regard to adverse impacts on the citizens of that region.

One complainant received a phone call late on Friday 13 march 2015, from a representative of AWE, questioning whether they had any complaint about the flaring and its impact.
Unfortunately he was not at home and because of the timing of the call has not been able to respond, within working hours.
It would be advisable to call more residents of the area and we are quite sure that the message delivered would've been appropriate for what the true community thoughts are on the matter.

APPEA,
You have been included because you are the industry mouth-piece that continually pushes that the Oil and Gas industry is not a threat to the health and well-being of the community.
.
THE MEDIA OUTLETS
We are informing you of our concern of what is happening within our region so that more people are aware of what is going to happen in a vast number of regions in this State.

We are at the forefront of what is happening now, and want it known to EVERYONE in Government and industry that decisions made now, will have a detrimental effect on peoples' lives now and into the future, long after Oil and Gas has left our area, even after the burning of fossil fuels is a long lost memory.

The accompanying attachment is a true indication to our opposition to what is happening.

We are aware that by the time that this letter is received, testing may well have finished and AWE will probably say we have nothing more to worry about.

How far from the truth is that?

Please note that a hard copy will be forwarded to all listed entities and individuals

FROM
The concerned and united community of Irwin.

To all of the parties to which this letter has been forwarded to, please note, that we the undersigned,

Hereby notify each and every party that we are making a formal complaint about the continuous noise and burnt gases/condensate pollution that is currently being emitted from the Waitsia Gas-well on Irwin Park @ Irwin about 10km east of Dongara, by the Oil and Gas Company AWE Perth Pty Ltd (O and G)

We are the residents and/or frequent visitors of/to the immediate area within 5km radius of the Locality known as Irwin Town-site and immediate surrounds, and are in the direct line of impact for ANY pollution event that may occur from within the area of drilling for O and G

We are also ratepayers within the Shire of Irwin and with that, voting members of the public, for Local, State and Federal Governments.

We understand that the oil and gas company, AWE Perth Pty Ltd is undertaking a testing program of the new Waitsia well to prove its flows, volumes etc

We are all disgusted with the level of noise/roar/acrid smell being emitted from the flare, said to be set at "quarter choke". We'd all hate to hear the noise of full choke!

Perhaps some of you would like to be around for that?

Some of us have young children who are finding it impossible to sleep at night.

The adults are complaining that they can't sleep.

To drown out the noise, even the volume of the TV has to be increased substantially.

The constant "thump" of the concussion has given many residents a continuous headache.

Many are enduring the pain of sore eardrums.

Also many residents are experiencing an elevated increase in hay-fever like symptoms, sore and running eyes and nose and throat irritation.

We live with it by day, go to sleep (hopefully) at night, and wake to it (sometimes numerous times) in the morning.

Yesterday the smell of burnt diesel (perhaps condensate) was very heavy in the air(Thursday 12-03-15)

Currently we are enjoying (without the noise) what is considered to be the best living time of the year in this locality. It's a blight on the Oil and Gas Company, that after suffering through 35C plus days that we cannot have our windows open to enjoy the cooling night breezes.

WE SHOULD NOT HAVE TO PUT UP WITH THIS NOISE, ACRID SMELL AND DISRUPTION.

One can wake at night, and the incessant drone of the choked flare does not allow you to go back to sleep.

We all have developed small landholdings as a way of life in this area, because of the peacefulness and beauty of this part of the Shire, and did so without expecting to have our lives impacted in this manner.

Unfortunately with what was discussed on radio on Tuesday 10 March 2015 by the CEO of AWE Mr Bruce Clement, this is only the precursor of more to come.

To best describe the noise

(1) It is like standing within the Perth Airport, and listening to the roar of a plane on the tarmac at full revs and going nowhere
(2) It makes the houses vibrate from the concussion
(3) The constant vibration from the concussion makes one's ears hurt
(4) Even an AWE employee noted to an executive, that he could hear the noise at the Corybas well –site which is a further 1.5+ km away
(5) The same AWE executive stated that he was surprised how far the noise was carrying and how loud the noise was, when visiting one complainant's farm on Wednesday 11th March 2015.
(6) The impression given was that something was going to be done to lessen the impact on the local residents, hopefully curtailing the noise, but to now nothing has been done.
(7) On numerous occasions, dependent on wind direction, the acrid smell of the fumes being emitted, are that strong to be almost overcoming.

Everyone of you live kilometres away from this area and are not enduring the impost of this "noise/acrid smell invasion"

As citizens we are entitled to a peaceful night's sleep, especially as on the next day we have to perform our duties in a normal and fulfilling manner.

We acknowledge that a meter used for reading decibels of noise may show that the actual level of noise is not too extreme, but what it doesn't read is the continuity of the never changing sound and the annoying frequency of that noise.

What we cannot understand is, why after testing on the Sunday 8th March 2015 with the same extreme noise/roar/acrid smell from the site, and the subsequent joyous announcement to the ASX on Monday 9th March 2015 that the "find" was as big as previously announced and that contracts were being negotiated for the sale of the gas, THAT ANY MORE TESTING WAS NECESSARY?

To us, it appears a blatant waste of the gas, and a definitely unnecessary interruption to our lives, all in the name of profits.

THE UNDERSIGNED on 13th MARCH 2015

NAME	ADDRESS	PHONE/FAX/E-MAIL	SIGNATURE
John LaLor	[redacted]		
PATRICIA LALOR			
Kate LALOR			
Shirley Scott			
David Bridley			
PATRICIA MARINCI			
Rachel Bagshaw			
Dot MORGAN			
JOHN. L. MORGAN			
Judi Lawrie			
JIM MARett			

THE UNDERSIGNED

NAME	ADDRESS	PHONE/FAX/E-MAIL	SIGNATURE
CHRIS COLLIER	[redacted]		
MARY COLLIER			
MICHELE LALOR			
DIANNE HORNE			
MARIA BROWN			
CAROLINE PIZZEY	[redacted]		
Lyn Williams			
Jaimey-lea Watkins			
Marion Thompson			
David Price			
Joshua Price			
JORDAN PIZZEY			
SHIRLEY KNIGHT			
Ray Button			
Kelly Thorne			

THE UNDERSIGNED

NAME	ADDRESS	PHONE/FAX/EMAIL	SIGNATURE
JULIE BURA	[redacted]		
Stewie+Vanessa Gall			a Gall.
MARGARET A			MG Scott
ROD COPELAND			R Copeland.
ANNETTE COPELAND			
Nicola Burr			
[illegible]			
Jonathan Moss			

ATTACHMENT 2

AWE Letter dated 20 March 2015

Ref: AWE1275LET

20 March 2015

[redacted]

Dear Rod and Annette

AWE Limited – Senecio-3 Flow Test

Thank you for raising your concerns about AWE's recent flow test operations at the Senecio-3 appraisal well site, located 14.5 kilometres east of Dongara. Following a complaint received on Sunday, 15 March, AWE immediately suspended the flow testing activity and organised a meeting with available community members for the following evening (Monday, 16 March) to discuss the issue.

This is an example of the value we place on having good relationships with the local community, especially in the areas we operate. We seek to continually improve our operations and use occasions like this to obtain feedback from the community to make operational or systems adjustments as required.

The extent to which noise carried, particularly in the evening, was unexpected, and we believe resulted from prevailing weather conditions at the time.

Prior to commencing the flow test program, and based on the risk assessment developed for the Senecio-3 Environmental Plan, AWE representatives spoke with a number of local residents living in close proximity to the Senecio-3 well site and the Shire of Irwin. The limited noise impact that occurred during the flow testing of the preceding Senecio-2 well, which was closer to Irwin residents, was used help to determine the level of likely concerns regarding Senecio-3.

AWE also used the risk assessment process to design and implement additional noise control measures developed specifically for the Senecio-3 flow test. These included a silencing control on the flare tip line and the installation of higher than normal bund walls around the flare pit.

Feedback from residents indicates that the noise was louder and more disruptive than we anticipated for some Irwin residents. Although the noise created by the flow test did not exceed anticipated levels on site, it has obviously resulted in a level of discomfort for some nearby residents.

AWE has acknowledged your feedback and has worked collaboratively with residents to rectify the immediate issue. On behalf of AWE, I apologise for any impact that our operations may have caused you, and assure you that we are already extending our level of engagement to a broader audience and will continue to engage at this level.

As part of our program to be a good neighbour, AWE is assessing whether additional noise control methods could be implemented on-site for any future flow testing. We will of course communicate these measures with you prior to any flow testing.

AWE will also review the factors that contributed to the recent concerns and will incorporate this work in any future programs.

If you have any questions, please don't hesitate to contact me via email at midwest@awexplore.com.

Yours sincerely

David Guise
Regional Manager – Western Australia

AWE PERTH PTY LTD [redacted]

ATTACHMENT 3

Gemec Monitoring Data

Table 1: Ambient Air Analytical Results - Volatile Organic Compounds

Sample ID	Date	Total Sampling Minutes	Acetate, 2-metho yethyl-	Ben ene	Ben ene, 1,2, -trimethyl-	Ben ene, 1, -dichloro-	Ben ene, ethyl-	Butylacetate	Cyclohe ane	Decane	Disulfide, dimethyl-	Ethane, 1,1,1-trichloro- (1,1,1-TCA	Ethanol, 2-buto y-	Ethanol, 2-etho y-	Ethene, tetrachloro- (PCE	Ethyl tert-butylether	Ethylene, trichloro- (TCE	Heptane
1 B057 001	10.0 .15-20.0 .15	1 177	0.		0.05	0.05	0.0	0.0	0.0		0.0	0.05	0.05	0.0	0.0	0.0	0.0	
1 B057 002	10.0 .15-20.0 .15	1 1	0.			0.05	[1]	0.0			0.0	0.05	0.05	0.0	0.0	0.0	0.0	[1]
1 B057 00	10.0 .15-20.0 .15	1 1 2	0.		0.05	0.05	0.0	0.0	0.0	0.05	0.0	0.05	0.05	0.0	0.0	0.0	0.0	0.0
1 B057 00	10.0 .15-20.0 .15	1 077	0.			0.05		0.0			0.0	0.05	0.05	0.0	0.0	0.0	0.0	
NOHSC E posure Standard (TWA [2]			NE	1 000	NE	51000	000	71 000	10 0000	NE	NE	NE	12100	1 000	NE	NE	270000	1 0000
Laboratory Limit of Reporting			0.	-	0.05	0.05	0.0	0.0	0.0	0.05	0.0	0.05	0.05	0.0	0.0	0.0	0.0	0.0

Notes: all concentrations reported in micrograms per cubic metre (g m
'NE' denotes screening level not established or is under review
'-' denotes not obtained

1. sample response greater than highest standard (00 ng
2.Time-Weighted Average (NOHSC 1 5
. screening level for p - Dichloroben ene

Table 1: Ambient Air Analytical Results - Volatile Organic Compounds

Sample ID	Date	Total Sampling Minutes	He an-1-ol, 2-ethyl-	He ane	Isopropyl acetate	Limonene	Meth-1-o y, 2-propanol-	Methyl tert-butylether	Nonane	Octane	Pinene, -	Styrene	Toluene	Undecane	ylene, m- & p-	ylene, o-
1 B057 001	10.0 .15-20.0 .15	1 177	0.07		0.0	0.0	0.0	0.0	0.07	0.05	0.17					
1 B057 002	10.0 .15-20.0 .15	1 1	0.07		0.0		0.0	0.0		1			1		1	1
1 B057 00	10.0 .15-20.0 .15	1 1 2	0.07	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.17	0.0		0.0	0.0	0.0
1 B057 00	10.0 .15-20.0 .15	1 077	0.07		0.0		0.0	0.0			0.17					
NOHSC E posure Standard (TWA [2]			NE	17 000	10 0000	NE	NE	NE	1050000	1 00000	NE	2 1000	77000	NE	50000	
Laboratory Limit of Reporting			0.07	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.17	0.0	-	0.0	0.0	0.0

Notes: all concentrations reported in micrograms per cubic metre (g m
'NE' denotes screening level not established or is under review
'-' denotes not obtained

1. sample response greater than highest standard (00 ng
2.Time-Weighted Average (NOHSC 1 5
. screening level for ylene (o-, m-, p- isomers

AWE Perth Basin Operations

Coorow Community Reference Group
Drover-01: Groundwater monitoring

23 July 2015

Overview

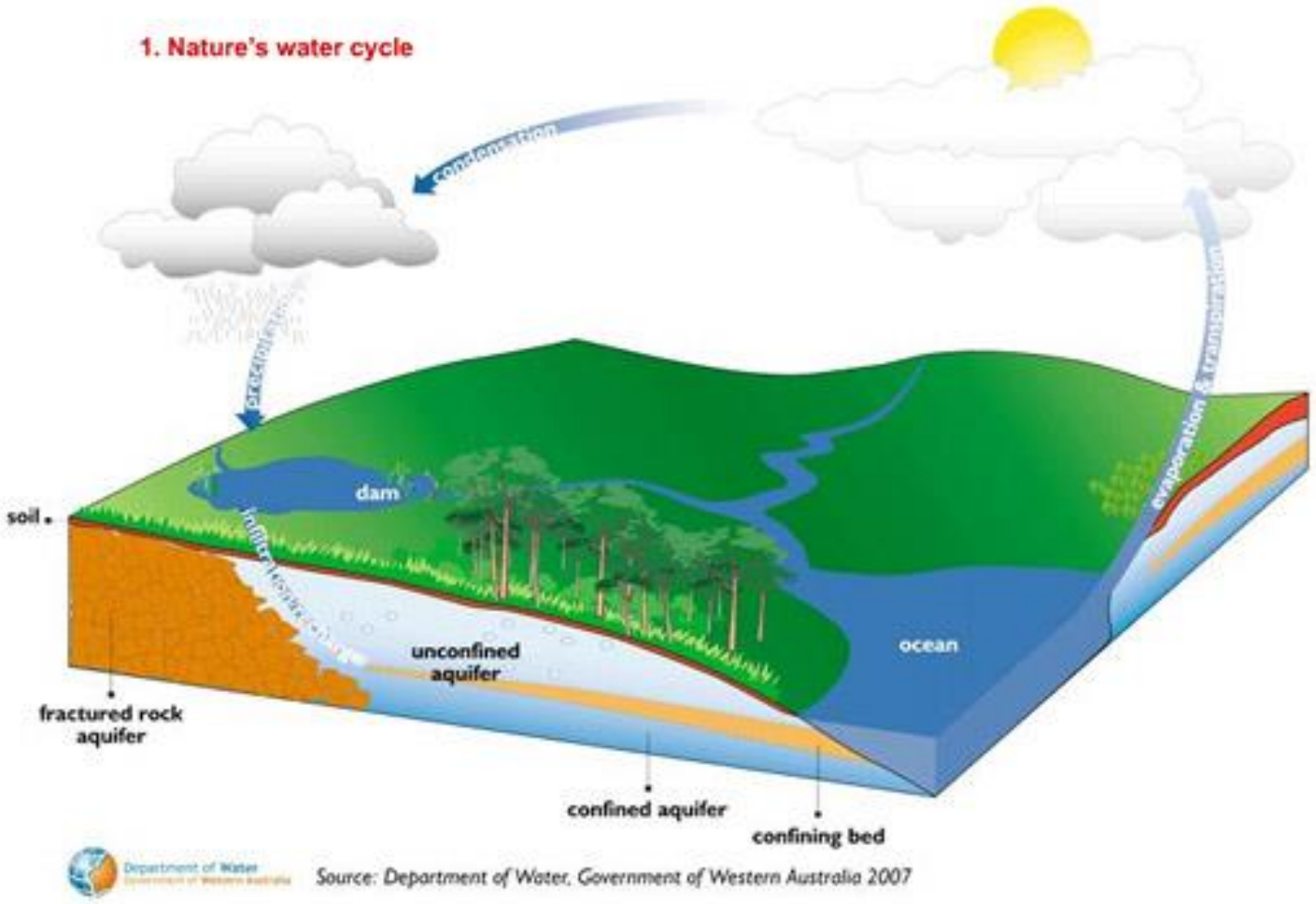
- Setting the scene - Groundwater monitoring basics

- Drover 01
  - Groundwater monitoring details
  - Recent monitoring results

- Next steps

Setting the scene - Groundwater monitoring basics

Groundwater is a reserve of water beneath the earth's surface in pores and crevices of rocks and soil.



Groundwater monitoring program an important risk management tool

Setting the scene - Groundwater monitoring basics

Groundwater monitoring bores are used to:

- determine the nature and properties of soils through which liquids may seep;
- provide access to groundwater for measuring its level, physical and chemical properties; and
- allow groundwater samples to be withdrawn for laboratory analysis

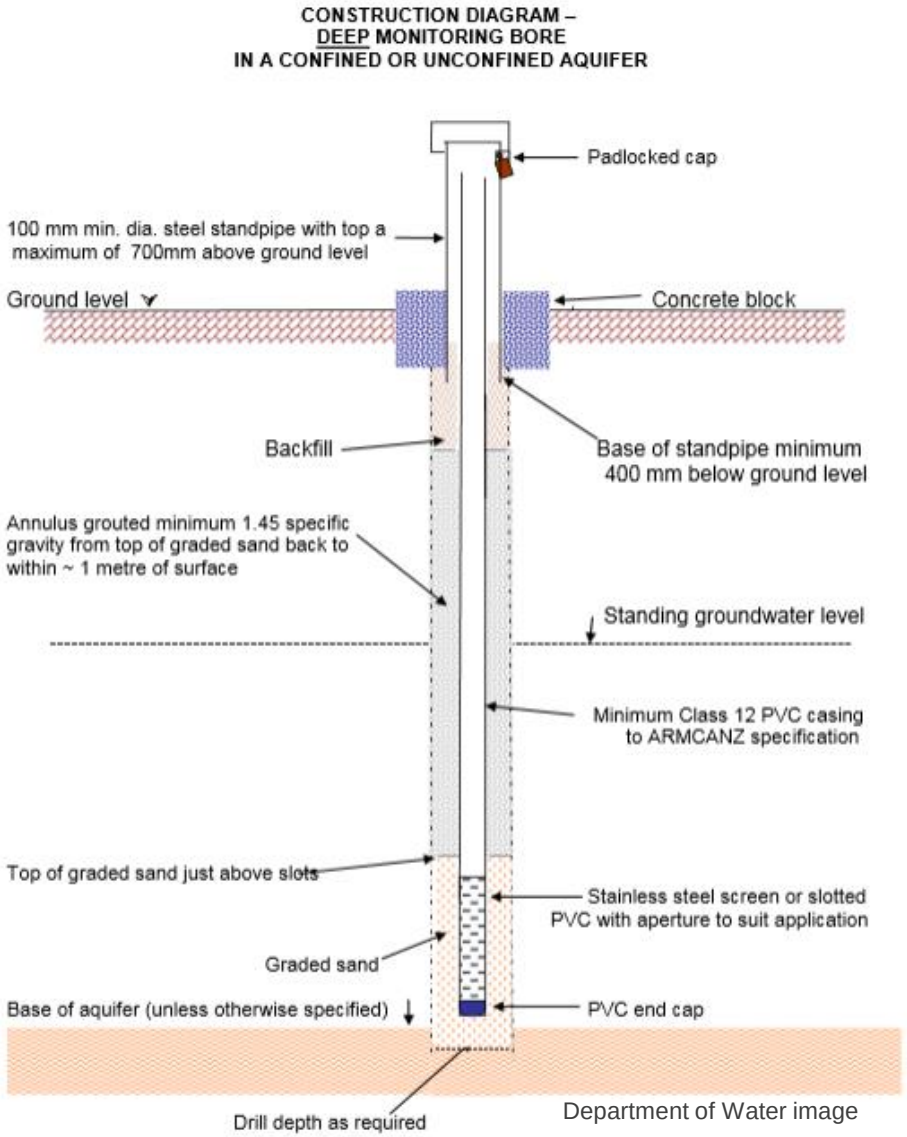
Photo courtesy of DoW (not Drover-1)

Monitoring bores are mainly needed to assess changes to water table levels and groundwater quality

Setting the scene - Groundwater monitoring basics

Factors considered

- Site of monitoring bores
- Bore construction and drilling technique (eg depth, diameter, main casing, completion)
- Water sampling techniques
- Equipment and site hygiene
- Bore drillers required to be qualified and licensed for the aquifer/s at the site



Department of Water image

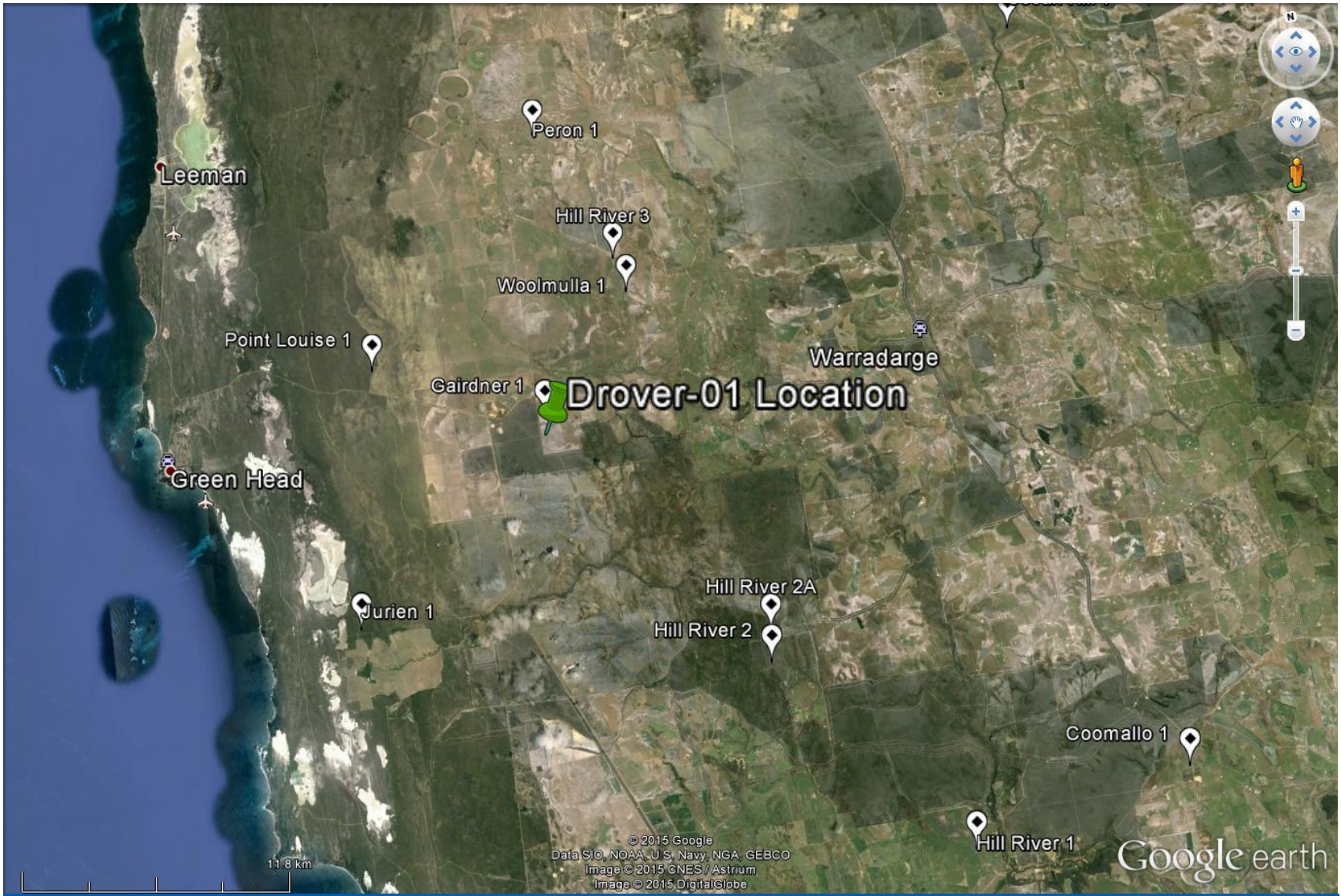
Groundwater monitoring program is tailored to each site and activity

Drover-1

Groundwater Monitoring Assessment and Planning

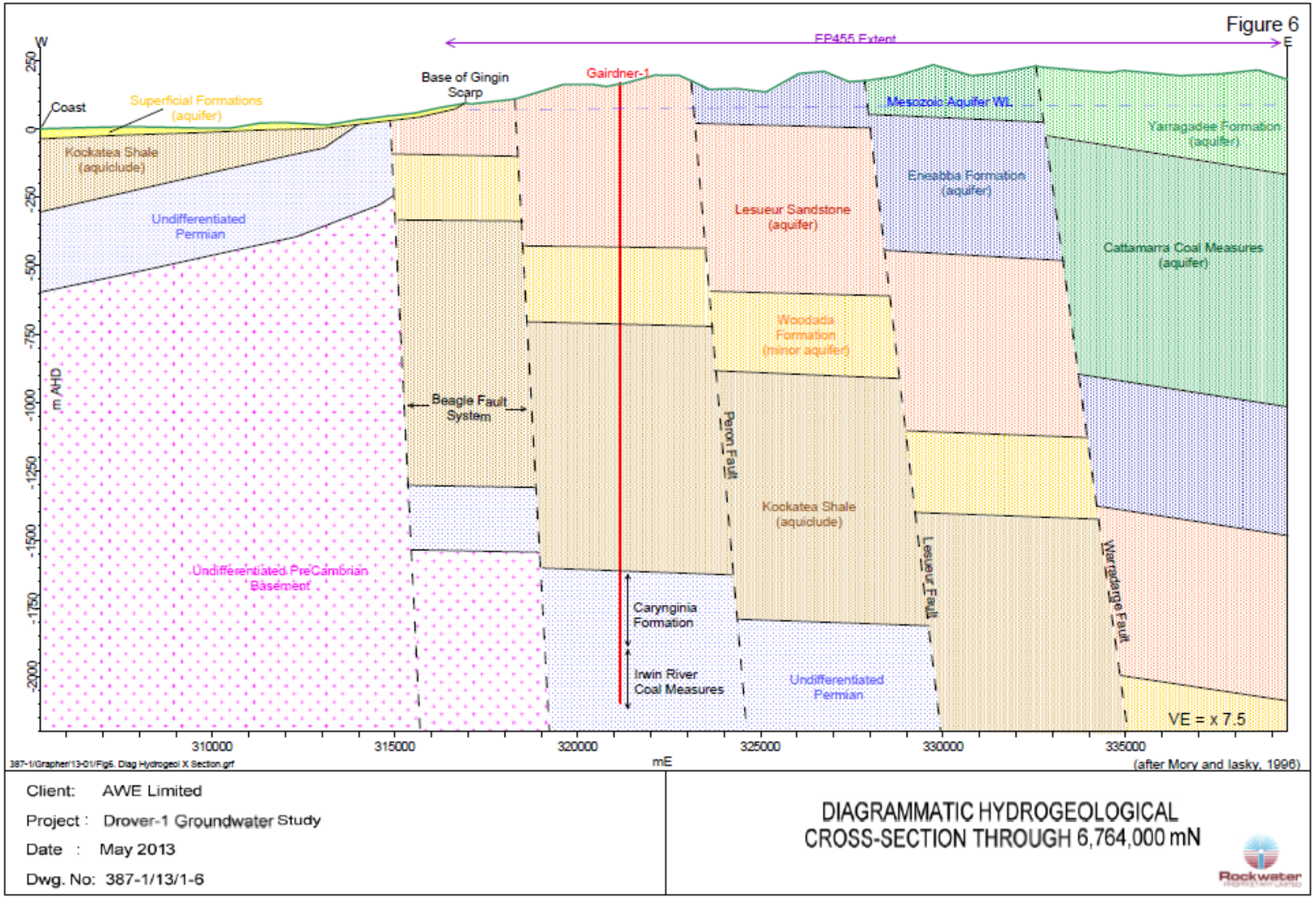
AWE

Exploration wells in the Drover-1 region



Exploration activity has been in the region since the 1960s

Drover-1 Cross Section from Ground Water Study



Hydrogeological assessment undertaken during Drover-1 planning phase drew on historic data

Drover -1 Regulatory assessment

Approvals process for the proposed Drover-1 well included review and assessment by:

- Department of Mines and Petroleum (DMP)
- Department of Water (DoW)
- Department of Parks and Wildlife (DPaW)
- Environmental Protection Authority (EPA)
- Appeals Convenor

Risk management controls

- DoW identified highest risk to water resources was from possible surface spillage of chemicals/diesel fuel
- DoW estimated that if any spill was not contained or remediated, it would take hundreds of (up to 800) years to travel the distance to Mt Peron borefield, which is approximately 4 km away.
- Depth to groundwater is 100 m. This gives ample time for containment and clean up of any surface spillage.
- If there was any surface spillage, AWE would promptly implement spill containment and clean up measures to prevent it from seeping offsite and into subsurface water.

In its response, the Department of Water recommended the adoption of a monitoring program and a contingency plan to the EPA to reduce this risk.

Groundwater monitoring program an important risk management tool

Drover-1 Groundwater Monitoring Advice

Independent consultants

- Designed the monitoring program (Rockwater) reviewed by DoW
- Monitoring bore installed by licensed water bore driller (?)
- Conduct monitoring on a six-monthly basis (Gemec)

DoW reviewed proposed monitoring program

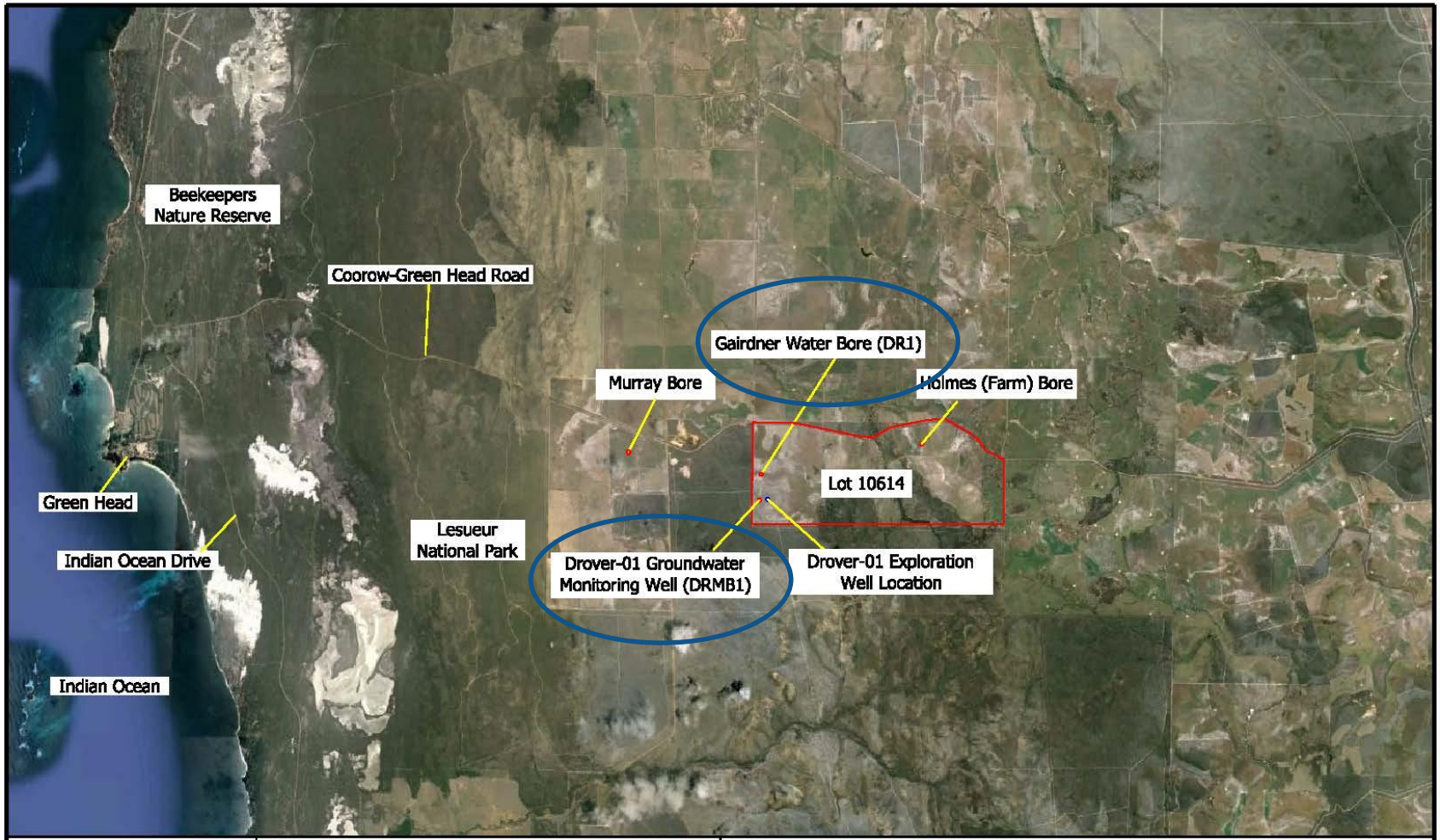
- Advised installation of a monitoring bore downstream
- Approved bore location and design based on site specific groundwater depth and flow
- Review monitoring results routinely

Drover-1

Groundwater Monitoring Details

AWE

Drover-01 bore locations



gemec
ENVIRONMENTAL CONSULTANTS
PO Box 89
Melville W.A. 6956
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F: +61 8 9339 0073
W: www.gemec.com.au

Water bore location
Lot boundary

0 1 2 3
Scale (km), approx.

Assumed Groundwater Flow Direction - Rockwater 2013

Regional Aerial Photograph (October 2013) Showing the Drover-01 Exploration Well & Groundwater Abstraction Bore Locations

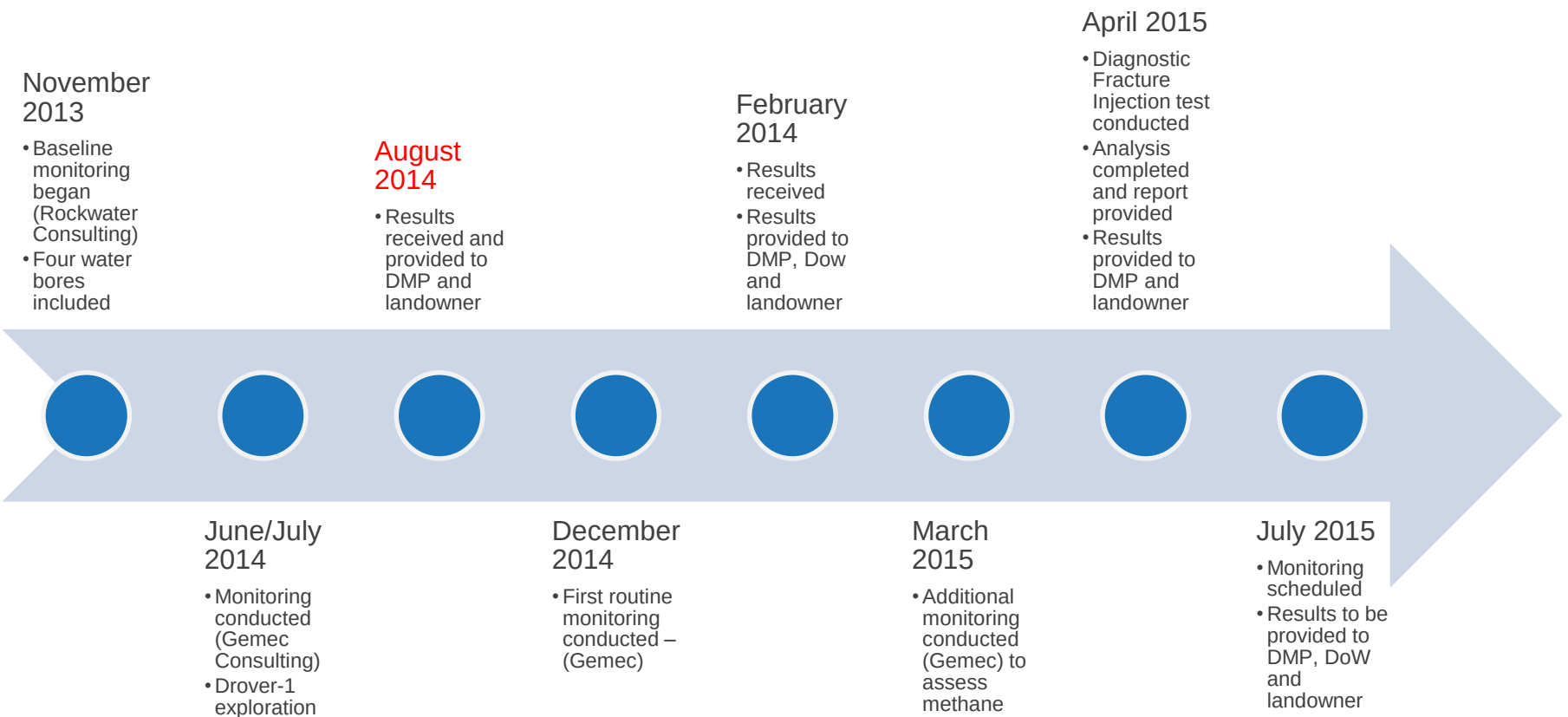
SOURCE: *Google Earth*

AWE Limited - Drover Site

Lot 10614 (9287) Coorow-Green Head Road, Warradarge, Western Australia

Drawn: SL	Date: 27.03.15	CHECKED RB	APPROVED RB	DRG No.	Figure 1
Scale: As Shown					

Drover-01 Groundwater Monitoring



Sampling consistently prior to drilling and following

Drover-1

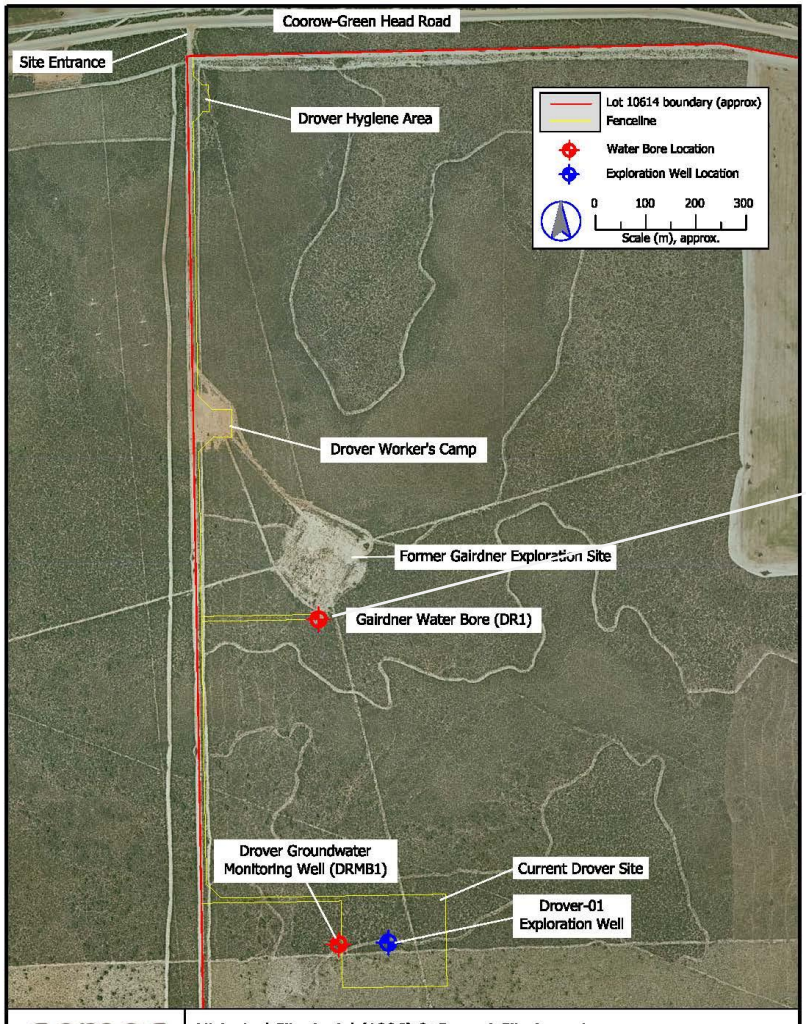
Recent monitoring results

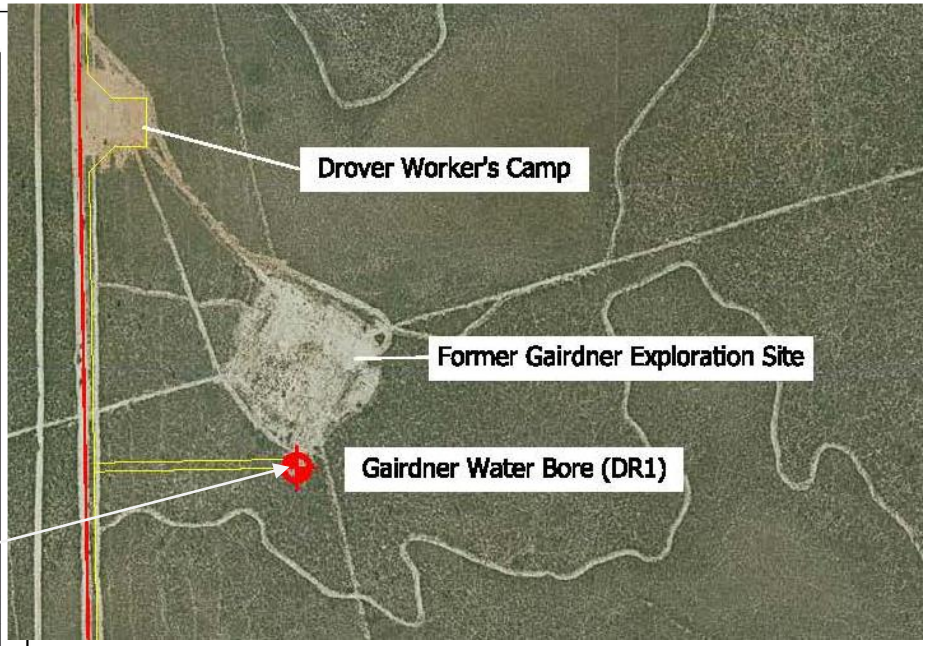
AWE

Recent Monitoring Results

- Preliminary results were provided in early February to AWE
- Most components tested at the four bores were in accordance with the baseline and previous monitoring results
- Results from two bores were different
  - Elevated concentrations of methane found
    - DR1 (4 mg/L)
    - DRMB1 (0.5 mg/L)
- AWE promptly advised DMP, DoW and the landowner of the initial results
- Independent consultant resampled the bores
- Analysis (stable isotopic) undertaken by University of Queensland to help identify the methane source and better understand the initial results
- Both bores were resampled March 2015

Potential Source





- Discussion with landowner (March) highlighted Gairdner-01 well mud sump as a possible source of hydrocarbon contaminants.
- Landgate aerial photo (1996) reveals well site immediately north of Gairdner water bore (DR1)

Methane isotope analysis

Background:

- Gemec commissioned University of Queensland (UniQuest) to undertake methane isotope analysis of samples collected from both bores.
- Dissolved methane can be of inorganic, microbial or mixed origin with the distinction made primarily on the basis of the stable isotope compositions of methane and associated groundwater.
- The carbon isotope differences between methane and CO2 and the hydrogen isotope difference between methane and associated groundwater may provide a better indication of the origin of the gases than the absolute carbon and hydrogen isotope values.

Methodology:

- Carbon, hydrogen and oxygen stable isotopic analyses were conducted using gas source isotope ratio mass spectrometry (IRMS) in The University of Queensland (UQ) Earth Sciences Stable Isotope Geochemistry Laboratory (UQ-SIGL).

Conclusions

- The methane found within DR1 and DRMB1 is of microbial origin
- The methane sources for each bore are not related, although both are linked to the biodegradation of hydrocarbon
- The source of TRH (Total Recoverable Hydrocarbons) within DRMB1 has been identified as from the drill muds and casing glue
- The TRH source within DR1 appears to be a result of the Gairdner exploration well activities, possibly an unlined mud sump buried on site

Based on the additional studies, Gemec concluded that:

The presence of hydrocarbons is not considered a result of AWE activities in relation to the drilling of Drover-01 exploration well.

Future plans

- Advise other stakeholders (ie CRG and Shire) of report findings
- Based on results and discussions with regulators, no further methane isotope analysis planned
- Continue six-monthly monitoring, including methane levels, at Drover-01 as per Environment Plan commitments
- Discuss any further steps when, and if, required

Supporting slides

As required

AWE

Results

DR1 - Methane concentrations similar to previous ~4,000 ug/L.
DRMB1 – Increase to 500 ug/L.

GROUNDWATER MONITORING EVENT
AWE LIMITED - DROVER-01 LOCATION
LOT 10614 (9287) COOROW-GREEN HEAD ROAD
WARRADARGE, WESTERN AUSTRALIA
MARCH 2015

Table 1: Historical and Current Groundwater Analytical Results - BTEXN, TRH, MTBE & Methane

Sample ID	Date	SWL (m btoc)	PID (ppm_v)	BTEXN						TRH				MTBE	Methane
				Benzene	Toluene	Ethylbenzene	m+p Xylenes	o-Xylenes	Naphthalene [1]	C6-C10 less BTEX	>C10-C16 less naphthalene	>C16-C34	>C34-C40		
DR1	13.11.13 [2]	103.880	NP	<1	**18**	**77**	**172**	**47**	<5	**150**	**120**	**390**	<100	<5	**15**
			Silica Gel Cleanup								<100	**290**	<100		
	10.02.14	104.084	-	<0.5	**2**	**21**	**18**	**9.5**	<0.5	**93**	**110**	<500	<500	<0.5	NT
	10.06.14 [3]	-	-	<1	**2**	**6**	<2	**3**	<1	<10	<50	<100	<100	<1	**48**
	17.12.14	104.086	0.0	<1	**6**	**13**	**20**	**7**	<1	**40**	**150**	**140**	<100	<1	**4000**
	11.03.15	104.227	2.9	<1	**9**	**37**	**71**	**20**	<1	**100**	**180**	<100	<100	<1	**3800**
	Dup 1			<1	**9**	**34**	**64**	**18**	<1	**93**	**160**	<100	<100	<1	**3500**
	RPD			NA	0	8	10	11	NA	7	12	NA	NA	NA	8
	Split 1			<1	**10**	**40**	**70**	**23**	<1	**67**	**90**	<100	<100	<1	**4000**
	RPD			NA	11	8	1	14	NA	40	67	NA	NA	NA	5
DRMB1	12.06.14	103.748	12.6	<1	<1	<1	<2	<1	<1	**360**	**150**	**120**	<100	<1	<5
			Silica Gel Cleanup								<50	**110**	<100		
	16.12.14	103.533	0.0	<1	<1	<1	<2	<1	<1	**210**	**220**	**190**	<100	<1	**160**
	11.03.15	103.558	-	<1	<1	<1	<2	<1	<1	**250**	**200**	**120**	<100	<1	**500**
Holmes (Farm) [3] Bore	21.10.13 [2]	-	NP	<1	<2	<2	<2	<2	<5	<20	<100	<100	<100	<5	<10
	10.06.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	**10**
	19.12.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	<5
Murray Bore [3]	21.10.13 [2]	-	NP	<1	<2	<2	<2	<2	<5	<20	<100	<100	<100	<5	<10
	19.12.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	<5
Domestic Non-potable Use (NPUG)				10	25 [4]	3 [4]	20 [4]		NE	NE	NE	NE	NE	12 [4]	NE
Long-term Irrigation Water (LTV)				NE	NE	NE	NE	NE	NE						
Stock Watering (SW)				NE	NE	NE	NE	NE	NE						
Groundwater HSL-D (sand)				5000	NL	NL	NL	NL	NL	70					
Laboratory Limit of Reporting - MPL				1	1	1	2	1	1						
Laboratory Limit of Reporting - SGS				0.5	0.5	0.5	1	0.5	0.5						
Laboratory Lim															

Notes: all concen
77 sha
'NA' denotes not a
'NE' denotes scree
'NP' denotes data
'NL' denotes scree
'NT' denotes 'not
'RPD' denotes rela

1. nap
2. sam
3. grou
4. aes
5. con

DRMB1 – TRH concentrations chromatograms indicate source to be: Liqui-Pol (drilling mud) and Pipe master (PVC pipe cement)
DR1 – Possible source of TRH identified as Gairdner drilling mud sump.

Note: The sampling methodology has varied across the 5 GME's as outlined below:
13.11.13 – Airlift and bailer
10.02.14 – Low flow pump (methane not tested)
10.06.14 – Sampled directly from PVC pipe outlet at freshwater pond
17.12.14 - Low flow pump
11.03.14 - Low flow pump

Methane isotope analysis results

- Results indicate the dissolved methane in both wells is of microbial origin and linked to the biodegradation of hydrocarbon.

- The very different concentrations of BTEXN, C6-C36 TRH and methane in the two wells, together with the methane carbon and hydrogen isotope systematics indicate the presence of methane in the two wells is unrelated.

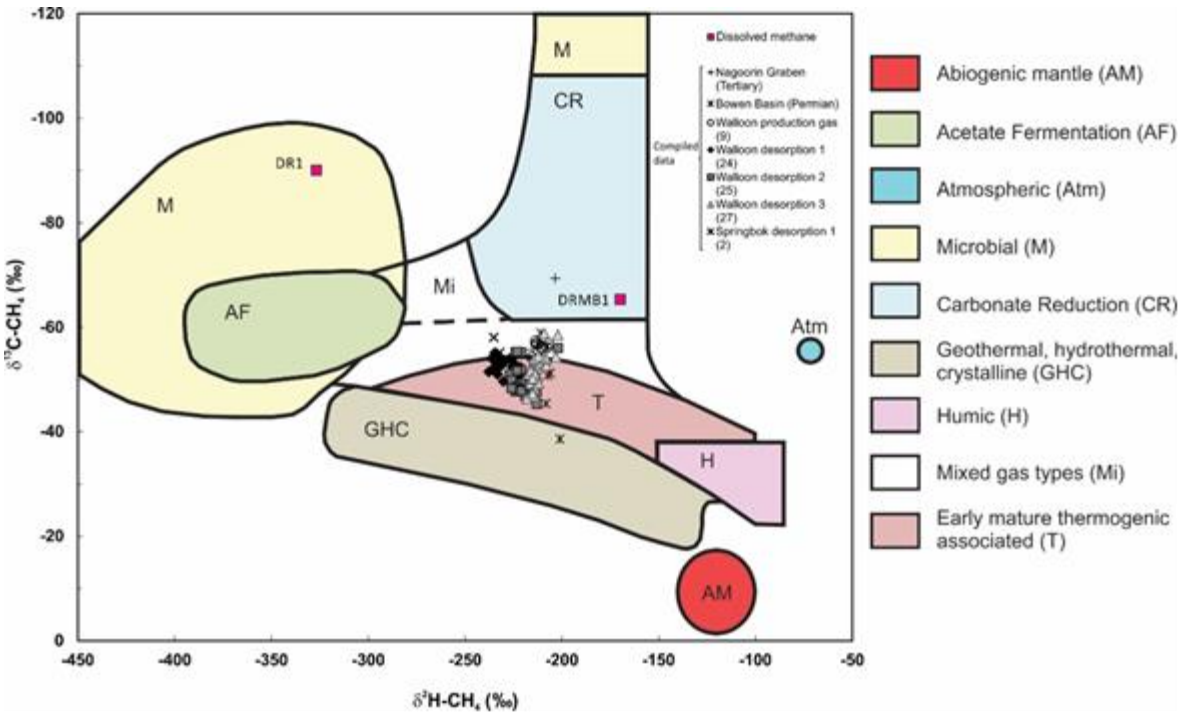


Figure 4. $\delta^{13}C$ vs $\delta^{2}H$ plot of CH_4 stable isotope compositions for dissolved methane samples DR1 and DRMB1. Results from coal measures in Queensland are included for comparison. Walloon Subgroup production gas data are from Draper and Boreham (2006). Walloon and Springbok desorption data from Hamilton et al. (2014). Bowen Basin production gas data are from Draper and Boreham (2006) and Kinnon et al. (2010). Nagoorin Graben data are from Draper and Boreham (2006). Fields on plot modified from Draper and Boreham (2006) after Whiticar et al. (1990) and Whiticar and Schaefer (2007).

Source: Groundwater methane isotope analysis, UniQuest, University of Queensland, 5 May 2015.

Drover-1 Shire of Coorow Community Reference Group

DMP: Community Partnership Awards

The journey of the Drover-1 Shire of Coorow Community Reference Group: from a place of mistrust, frustration and cynical attitudes to a position of trust, respect and finding common ground between the coastal towns of the Coorow community and AWE Pty Ltd. A humbling and fascinating story on how community empowerment in any project can be beneficial and rewarding for all stakeholders and projects.

"This community process was an eye opener. It was a great experience"

Bev Port-Louis (CRG Yued Aboriginal representative)

2016

Joint Submission: Drover 1 CRG and AWE Limited Pty Ltd

Submission Highlights

Foreword

At the outset, I was very sceptical about the then proposed **Drover-1 Shire of Coorow Community Reference Group (CRG)**. In the end, I was very pleased with the many positive outcomes achieved by the group. As a Shire councillor and community member, I served as a Steering Group member for the CRG from the first meeting in November 2014 until the end of 2015.

There were many things I liked about the CRG process. Firstly, the CRG gave us an independent, community body which allowed us to have our say about the Drover-1 Exploration Project (Project) and explore the key issues. Secondly, we were provided an independent resource which helped us design, facilitate and run the process of the CRG. This was invaluable as it enabled us to focus on the Project rather than the administration of the CRG. Finally, the outcomes. The unique process we adopted to run the CRG enabled us to learn about the Project through open, non-threatening dialogue with AWE and the various government agencies (DMP, DoW, DoH, CSIRO). This enabled us to identify and seek answers to key questions as well as obtain clarification and certain commitments concerning the Project.

We certainly did have our share of disagreements – especially in the early meetings. After all, we were dealing with a highly emotive issue – potential fracking. We also didn't solve everything in our journey and we didn't get everything we would have liked. But we absolutely had community empowerment and importantly we managed to have a significant positive influence on the Project as well as government department processes. This is something I did not think we would achieve before we started this journey.

I believe that the CRG process created real benefit and value for our community. I give enormous credit to AWE and the community for sticking with the CRG process and working together in a collaborative and empowering manner. Credit must also be given to the various government departments who sent guest speakers to inform the CRG on matters such as departmental policy and assurances to the community, risk assessment and their views of the science and engineering relating to Drover-1. I believe our CRG set a great example to future projects on how to place the community at the heart of a project and have open, two-way communication that fosters trust and respect between all parties.

I am very pleased to have been involved in the journey that was the Drover-1 Shire of Coorow CRG and I welcome a shared nomination with AWE for the DMP Community Partnership Award.

Guy Sims

(Coorow Shire Councillor, Drover-1 Shire of Coorow CRG Steering Group member)

Submission Highlights

CRG: Building Trust and Respect

2014 – Our beginning

"I was very anxious before the first meeting. I didn't know what to expect"

Bev Port-Louis (Traditional Owner representative)

"There was zero trust with AWE and there was a bit of emotion and heat at the first meeting"

Guy Sims (Coorow Councillor)

"I had initial doubts about the CRG process. I thought it was too touchy feely"

David Guise (AWE Regional Manager)

"I was very suspicious of most people at my first meeting. I tried to keep an open mind"

Tim Gilbertson (Community member)

"***When I heard that a CRG was being established, I found AWE scary and I was negative towards them"***

Jenny Griffiths (Community member)

2015 - Final thoughts

"The CRG process created value to our community and enabled it to grow. I take my hat off to AWE"

Bev Port-Louis (Aboriginal representative)

"We got the real facts from the process. The CRG created real value for the community"

Guy Sims (Coorow Councillor)

"The CRG process worked. We developed strong relationships and trust with the community"

David Guise (AWE Regional Manager)

"Top marks. Well informed. People had their say. We should use this process in the future. It's hard for anyone to hijack the CRG. DMP and DoW provided powerful information"

Tim Gilbertson (Community CRG member)

"We would definitely use this CRG process in the future for community engagement"

Jenny Griffiths (Community CRG member)

Submission Highlights

Summary

Drover-1 Exploration Project

The Drover-1 exploration well site is located on private, agricultural land in the Shire of Coorow, adjacent to the Lesueur National Park and near the Mount Peron Water Reserve (refer map). It is approximately 220 km north of Perth.

The well site was prepared for gas exploration in mid 2014 following initial stakeholder consultation undertaken in late 2013. The well site was successfully drilled in mid-2014 without any significant health, safety or environmental incidents.

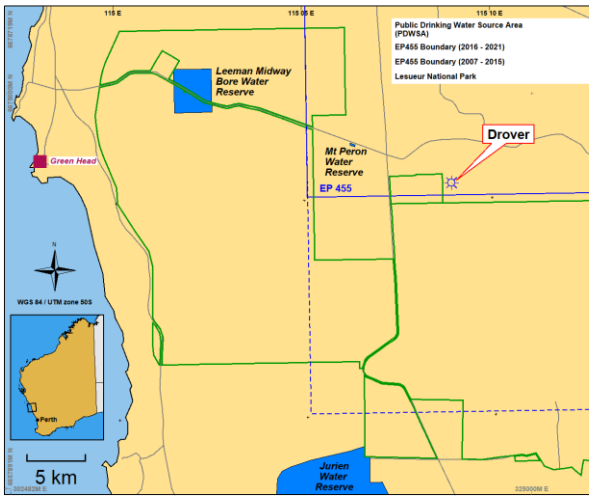


Figure 1: Location of Drover-1 (Source: AWE, April 2016)

Further information about the Project can be found here http://www.awemidwest.com.au/what-we-do/drover-1-exploration/

Following a series of tests between 2014 and April 2015, it was concluded that Drover-1 was unlikely to have a sufficient commercial flow rate of gas. As a result, the well site has been decommissioned and the site will be rehabilitated by mid-2016.

Community Reference Group (CRG)

Prior to the CRG being established, AWE had received all necessary approvals for the Project. However, due to a spike in community concerns arising in August 2014 around drinking water protection for the coastal towns of Green Head and Leeman, the approvals processes and potential lifestyle changes, an independently facilitated Community Reference Group (CRG) was established in late 2014 and met through to the end of 2015.

The purpose of the CRG was to place local community members at the centre of the consultation process with a clear line of communication between AWE and other stakeholders. The CRG also was designed to help reestablish trust and respect between community, industry and government.

All interested community members living and/or working or with other interests in the Shire of Coorow were welcome to attend meetings. This included Traditional Owners or their representatives with a current and/or historical connection to land in the Shire of Coorow. Meeting venues were shared between coastal towns within the Shire of Coorow at Green Head and Leeman.

Although independently facilitated, the CRG (refer Figure 2) was governed by a community selected Steering Group. Representation on the Steering Group included: local community and business owners (mainly from Green Head and Leeman), Traditional Owner (Yued), Shire of Coorow (staff and council) and NGO groups.

The independent resource was used by the Steering Group to assist in the design, facilitation and background administration of the CRG. This was helpful as it enabled community members to focus on the Project rather than the processes involved in running the CRG. The CRG funding was provided by AWE but not tied in any way to outcomes. The community was the monitor of independence of

the facilitator.

Once established, the CRG was open to invite input from external organisations as relevant. This included AWE, Conservation Council of WA, state government agencies such as Department of Mines and Petroleum, Department of Water, Water Corporation, Department of Parks and Wildlife, Department of Health and also academics and/or third party consultants to address technical or specialist questions.

Figure 2: Drover-1 Community Reference Group 2015 (Photo: with permission CRG)

Although uncommercial results from the exploration program led to AWE deciding to decommission the well site, post-CRG interviews with participants indicated that the CRG process was an overwhelming success and created real value for the community (Source: Independent Lessons Learned Report: Appendix A). Furthermore, all parties would definitely use this process again – they felt heard and respected and genuine human connections were made.

AWE

AWE is a medium size Australian energy company. AWE, and its predecessors, have been operating in the Mid West since the 1960s. All of AWE's operations staff live in the communities in which they operate. AWE does not employ FIFO employees in its Mid West operations.

Figure 3: Mid West AWE facilities employees

The Drover-1 well site is an exploration site in the Shire of Coorow located 17 km to the east of Green Head (Refer Figure 1). The well site was established to find more gas resources in the Mid West in order to complement those that the company already owns. Further information about the Project can be found here: http://www.awemidwest.com.au/what-we-do/drover-1-exploration/.

Selection Criteria

1.0 Selection Criteria: Leadership/Innovation in Engagement

1.1 How and when did the partnership come about?

Prior to the CRG forming, AWE had undertaken project planning that included stakeholder engagement activities for the Project. This had involved meetings with the Coorow council as well as council staff in 2013. AWE also hosted an open community information session, with assistance from the Coorow Council, and then circulated flyers and project update letters to shire residents at key project milestones. During this time, no significant concerns were raised about the proposed Project.

Leeman and Green Head are small coastal towns on the edge of a predominately agricultural shire. Green Head has a high demographic of retirees and holiday home owners. Both communities get their drinking water supply from the Mt Peron Water Reserve. Exploration has been occurring in the project area since 1978, however there has been limited resources activity in the Coorow Shire since 1990.

Following media focus on a group of concerned residents' views about potential contamination of their drinking water by the Project, a late agenda item was then raised at the August 2014 Council meeting. Council subsequently carried a resolution, which resulted in developing a Petroleum, Mining and Extractive Industries Policy, which specifically covered hydraulic fracture stimulation within the Shire. Meanwhile, further discussions were occurring between AWE, the Shire of Coorow and some community members. From this, AWE offered to fund an independent CRG *process* to identify and work through shared community concerns about the Project in the Shire of Coorow.

The independent CRG option was explored during a community meeting held in Greenhead on 8 October 2014 and a decision was made by those present to proceed with the offer. The first formal CRG was held on 5 November 2014 and the final official meeting held 9 September 2015. Informal relationships are continuing as rehabilitation of the well site progresses.

An independent facilitator was funded by AWE to design and facilitate the CRG process. The role of the facilitator was not tied to ensuring achievement of any particular outcome or agenda.

1.2 How did parties interact to promote inclusive dialogue and relationship building?

Formal Interactions

The CRG met to discuss progress against key issues and at key project milestones. From the beginning, all participants believed open dialogue was an important part of working through issues involving the Project. As such, invited guests such as AWE, Department of Mines and Petroleum, Department of Water, Department of Health and CSIRO were asked to come to certain meetings to listen to and understand the views of the community and respond to their queries. This exchange of information often involved presentations and the occasional use of physical materials to help demonstrate operational practice.

Conversations during each meeting were captured on a white board by the facilitator at the front of

the meeting using 'spider mapping' technique. This technique helped enable the threads of the conversation to be better tracked and for participants to see how their issues were being tracked and recorded. Points of difference were also captured during the meeting along with outstanding actions.

The initial meetings were focussed on establishing the CRG with AWE briefly introducing the Project and initial engagement activities. As meetings progressed and topics were discussed in more detail, AWE and other presenters were invited to stay for longer periods of time. Ground rules were established early in the CRG process based on respect and inclusion. The CRG participants welcomed Shire non-residents although they discouraged people from using the forum for their own purposes.

Draft minutes were prepared and distributed for comment by the independent facilitator to everyone attending meetings or wishing to be on the mailing list (Refer Figure 4). More than 200 people were on the distribution list which covered a wide range of organisations and locations. Final minutes with agreed corrections were then sent out, which enabled progress on key issues to be tracked.

The independent facilitator and the community also established a small Steering Group that could work and plan scheduling, preparation for, and notifying people about future CRG meetings. There was enormous power in the local community acting as a unified group for the CRG.

Figure 4: CRG relationships

Informal Interactions

CRG members advised that one of the most powerful relationship building mechanisms during the journey of the CRG was the informal meetings (Refer Appendix A). For example, site tours (refer Figure 5), post meeting catch-ups and afternoon teas were critical in developing human connections and understanding each other's point of view. These sessions significantly contributed to building trust and respect.

Supporting documentation

Supporting documentation such as minutes, ground rules, maps are available on request.

Figure 5: Site tours helped with relationship and trust building

1.3 How did the engagement practices demonstrate leadership, or an improvement to or establishment of innovative approach?

Classical Community Consultation

Classical community consultation in Western Australia has often placed the company at the centre of the consultation process. Under these consultation models, the company controls the project information and how it is communicated. It tends to be a one way flow of information. For example, often, a public meeting is held where the agenda has been set by the company without effective prior consultation with people who are most likely to be affected by the proposal. Such consultation prevents the community from effectively collaborating together to identify common issues and concerns as well as potential community benefits. This can lead to the community feeling like that they are isolated, voiceless and part of an administrative "tick and flick" exercise. This leads to everyone feeling frustrated.

Drover-1 Shire of Coorow CRG – a different approach

The Drover-1 Shire of Coorow CRG approach placed the community at the centre of the engagement process. It enabled the community to come together in a non-threatening environment to form a united collective and to articulate the important issues and what additional information they wanted about the Project.

The community was also resourced with an independent facilitator to help organise, design and facilitate the process. This enabled meetings to have an independent voice to keep the meetings on track and to hold all participants to account. It also prevented interest groups from manoeuvring the meeting agenda.

This innovative approach required a "leap of faith" by AWE and the community and required trust and respect between all parties in order to work.

In the oil and gas industry in Western Australia, such comprehensive consultation and resourcing for a single well exploration project is unusual and unprecedented. However, the extra effort given to this Project was in response to community interest in groundwater management aspects and reflects a genuine desire by all participants to improve the understanding of everyone's views.

1.4 How were the community's values integrated into the business operations?

Key community values and questions were identified early in the CRG meetings (Refer Table 1). These items led to a number of commitments being made by AWE and government agencies to

ensure that community values were being addressed by the Project. Examples of community values being heard and implemented into the project included (sourced from minutes):

Table 1: Community Values and Resolutions

Community Value	Resolution	Responsible	Status
Community empowerment around being heard on issues of concern	Offer and acceptance to support independently-facilitated and resourced Community Reference Group – Oct 2014	AWE/community	Agreed and implemented
Fracking concerns and perceived impacts on water supply	No hydraulic fracture stimulation of Drover-1 Well before April 2015 – Nov 2014 Presentations on fracking from DMP, DoW, DoH	AWE Government	Agreed Ongoing
Water supplies assured	Leeman and Green Head potable water supplies assured – Nov 2014	Department of Water	Agreed
Site Access	Agreed public access to site (subject to safety requirements) – April 2015	AWE	Agreed
Available information, trusted information	Agreed timely access to monitoring results - April 2015 Appointment of independent scientist – agreed but not pursued by CRG (not required) Information from government agencies	AWE CRG Govt agencies	Agreed Agreed Agreed
Future protection of sensitive water areas	AWE agreed to facilitate a CRG meeting with DMP and DoW to determine if Mt Peron water supply could be permanently removed from future exploration leases.	CRG	Meeting held

2.0 Selection Criteria: Benefits of the collaboration

2.1 What initiatives arising from the partnership have benefited the community?

This process benefited the community and AWE because it allowed the Project to be better shaped to match community expectations.

Dealing with Community Questions

The CRG process enabled the community to develop and track a list of questions that were specific to their needs and interests. For example, the following questions were asked and answered in the first CRG meeting in November 2014.

- How are leases assigned to companies like AWE to drill wells like Drover-1?
- What is AWE entitled to do at Drover-1 under its current lease or equivalent?
- What factors were considered by whom in the lead-up to and during the approval process for Drover-1?

New questions from the community continued to be identified and tracked via minutes of subsequent meetings. If questions were not addressed, then attempts were made at the subsequent meeting to respond.

Working towards commitments

The CRG process enabled the community to articulate and seek from AWE and the government a number of key commitments concerning the Project. Many of these commitments helped to shape the Project (Refer Table 1).

2.2 What are the specific beneficial outcomes for the community?

There were many beneficial outcomes that the community and AWE were able to obtain by participating in the collaborative CRG process. Many of these benefits are captured in Appendix A. Some of the significant benefits included:

- The community was able to establish a formal group that empowered them to have a high level of influence on the Project (refer section 2.1)
- The community was able to use an independent facilitator as a resource to design, organise and run its meetings. This enabled the community to focus on the Project rather than the administration of the CRG. This saved the community considerable personal time
- A high level of trust and respect was established between the community and AWE
- Stronger relationships and friendships were built within the community as a result of the CRG process
- The community was able to learn more about the broader onshore energy industry especially the regulatory processes involved
- AWE and government agencies were provided an opportunity to listen to the community in a non-threatening environment and were then able to provide tailored information based on the community concerns and issues
- At a regional and state level, AWE and government agencies were able to better understand the key community issues around the onshore energy industry. For example, a community top 10 questions list was developed for use in the Mid West region so that future projects can better understand and tailor their consultation to answering these 10 questions.

2.3 How was consensus reached on the value of such projects?

The CRG process generated a list of common questions and various commitments sought through consultation with the community. Each outstanding question and commitment was tracked throughout the CRG process (Refer 1.4).

3.0 Selection Criteria: Commitments to providing sustainable and enduring outcomes

3.1 How has the partnership made a positive sustainable difference for the community?

The CRG process has reconnected the community, government and AWE. At the heart of the process, human connections have been made with the core outcomes being mutual respect and trust. This is an outstanding achievement given the highly contentious issue of "fracking" in some sections of society. Other communities in the area are now considering using a similar CRG framework in relation to future industry projects and use the lessons learned (refer appendix A) and top 10 questions to enable community empowerment in any project.

The model applied at the Drover-1 Shire of Coorow CRG has been accepted as a new method for empowering community in project development. The same successful model is being considered for another AWE proposal in the Shire of Irwin in 2016. There have also been discussions for a broader Mid West regional CRG forum as a result of the Drover-1 CRG work.

The process was also the first time that many of people in the local community had an opportunity to work with and hear the views of a Yued Traditional Owner. The Yued Traditional Owners also felt that they had a voice and ownership in the process, which was a welcome outcome.

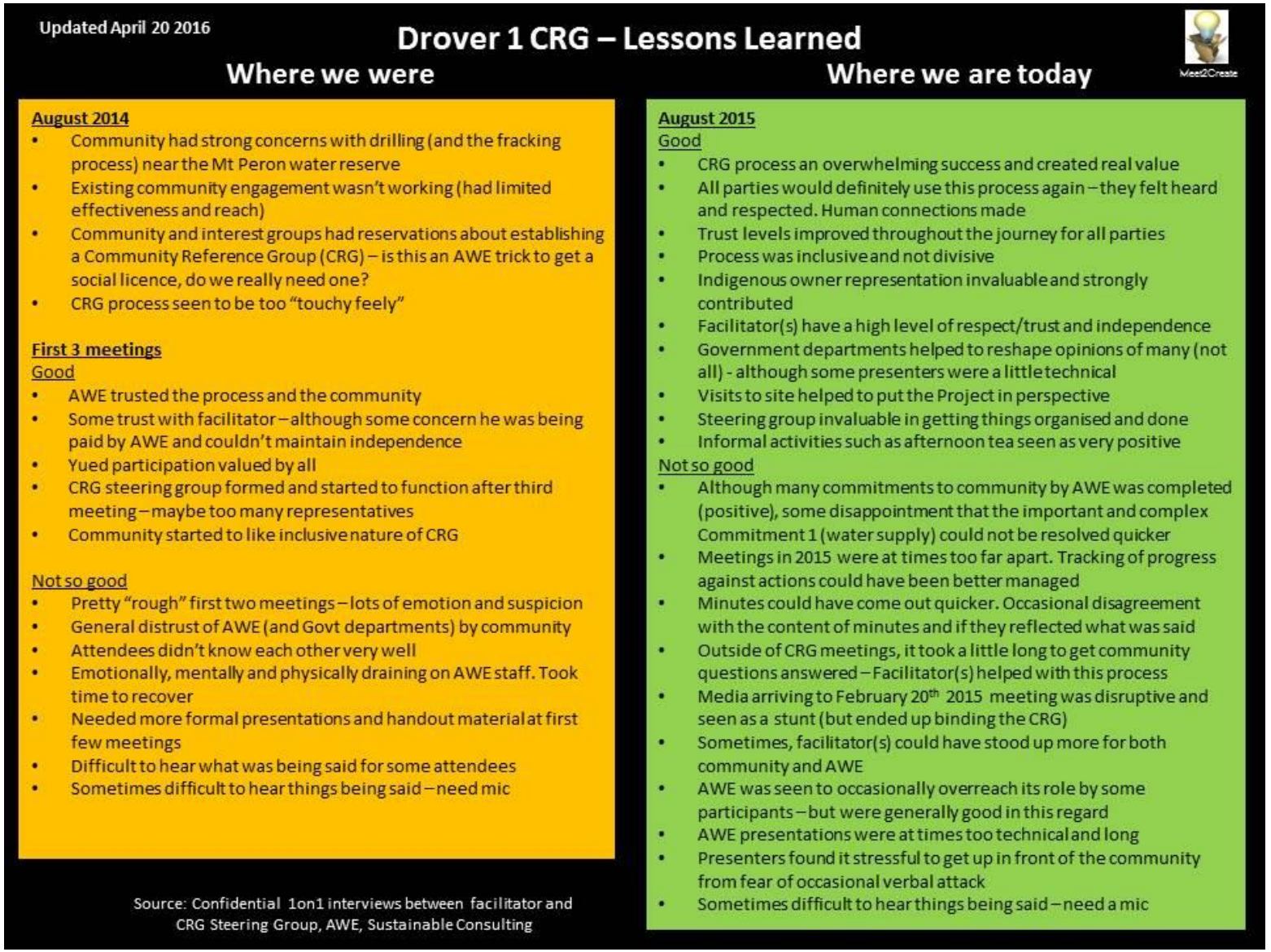
3.2 How will the collaboration benefit the community beyond the life of the resource project?

The CRG has set a benchmark for collaboration and community empowerment. In the future, it is highly likely that other resource companies will be encouraged to undertake a similar method of community engagement in the Mid West region.

Beyond the life of this Project, the CRG has set the scene for AWE's next exploration phase in the recently renewed permit area. The goodwill and trust that has already been established between community, AWE and government departments will facilitate engagement for further exploration activities AWE may propose to undertake.

3.3 How does the project extend beyond normal requirements and obligations?

In mid 2014, AWE had already received approval to commence its exploration activities associated with the Project. The company was not legally obligated to undertake any further community consultation processes. However, when there was a spike in community concerns in August 2014, AWE offered to place the community at the centre of the consultation process through establishing an independently facilitated CRG process. This "extra" community consultation is not traditionally part of an onshore energy exploration project. However, this step proved to be extremely beneficial to all stakeholders with relationships that are lasting beyond the timeframe of the project.


Updated April 20 2016
Drover 1 CRG – Lessons Learned
Where we were
Where we are today
Meet2Create
August 2014
• Community had strong concerns with drilling (and the fracking process) near the Mt Peron water reserve
• Existing community engagement wasn't working (had limited effectiveness and reach)
• Community and interest groups had reservations about establishing a Community Reference Group (CRG) – is this an AWE trick to get a social licence, do we really need one?
• CRG process seen to be too "touchy feely"
First 3 meetings
Good
• AWE trusted the process and the community
• Some trust with facilitator – although some concern he was being paid by AWE and couldn't maintain independence
• Yued participation valued by all
• CRG steering group formed and started to function after third meeting – maybe too many representatives
• Community started to like inclusive nature of CRG
Not so good
• Pretty "rough" first two meetings – lots of emotion and suspicion
• General distrust of AWE (and Govt departments) by community
• Attendees didn't know each other very well
• Emotionally, mentally and physically draining on AWE staff. Took time to recover
• Needed more formal presentations and handout material at first few meetings
• Difficult to hear what was being said for some attendees
• Sometimes difficult to hear things being said – need mic
Source: Confidential 1on1 interviews between facilitator and CRG Steering Group, AWE, Sustainable Consulting
August 2015
Good
• CRG process an overwhelming success and created real value
• All parties would definitely use this process again – they felt heard and respected. Human connections made
• Trust levels improved throughout the journey for all parties
• Process was inclusive and not divisive
• Indigenous owner representation invaluable and strongly contributed
• Facilitator(s) have a high level of respect/trust and independence
• Government departments helped to reshape opinions of many (not all) - although some presenters were a little technical
• Visits to site helped to put the Project in perspective
• Steering group invaluable in getting things organised and done
• Informal activities such as afternoon tea seen as very positive
Not so good
• Although many commitments to community by AWE was completed (positive), some disappointment that the important and complex Commitment 1 (water supply) could not be resolved quicker
• Meetings in 2015 were at times too far apart. Tracking of progress against actions could have been better managed
• Minutes could have come out quicker. Occasional disagreement with the content of minutes and if they reflected what was said
• Outside of CRG meetings, it took a little long to get community questions answered – Facilitator(s) helped with this process
• Media arriving to February 20th 2015 meeting was disruptive and seen as a stunt (but ended up binding the CRG)
• Sometimes, facilitator(s) could have stood up more for both community and AWE
• AWE was seen to occasionally overreach its role by some participants – but were generally good in this regard
• AWE presentations were at times too technical and long
• Presenters found it stressful to get up in front of the community from fear of occasional verbal attack
• Sometimes difficult to hear things being said – need a mic

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Baseline Characterisation and Monitoring Protocols for Development of Shale and Tight Gas Resources, Northern Perth Basin

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Final Report for the Northern Perth Basin Consortium

CSIRO
AWE Perth Pty Ltd
Latent Petroleum
Norwest Petroleum
Origin Energy
WA Department of Mines and Petroleum

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Executive summary

The northern Perth Basin is highly prospective and offers significant potential for the development of shale and tight gas resources. This development requires stimulation methods involving fracturing gas-bearing, low permeability strata. Experience in shale and tight gas exploitation globally, particularly North America, has suggested that in some cases fugitive methane from the reservoir may migrate into near-surface environments including ground water or even atmosphere. While this occurrence is not typical and can be mitigated by good engineering practices, Australian communities, regulators and resource companies are aware of these potential outcomes.

As such, CSIRO, in collaboration with UWA and four onshore gas explorers (Latent Petroleum, AWE Perth Pty Ltd Limited, Origin and Norwest), and the WA Department of Mines and Petroleum (DMP) have established a coordinated Research Program into methods of establishing baseline values of environmental indicators and of monitoring techniques for these indicators prior to and during the development of tight and shale gas resources. The goals of this Research Program are to improve: 1) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact, and 2) understanding of suitable methods and protocols for establishing environmental baselines associated with tight gas development. The Research Program will consider monitoring aspects in four environmental domains: deep subsurface, shallow sub surface, surface and near-surface atmosphere.

The work described in this report represents the first project of the proposed Research Program. The most significant outcome is that this study represents the first attempt to gather ambient concentration values of methane in the groundwater and the near-surface in the northern Perth Basin. In most cases the data gathered in this study represents a "snapshot" of methane distribution across the area at the time of data gathering.

With respect to the higher level goals of the proposed Research Program, this project has concluded that:

1. Although there exists a good interpretation of regional flow in the northern Perth Basin, at this stage there is inadequate monitoring of the key aquifers for establishing baseline conditions.
2. Ambient levels of CH_4 across the basin were found to be consistent with the published values from atmospheric CH_4 monitoring stations. It is recommended that the impacts of stationary sources (facilities, towns, lakes and old petroleum wells) and from mobile sources, such as cattle, be investigated in future studies.

3. The concentrated soil gas flux survey found no anomalous readings and the data indicated the flux was being controlled by microbial action. Additional sampling and modelling is recommended.
4. Long-term monitoring of soil gas flux rates to understand seasonal variations are important to place the soil gas flux surveys in context and may provide the basis to allow predictions of changes in methane flux rates related to changing climatic conditions. During this project a system was developed to provide ongoing, continuous (every 20 minutes) measurements of soil gas flux. Due to ongoing system problems very little useful data was obtained, however, the system is now considered robust and following further testing will be ready for future deployment.

1 Introduction

Recovery of shale and tight gas in Australia offers significant new potential for both large and small resource companies. The process of extraction of gas from shales and tight reservoirs requires stimulation methods involving fracturing gas-bearing, low permeability strata. Experience in shale and tight gas exploitation globally, particularly North America, has suggested that in some cases fugitive methane from the reservoir may migrate into near-surface environments including ground water or even atmosphere. While this occurrence is not typical of shale and tight gas development and can be mitigated by good engineering practices, Australian communities, regulators and resource companies are aware of these potential outcomes. Western Australia's natural gas from shale and tight rocks industry is currently in the early stages of exploration and evaluation. As such, it is timely to initiate studies to understand the baseline levels of CH_4 that may be present across the northern Perth Basin. This will provide the initial data required to understand the controls on the system and develop monitoring systems to effectively and efficiently monitor changes that may occur over time.

As such, CSIRO, in collaboration with four onshore gas explorers (Latent Petroleum, AWE, Origin and Norwest), and the WA Department of Mines and Petroleum (DMP) have established a coordinated Research Program into methods of establishing baseline values of environmental indicators and of monitoring techniques for these indicators during the development of tight and shale gas resources. The goals of this Research Program are to improve: 1) understanding of suitable methods and protocols for establishing environmental baselines associated with tight and shale gas development, and 2) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact. The Research Program will consider monitoring aspects in four environmental domains: deep subsurface, shallow sub surface, surface and near-surface atmosphere.

The Project described herein represents the initial phase of this Research Program. The objective of this Project is to examine the three shallower domains of the subsurface: (groundwater), surface (soil gas) and the near-surface atmosphere. A sub-project involving a passive seismic survey is published as a separate report (Issa et al, 2016). The outcomes of this project will provide the basis for refining data collection and analysis methods for future projects aimed at achieving the high level goals of the Research Program.

The study consisted of four components and was intended to build on work undertaken by CSIRO in the Surat Basin through GISERA and other programs. The four areas of study and the objectives are:

i) Groundwater: a desktop study intended to understand the current state of knowledge of the hydrogeology within each of the permit areas and a review of the analyses and methodologies used by each

ii) Mobile CH_4 Survey: a mobile survey of background levels of methane across the study area

iii) Soil Gas Flux Survey: an intensive survey taken across one of the permit areas to measure the CH_4 flux

iv) Long-term Soil Gas Flux measurement: a semi-permanent installation to complement the soil gas flux survey by measuring the soil gas flux over an annual cycle.

The methodologies used in each component and the results are discussed below.

1.1 Study Area

The study area was constrained by the extent of the permit areas of the four consortium members (Figure 1). The permit areas attributed to AWE within the study area are all operated by AWE, however permits L1/L2 are jointly owned by AWE 50% and Origin Energy 50%. The permit areas were correct at the time of the study. The study area includes several small towns, including Dongara and Jurien Bay. The study area also includes several oil and gas fields and the Dongara Processing Facility (DPF). The land use is predominantly farming and scrubland and includes national parks and several lakes.

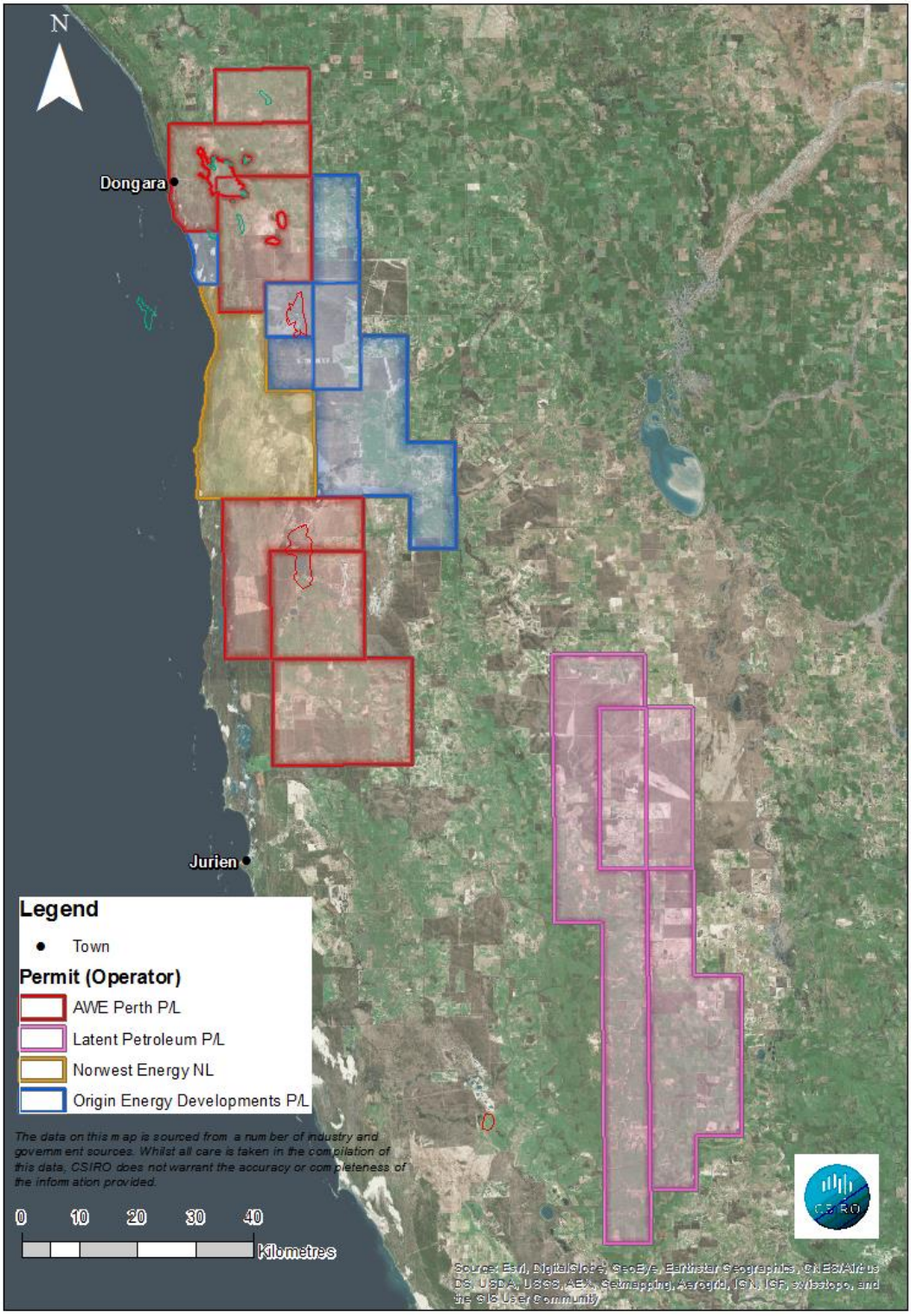


Figure 1 Study area constrained by the permit areas of the Consortium Members

2 Groundwater

2.1 Introduction

The objective of this component of the project was to review the current state of knowledge of the groundwater of the northern Perth Basin and to integrate where possible the regional hydrogeological interpretation with local data and with data being obtained by the consortium members. The study focused on groundwater data available within a 5 km radius of the permit areas. A working knowledge of the aquifers within this area is assumed.

2.1.1 Regional Information

The WA Department of Water (DoW) requires that all bores have a work approval and are registered, regardless of the intended purpose. Under WA's *Rights in Water and Irrigation Act 1914, Rights in Water and Irrigation Regulations 2000 and Water Services Act 2012*, a water access licence is required to extract water for all consumptive purposes except for stock and domestic purposes. The data from these bores is maintained in an online database, the online Water Information Reporting tool (WIR), including site details, water-level and water quality. In addition, the DoW is finalising a report on hydrogeological and groundwater resources for the northern Perth Basin (Department of Water, 2016), with the objective of compiling and analysing hydrogeological information and knowledge reported in various public and private reports and databases. Under a restricted access license agreement, the DoW has supplied CSIRO with ArcGIS files of the figures reported in the northern Perth Basin Bulletin and permitted use of these figures in the current report. However, these ArcGIS files cannot be distributed to any third party without further licensing from the DoW. The datasets used for generation of figures in the northern Perth Basin report have undergone rigorous screening and analysis by DoW and represent the best available interpretation of the groundwater regime of the northern Perth Basin, Autumn, 2007.

CSIRO conducted a search of the WIR online database (DoW, 2016) and identified 1896 registered bores located within 5km of the permit areas of the consortium members (Table 1). A hydrogeological study requires water-level and salinity data and each data point must be associated with an aquifer to be useful. Of the bores identified within the area of interest, 1383 have either water-level data (1080), salinity data (1193) or both (896). Of these, only 231 have a designated aquifer. However, a significant number of the remaining bores had construction data available (i.e. either screened interval depth or bore total depth). A methodology was developed to assign the data in these bores to an aquifer. The methodology is described below and resulted in an additional 890 bores being assigned a designated aquifer. Figure 2 and Figure 3 demonstrate the distribution of bores with water-level or salinity data, respectively, after the application of the methodology.

According to the WIR, the current status of these bores is largely unknown. Of the original 1896 bores, only 153 are designated as “Operational”, while the status of 1736 bores is “Unknown” (Table 2). The construction date associated with these bores also varies from 1900 (likely a default value) to 2014. The uncertainty associated with the status of these bores illustrates the difficulty of maintaining such a large database and demonstrates why a rigorous QC system is required to analyse the datasets.

Table 1 Summary of bores with useful data (source: WIR database)

	Number of records
Bores located within 5 km distance	1896
Bores with water-level, salinity data or both	**1377**
Bores with known aquifer information	231
Bores with construction data	890
Total Number of bores available for analysis	**1121**
Bores with no aquifer and insufficient depth data	256

Table 2 Status of groundwater bores (source: WIR database)

Status of bores	Number of records
Abandoned	1
Decommissioned	1
Non-functional	4
Not operating (historical)	1
Operational	153
Unknown	1736

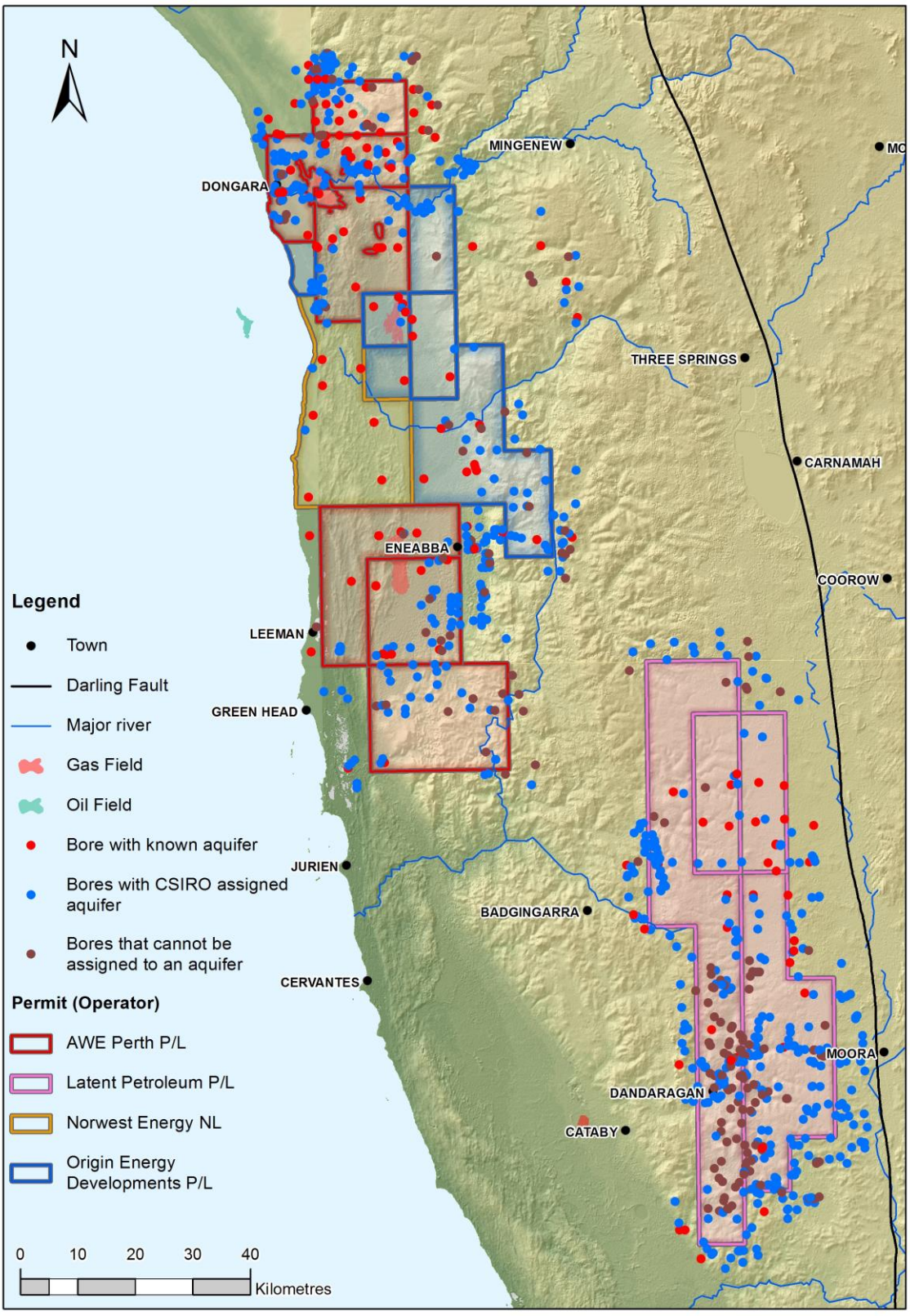


Figure 2 Location of groundwater bores in WIR database with water-level records within 5 km radius of permit areas.

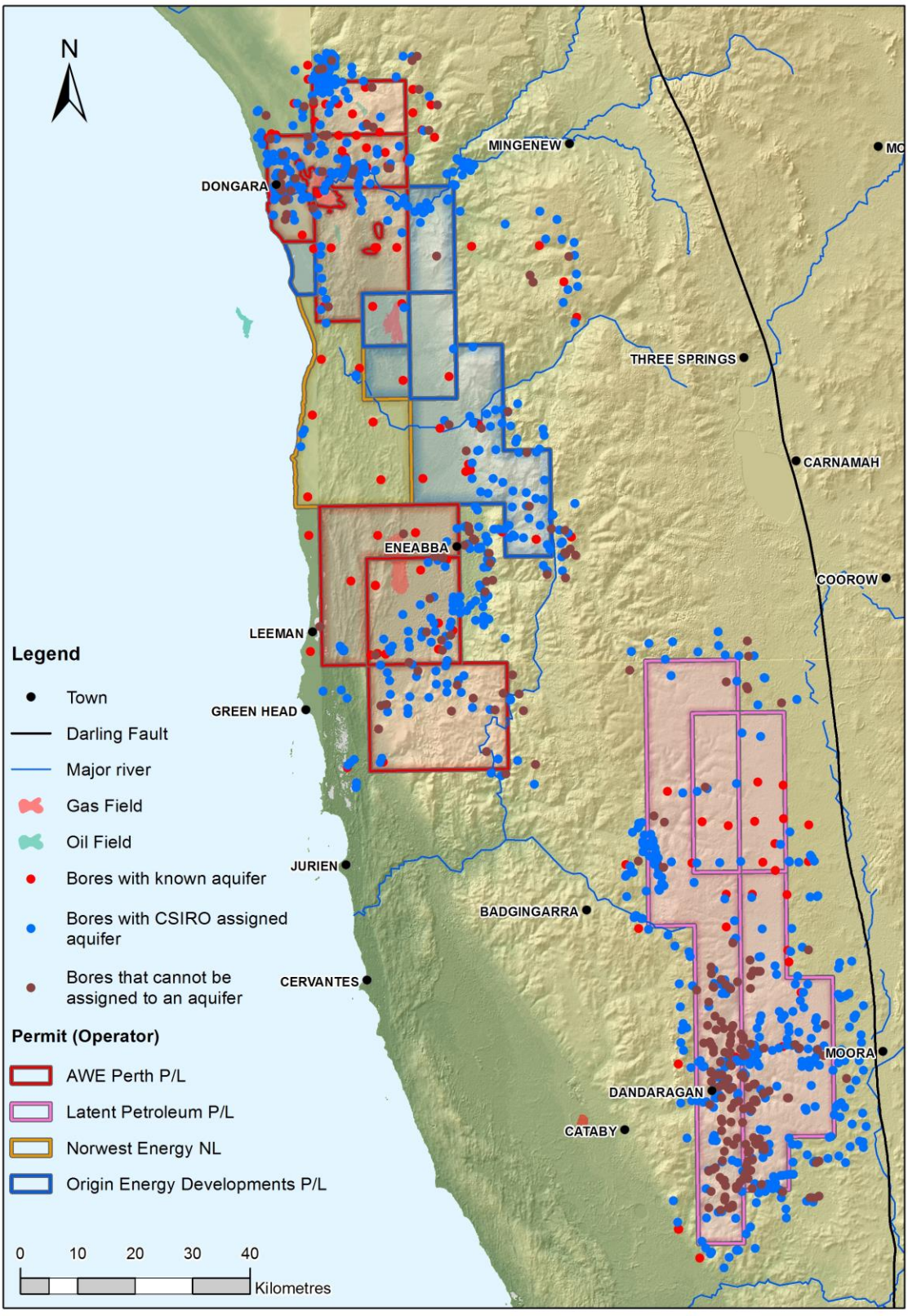


Figure 3 Location of groundwater bores in WIR database with salinity records within 5 km radius of permit areas

2.1.2 Localised data from consortium members

In the WIR database there are 10 groundwater and 7 salinity readings from 15 groundwater bores within the permit areas (2 AWE bores, 1 Latent Petroleum bore, 1 Norwest Energy bore and 11 Origin Energy bores) were available (Table 3). Figure 4 shows the locations of the consortium members (AWE and Latent) groundwater bores.

Data was supplied by AWE, Origin Energy and Latent Petroleum. In addition, Latent Petroleum provided a report commissioned from RockWater (2013). In the report, a MODFLOW groundwater model was developed to assess the potential impacts on the groundwater systems from the Warro Project activities and to inform a groundwater monitoring system. The results from the report indicate that there will no impact on the Yarragadee aquifer and a minor impact on the Parmelia aquifer due to Latent Petroleum's planned activities at the Warro Project area.

Unfortunately, we considered there was insufficient data to undertake a review of sampling protocols and reporting with respect to current regulations, as originally proposed. As an alternative, we carried out a review of the current state of the wells and monitoring data within the permit areas from the DoW database.

Table 3 Summary of monitoring data supplied by consortium members

Consortium Member	Number of bores	Reported Aquifer(s)	Groundwater-levels monitoring period	Salinity monitoring period
AWE	25	Yarragadee (19 bores); Eneabba (1 bore); Lesueur (3 bores); Bores with no co-ordinates (2 bores)	2008-2015	2007 - 2015
Latent Petroleum	14	Leederville – Parmelia and Yarragadee (based on RockWater, 2013)	No information	2014
Origin Energy	19	No information	No information	2011-2014

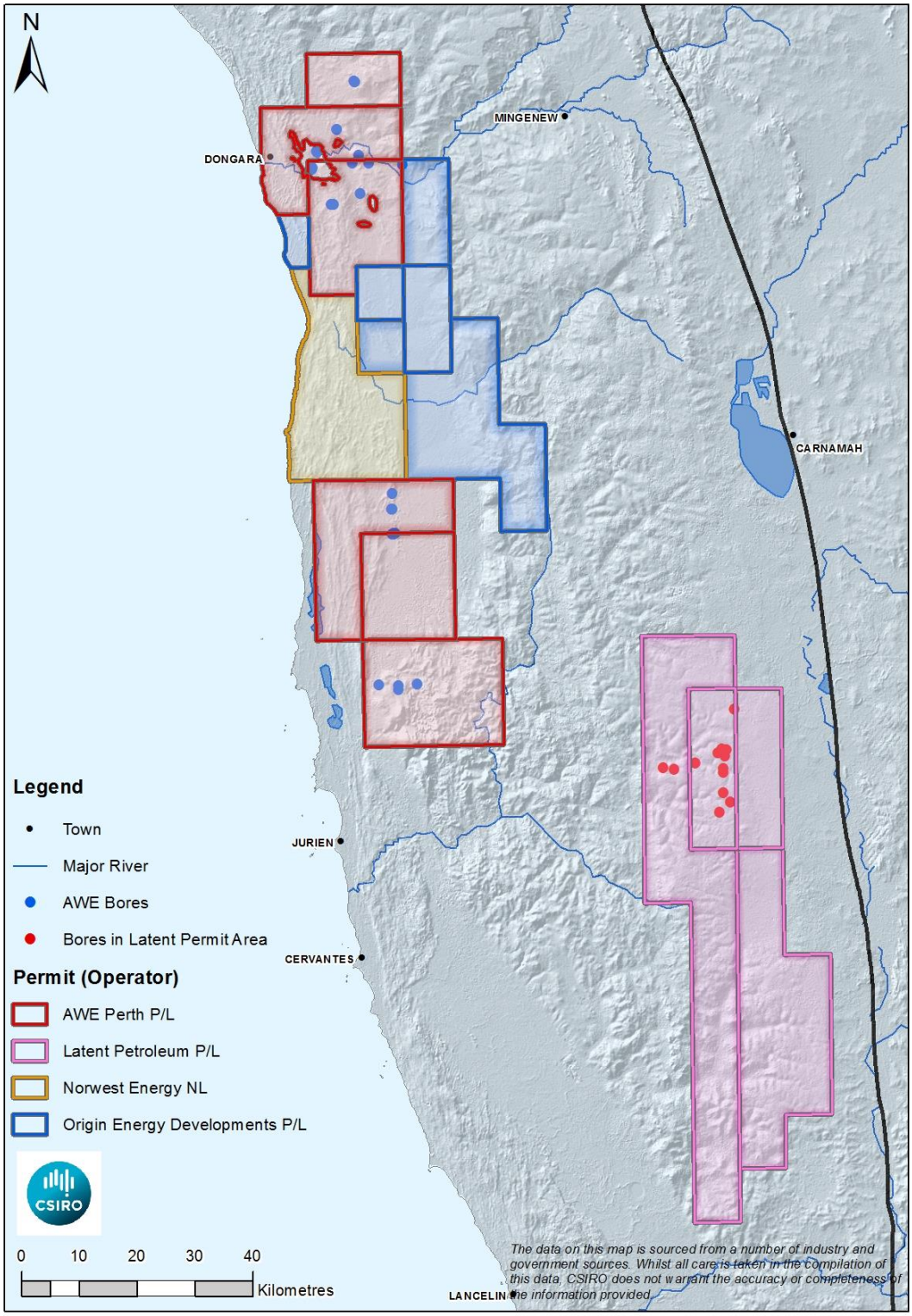


Figure 4 Location of consortium members permit areas and groundwater bores where data was supplied

2.2 Methodology

2.2.1 Methodology to assign aquifers

The methodology to assign an aquifer to bores with water-level and/or salinity data compared the total depth (or screened interval) of a bore relative to the nearest overlying aquifer surface (Figure 5). Therefore, the first step in the methodology was to create surfaces of each key interval from the available information and the second to run the comparison and assign the aquifer according to a set of parameters described below.

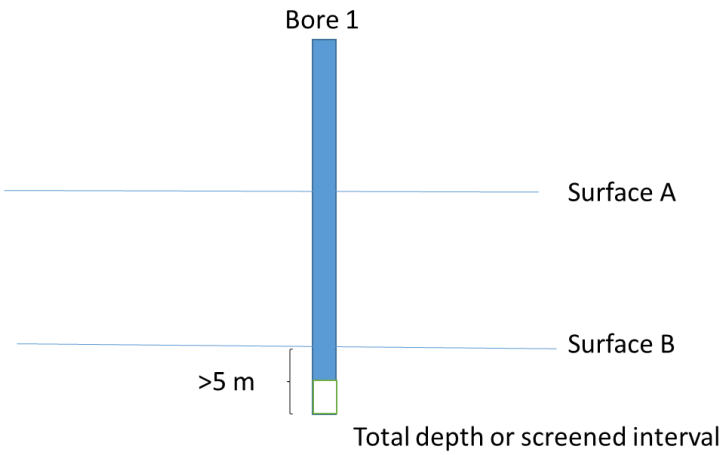


Figure 5 Schematic representation of methodology to assign aquifers

Geological Model Building

The DoW provided basal elevations and structural contours (isopachs) for 14 geological formations. These were used to create surfaces for each formation using various geoprocessing tools available in ArcGIS (version 10.3) software, as described below (Figure 6). It is assumed that reader has some familiarity with ArcGIS software. Details about the accuracy of the data are provided in Appendix A.1.

The base elevation/structural contours for a given formation (e.g. Yarragadee) were added to ArcGIS along with the fault networks present at the northern Perth Basin area. The contours were examined for continuity and to reflect any faulting in the area. Where discontinuities in the contours due to faults were observed the contours were split into individual fault blocks (Figure 6 (1)) for further processing. Once all the contour blocks were created, a rectangular raster surface for each formation was generated using *Topo to Raster* tool in ArcGIS (Figure 6(2)). The base polygon (Figure 6(3)) which covers the extent of the contours was split along the lines of the contour blocks and each individual polygon converted into a raster mask using *Polygon to Raster* tool (Figure 6(4)). The raster mask is then used to clip the generated formation surface to match the base polygon (Figure 6(5)), in order to generate an accurate extent of the contour block. After generation of the

surfaces for the individual contour blocks, formation surfaces are then mosaicked together (Figure 6(6)) using the *Mosaic* tool in ArcGIS software.

The generated surfaces were stacked based on the geological age as reported by Davidson (1995).

Table 4 presents the geological surfaces generated using the base elevation datasets provided by DoW.

Table 4 Geological surfaces generated using the DoW datasets

Stratigraphy	Represented in model	Represented as single layer or combined with other layer
SRTM/DEM	**Yes**	**Single layer**
Superficial formation	No	Single layer
Molecap Greensand	**Yes**	**Single layer**
Henley Sandstone	No	Single layer
Coolyena	No	Single layer
Leederville formation	**Yes**	**Single layer**
South Perth Shale	No	Single layer
Gage Sandstone	No	Single layer
Warnbro group	No	Single layer
Otorowiri formation	No	Single layer
Parmelia Group	**Yes**	**Single layer**
Yarragadee Formation Unit A	**Yes**	**All the four layers are combined as single layer in model**
Yarragadee Formation Unit B	**Yes**	
Yarragadee Formation Unit C	**Yes**	
Yarragadee Formation Unit D	**Yes**	
Lesueur Sandstone	No	Single layer

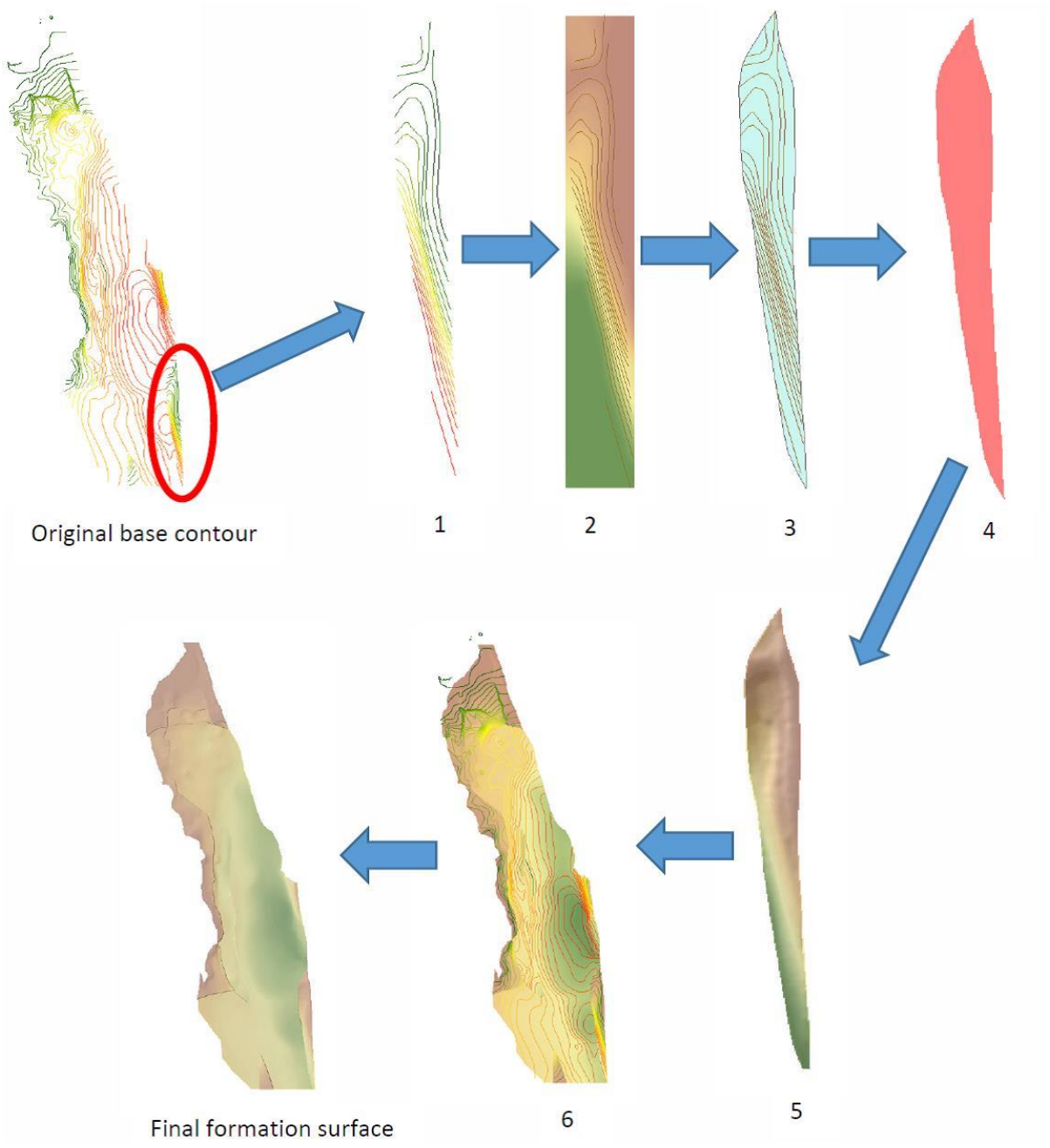


Figure 6 Methodology to generate formation surfaces

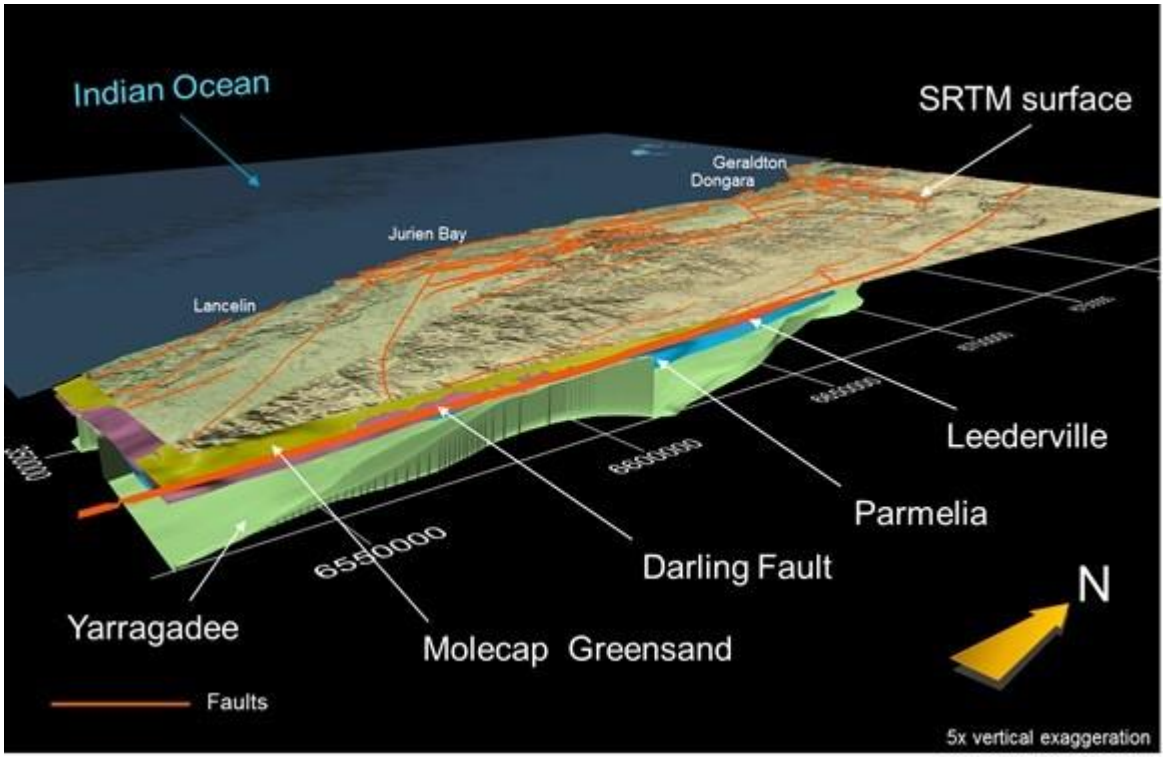


Figure 7 3D view of stratigraphic model generated for the northern Perth Basin

Assigning aquifers to the additional bores

The methodology was only applied to those bores with construction information (either screened interval or total depth) and water-level or salinity data. For each bore, an aquifer was assigned according to the following assumptions:

1. If there is no screened interval length, it is assumed to be 5 m and located at the bottom of the total depth of the bore
2. any bore with a screened interval (reported or assumed) penetrating a mapped formation/aquifer more than 5 m is extracting the water from that aquifer, and
3. any bore penetrating a mapped formation/aquifer less than 5 m is assumed to be extracting the water from both formations and not used in the analysis

The assumptions may not hold in all cases, so the classification is indicative, rather than definitive. Note that a longer interpretation of the screened interval or a requirement of a penetration greater than 5m will reduce the number of bores.

Nevertheless, application of the methodology significantly increased the number of bores with an assigned aquifer from 231 to 1,121. The distribution of bores within each aquifer unit is shown in Table 5 and Figure 8. The method was applied to each of the five aquifers, however, only the key Leederville-Parmelia (Figure 9) and the Yarragadee aquifers (Figure 10) are discussed here as they are the target aquifers for the AWE and Latent Petroleum

tight gas exploration activities. The aquifer extent in both figures is as defined in Department of Water (2016).

The additional bores identified in the Leederville – Parmelia aquifer are distributed largely to the east of the permits areas, but extend both north and south. The additional bores in the Yarragadee aquifer are concentrated primarily to the north and west of the permit areas. There are no additional Yarragadee bores in the south east part of the study area.

Table 5 Reclassification of groundwater bores

Aquifer	Number of bores		Number of bores having potentiometric head records	Number of bores having salinity records
	WIR database	After GIS analysis		
Superficial and Base of Superficial formation	44	423	313	363
Leederville – Parmelia	47	217	185	179
Yarragadee	93	407	349	339
Cattamarra- Eneabba-Lesueur	47	74	57	50
Total	231	1121	904	931

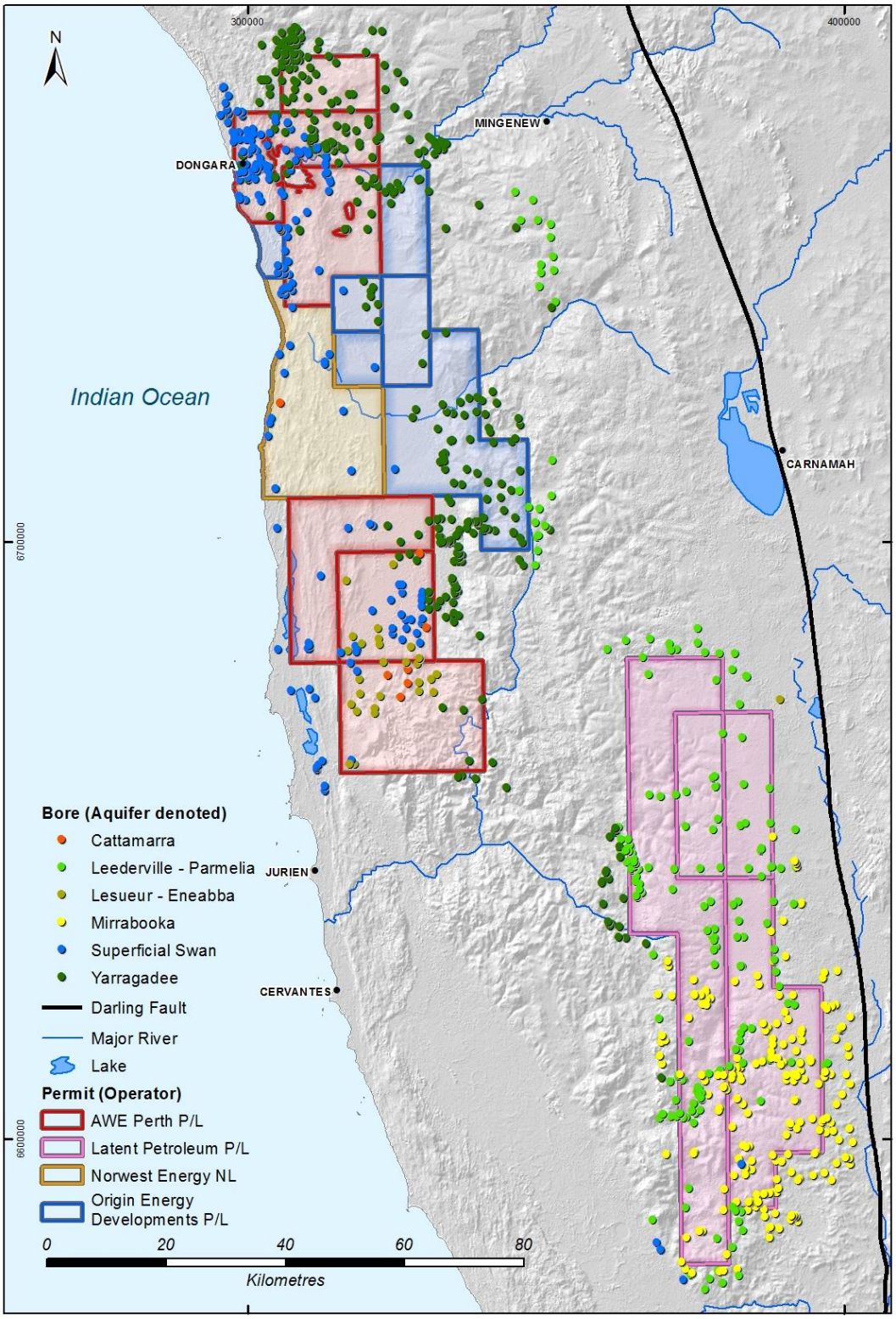


Figure 8 Distribution of bores within each aquifer

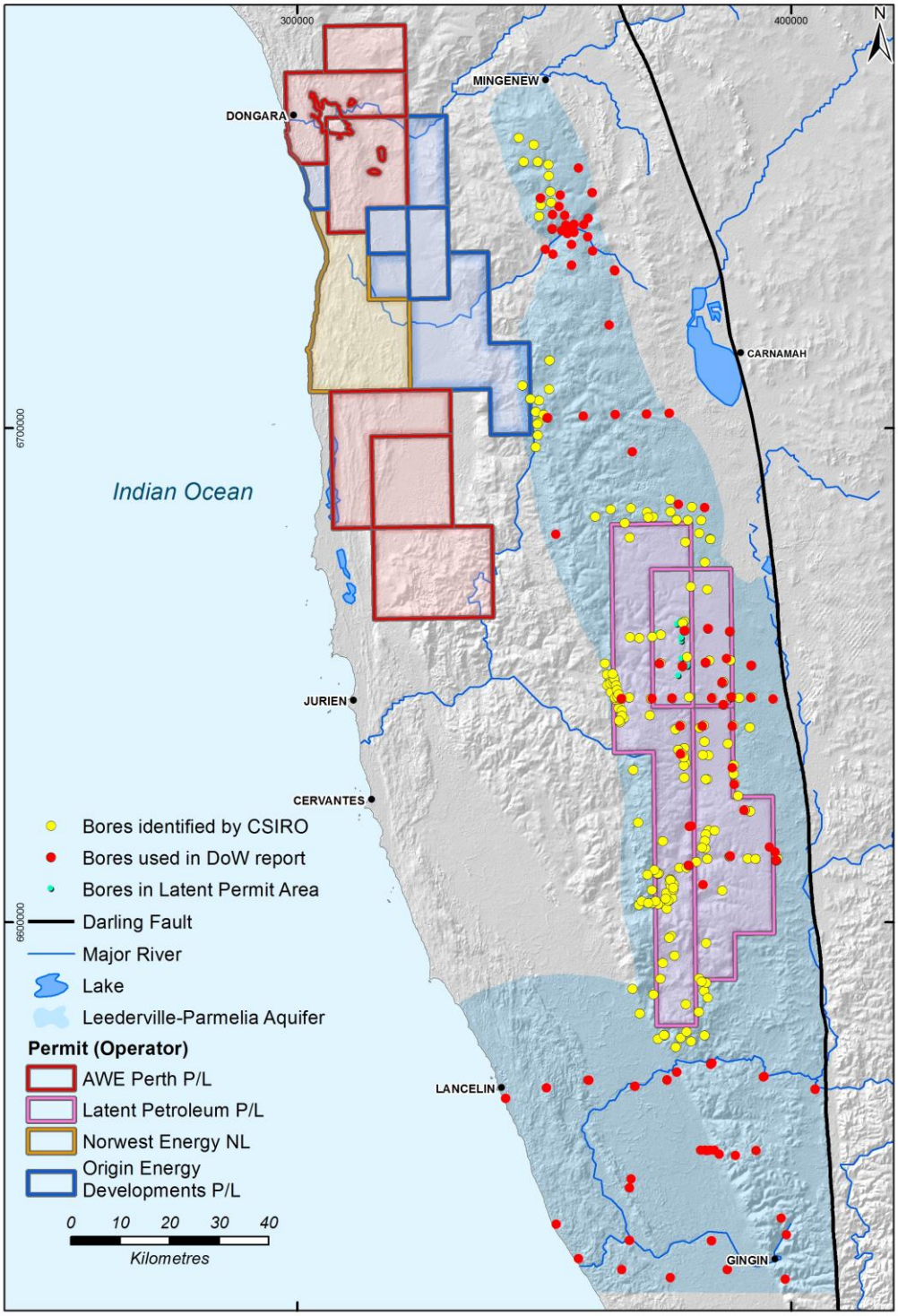


Figure 9 Bores located in the Leederville – Parmelia aquifer

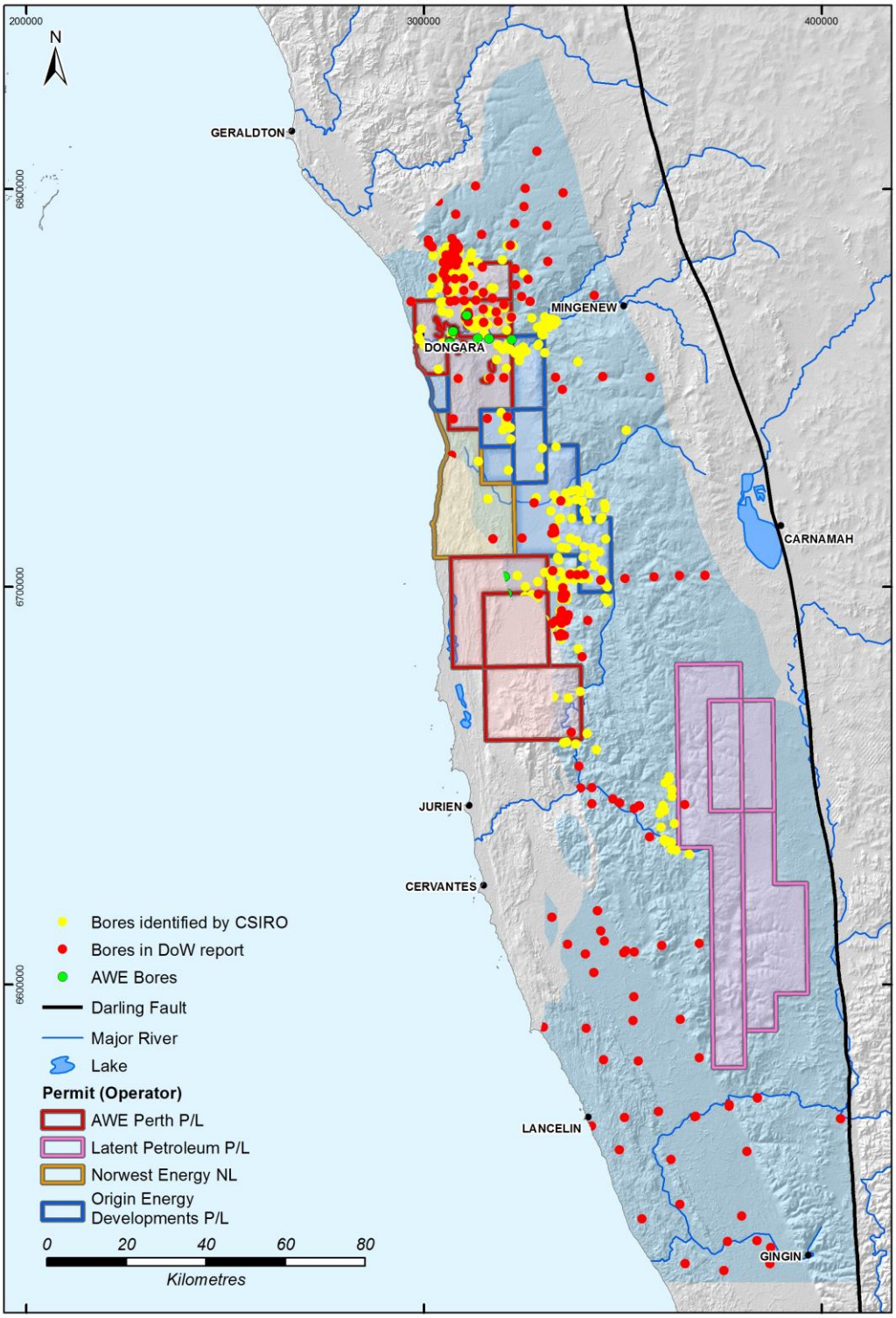


Figure 10 Bores located in the Yarragadee aquifer

2.2.2 Potentiometric head calculation and contour generation

There were four types of water-level measurement types recorded in the WIR database. For this data to be useful all measurements must be relative to a consistent datum, standard meters above Australian Height Datum (mAHD). Once in this format, the data can be used for trend analysis and for conversion to potentiometric head data. The potentiometric head data is then used to generate contours to determine the rate and direction of groundwater flow.

The four water-level measurement types and their application are:

i) static measurements from water-level measurement instruments; these were converted to mAHD (metres relative to Australian Height Datum) using the topography generated through the 3D modelling and used in the analysis

ii) water-levels reported in terms of mAHD; these records were used directly as reported

iii) Standard Level Elevation (SLE); this data format was used until 1998 and was discarded after 1998. There were 3812 groundwater-level records from 30 bores reported with respect to local (historical) datum, Standard Level Elevation (SLE). SLE is a non-standard datum and was used in past to avoid negative groundwater-level values. It requires local (site) topographic knowledge to converting these values to a standard datum value (mAHD). Conversion of SLE to mAHD is outside the scope of this project, therefore, these groundwater-level readings (3812) and the associated bores were not considered for the analysis

iv) datalogger readings reported as daily minimum, maximum and mean values. Only the only daily mean values were considered. During 2001-2016, there were 86,916 monitoring records obtained from data loggers, of these 28,972 were daily mean values.

The preferred method to present and analyse trends is to consider seasonal trends, i.e. the data should reflect both the minima (end of summer) and the maxima (end of winter) values. However, in this case there were insufficient monitoring records to produce meaningful results. Instead, the data from each bore for a specific year was averaged to create a yearly mean value. The yearly mean value was then used in the analysis. The data varied from one to two measurements for all bores in Leederville-Parmelia aquifer, with an exception of one bore which had 346 monitoring records for the 2015 monitoring year. For bores in the Yarragadee aquifer, monitoring records varied from one to 370 per year.

Based on the additional data,

- a new set of potentiometric head contours for each aquifer (Superficial, Leederville-Parmelia, Yarragadee and Cattamarra-Eneabba-Lesueur) from the year 2010 were generated (Table 6), and

- water-level trends over time for bores with data from 2007, 2010, 2011 and 2015 for the Leederville-Parmelia and Yarragadee aquifers were examined

The same process could not be applied to the salinity data as there was insufficient data generated after 2000 for either trend analysis or contouring.

Table 6 Summary of data from 2010 used to generate new potentiometric head contours

Aquifer	Number of bores		Number of potentiometric head records (calculated)		Direct (field) potentiometric head readings
	WIR database	After GIS analysis	WIR database	After GIS analysis	
Superficial and Base of Superficial formation	22	23	421	422	42
Leederville – Parmelia	28	28	47	47	50
Yarragadee	67	71	1492	1959	161
Cattamarra- Eneabba-Lesueur	18	18	41	41	31

To create the potentiometric head contours for an aquifer, a geo-referenced Surfer grid file is generated using default Kriging interpolation parameters. The Surfer grid files are exported to ArcGIS software and a set of potentiometric head contours generated using the *Contour* tool. The contours were clipped to the aquifer shapefile provided by DoW.

2.3 Results

The additional records obtained through the previous methodology were examined for their usefulness in either supplementing the interpretation provided by DoW; or providing more current information about the aquifers within 5 km of the permit areas. The monitoring results supplied by the consortium members to CSIRO as part of the project as well as the data in the WIR database were considered.

2.3.1 Local vs Regional interpretation

The current state of knowledge of groundwater flow in the northern Perth Basin is by Department of Water, 2016, which presents the regional hydrogeology for Autumn, 2007. One of the objectives of this component was to update the regional interpretation with additional local data from around the consortium members permit areas. However, a review of the monitoring records for new bores identified through the GIS analysis for the 2007 autumn (March -May) monitoring period identified no additional data. There were 15 groundwater-level monitoring records for 2007 in total, three records for February, one record in July, four in November and eight in December. Therefore, there is not sufficient information for 2007 autumn period to modify the existing model as presented in Department of Water, 2016, at the local scale for both potentiometric head and salinity profiles.

2.3.2 Number of monitoring bores and records

Groundwater-level monitoring records for all the bores located within 5km distance from the consortium members permit areas where subdivided into three monitoring periods, 1961 - 1980, 1981 – 2000 and 2001 – 2016 (Table 7). The results show that although the number of monitored bores within the area is declining, the number of water-level records from each bore is significantly increasing. This is due to the installation of data loggers and indicates that although the number of monitoring bores is decreasing, the resolution of the data from those bores that are monitored is increasing. There is a concomitant decline in the number of salinity records, which may be associated with the cost of obtaining and analysing samples (Table 7).

Figure 11 shows the distribution of monitoring bores for the 2000 - 2016 monitoring period. For this period, only 3,331 monitoring records represent the direct (field) water-level readings and the majority of the remaining records were calculated water-level readings obtained through data loggers in the bores. The number of measurements in a specific bore may increase from one or two per year up to 370. Installation of data loggers is relatively inexpensive and downloaded easily and quickly.

Table 7 Potentiometric head and salinity monitoring records for bores located within 5 km distance

Monitoring period	Potentiometric head		Salinity (TDS)	
	Number of records	No of bores monitored	Number of records	No of bores monitored
1961 -1980	7,195	310	934	363
1981-2000	11,632	307	104	37
2001-2016	93,518	212	103	36

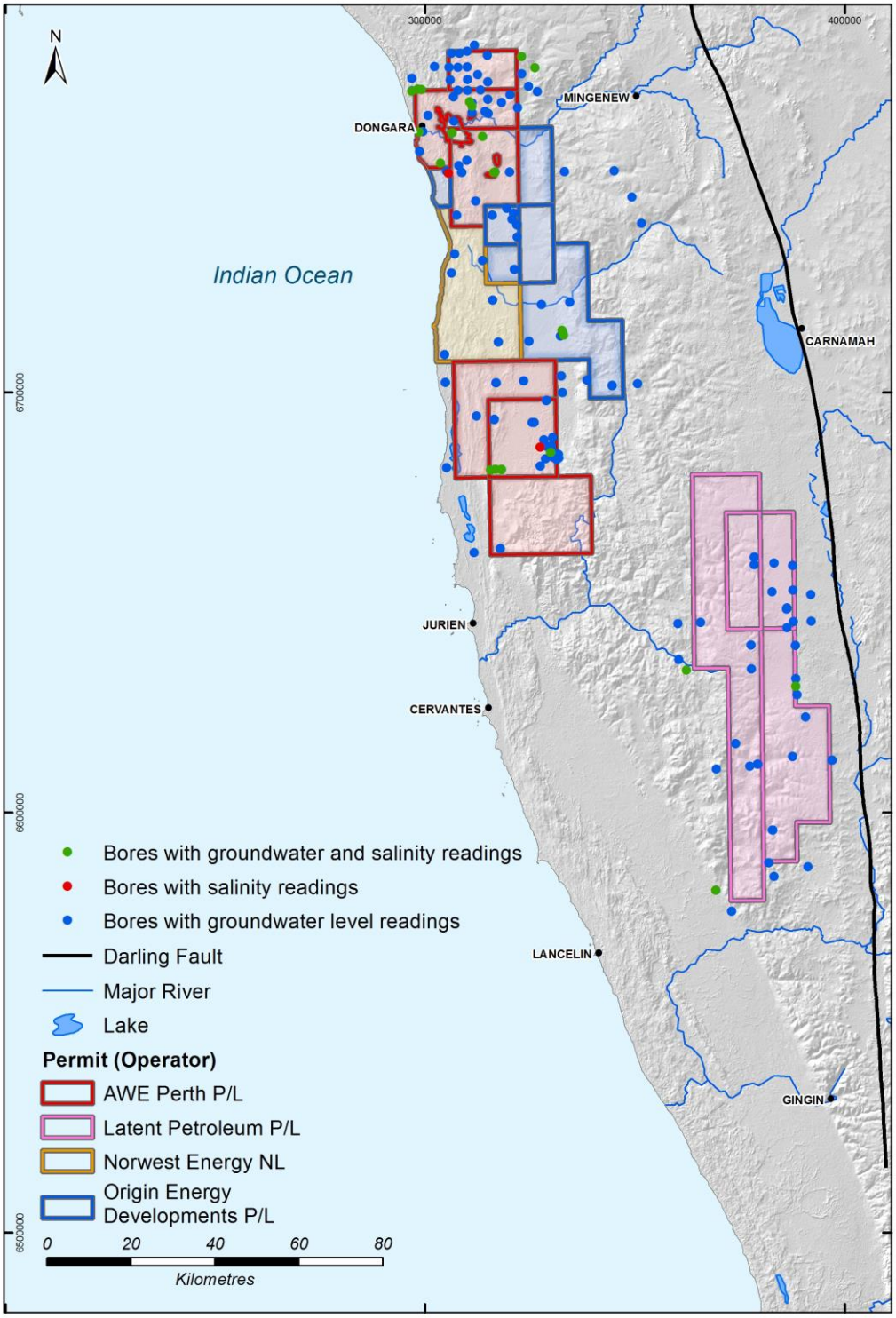


Figure 11 Distribution of monitoring bores for all aquifers for the period 2001 – 2016.

2.3.3 Groundwater Trends between 2007 and 2015

The original potentiometric head and salinity contours developed by DoW and reported in Department of Water, 2016 were created using the entire regional dataset available for 2007 autumn. Due to the scope of this project, potentiometric head contours were created for the Leederville-Parmelia and the Yarragadee aquifers using only bores within 5 km of the permit areas and data from 2010. While this limits the usefulness of the interpretation, a comparison of the data does highlight the importance of a regional perspective when considering local influences. As previously discussed, there was no salinity data available for this period from the publically available records. The only current data available in the permit areas is that being generated by the consortium members themselves.

To highlight local variations at individual bores, water-level trend profiles for 23 Leederville-Parmelia bores located within 5km distance from permit areas for the years 2007, 2010, 2011 and 2015 are considered. Similarly, water-level trend profiles for 73 Yarragadee bores located within 5km distance from permit areas for the years 2007, 2010, 2011 and 2015 are considered.

Leederville-Parmelia Aquifer

Bores considered for trend analysis for the Leederville-Parmelia aquifer are shown in Figure 12. During the 2007 – 2015 monitoring period, water-levels were almost constant with little fluctuations in all monitoring bores except ML3B (Figure 13). A significant decrease in water-level is observed in ML3B during 2007 autumn and 2010 monitoring, however remained at a constant value for both 2011 and 2015 monitoring periods. At the Latent Petroleum permit area, Department of Water (2016) have reported that groundwater flow is south to south-west towards the Lancelin and passes across the transition from the Leederville-Parmelia aquifer to the Leederville aquifer (14). Due to the consistent water-level data, it can be assumed that groundwater flow reported by Department of Water (2016) for 2007 autumn period is still valid for area surrounding these bores. Comparison of the potentiometric head contours for 2007 (Department of Water, 2016) and 2010 (CSIRO, Figure 15) show that both interpretations have almost the same number of bores within the areas and generally, flow is still directed south to south-west. However, the 2010 (CSIRO) contours contain a series of closed highs, which may be an artefact of the contouring method and the limited number of bores outside of the permit areas. Figure 9 shows there are a large number of additional bores located within the permit area which may be assigned to the Leederville-Parmelia aquifer. A survey of current water-levels and installation of water-level loggers across this area may provide a better understanding of the localised flow regime.

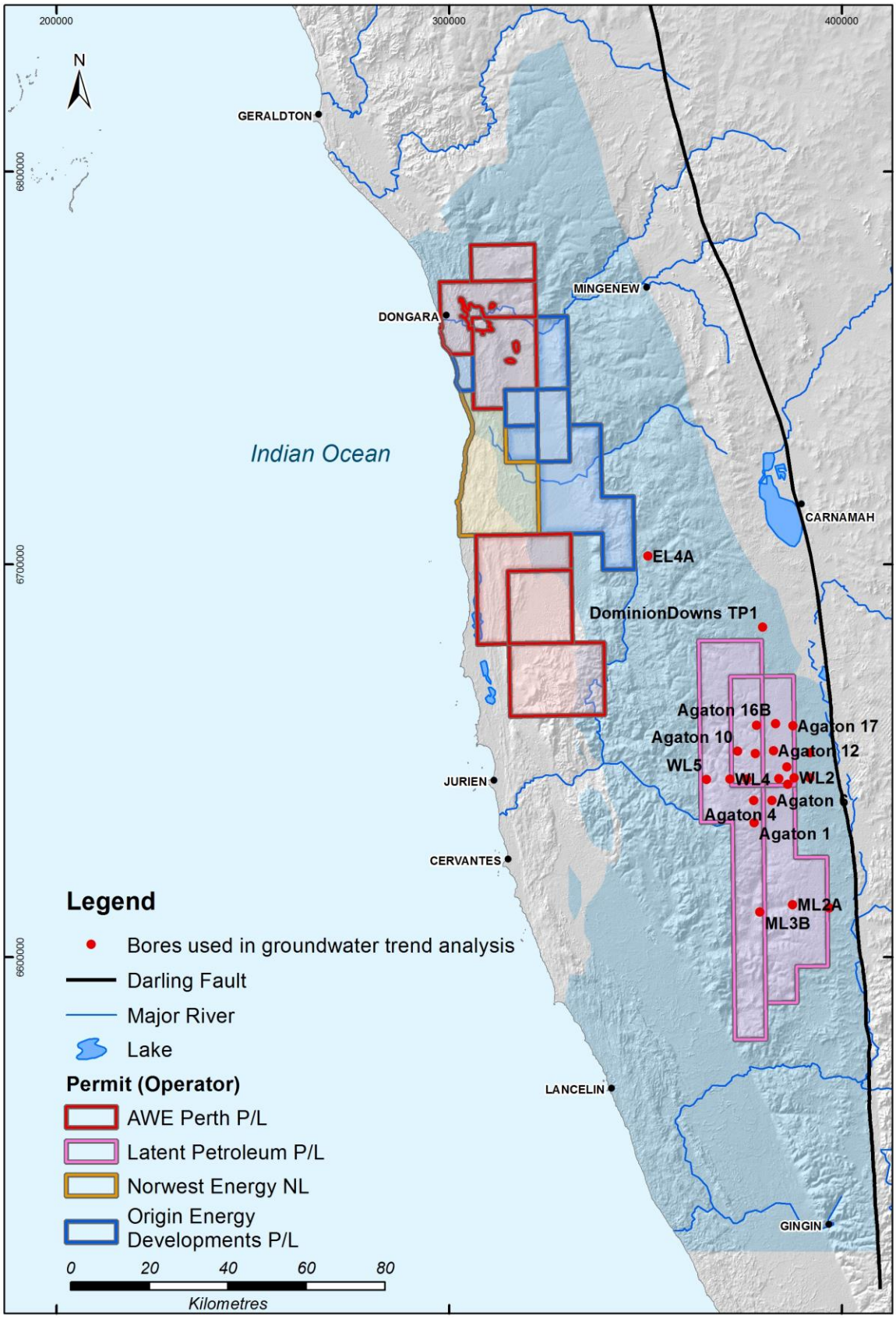


Figure 12 Locations of Leederville-Parmelia aquifer bores used for water-level time series

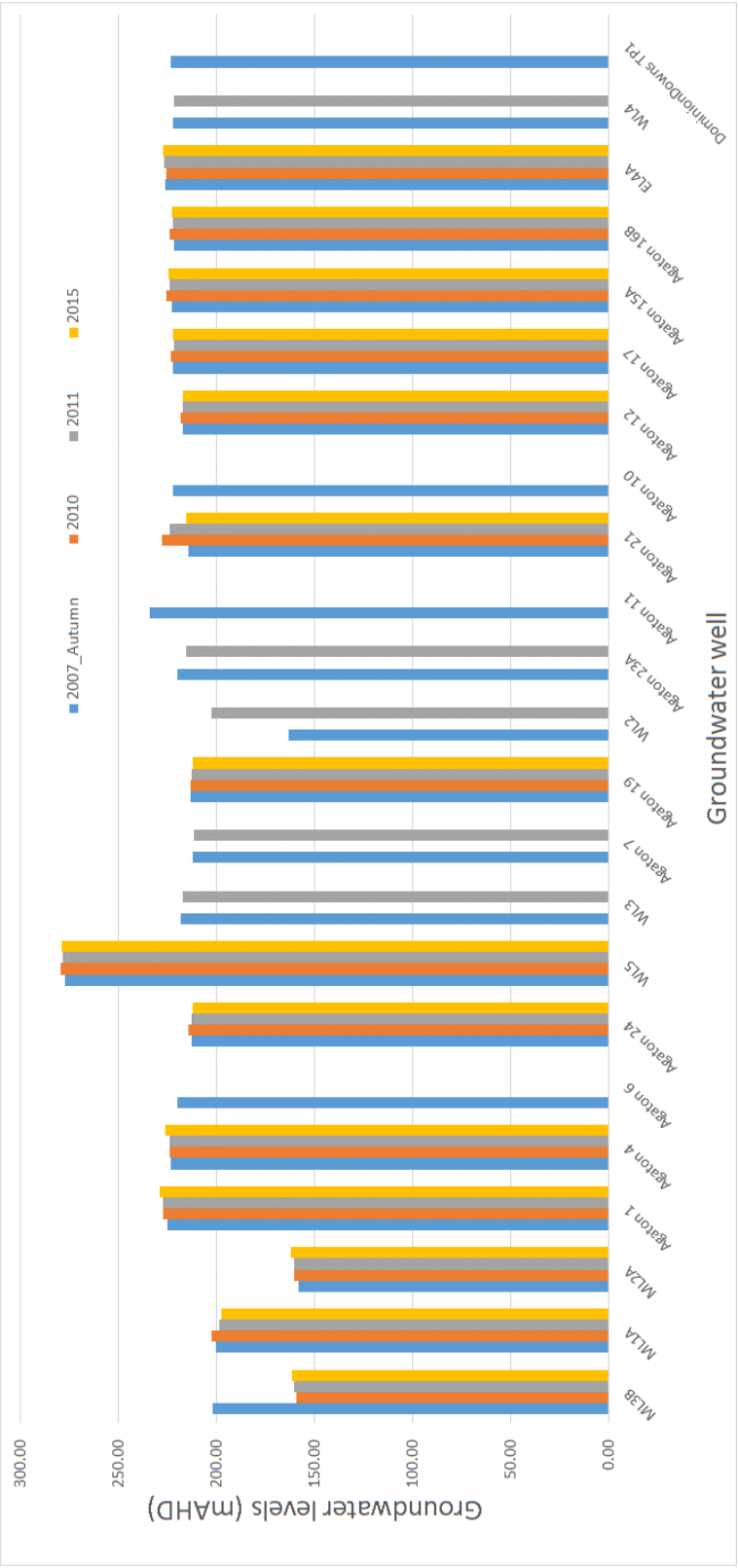


Figure 13 Water-level trends for bores in Leederville-Parmelia aquifer

Note: Water-levels for Agaton 7, WL2, WL3 and WL4 for 2011 were taken from RockWater (2013) report and they represent a single monitoring value.

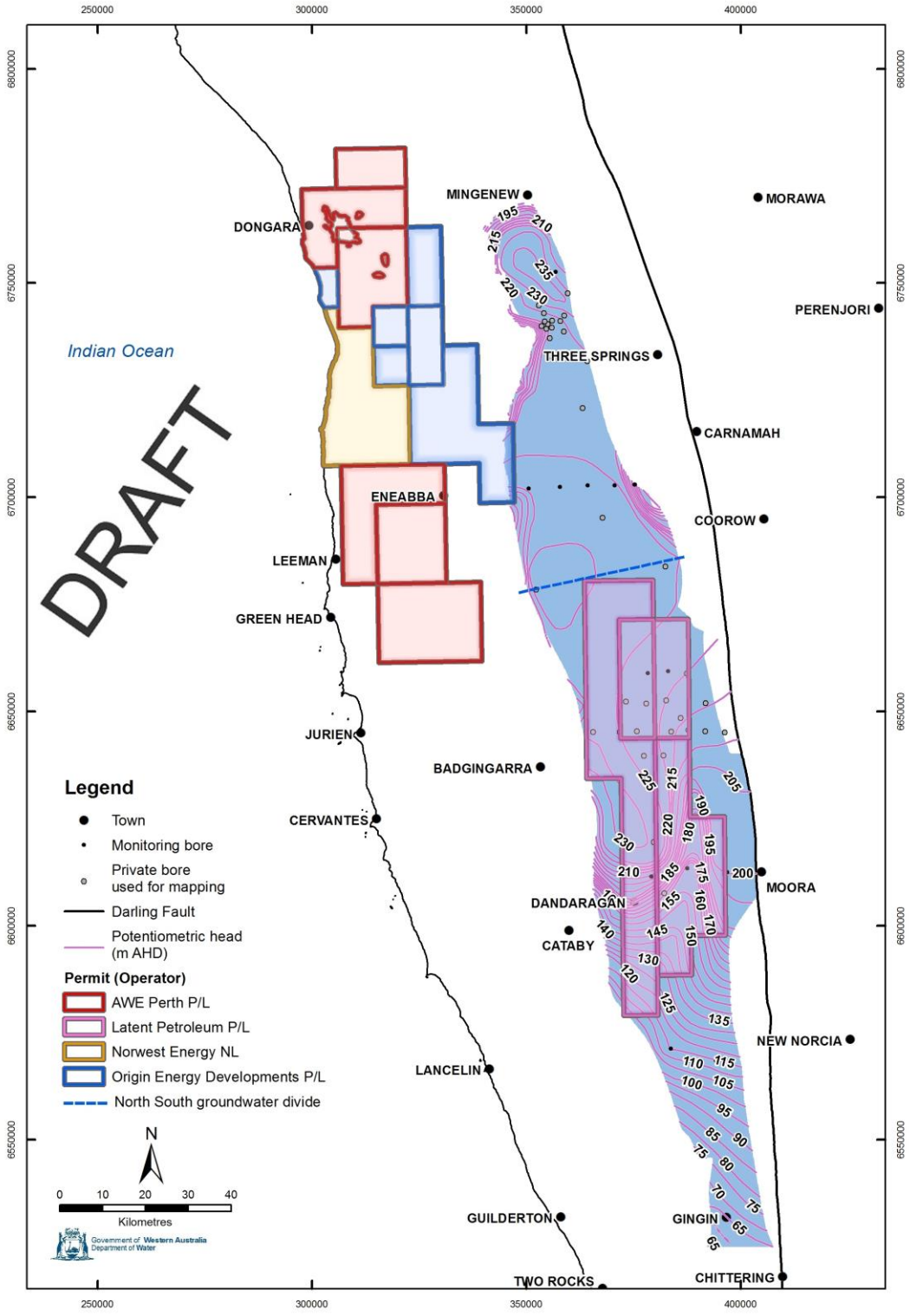


Figure 14 Leederville-Parmelia aquifer potentiometric head for 2007 autumn monitoring period (Source: Department of Water 2016)

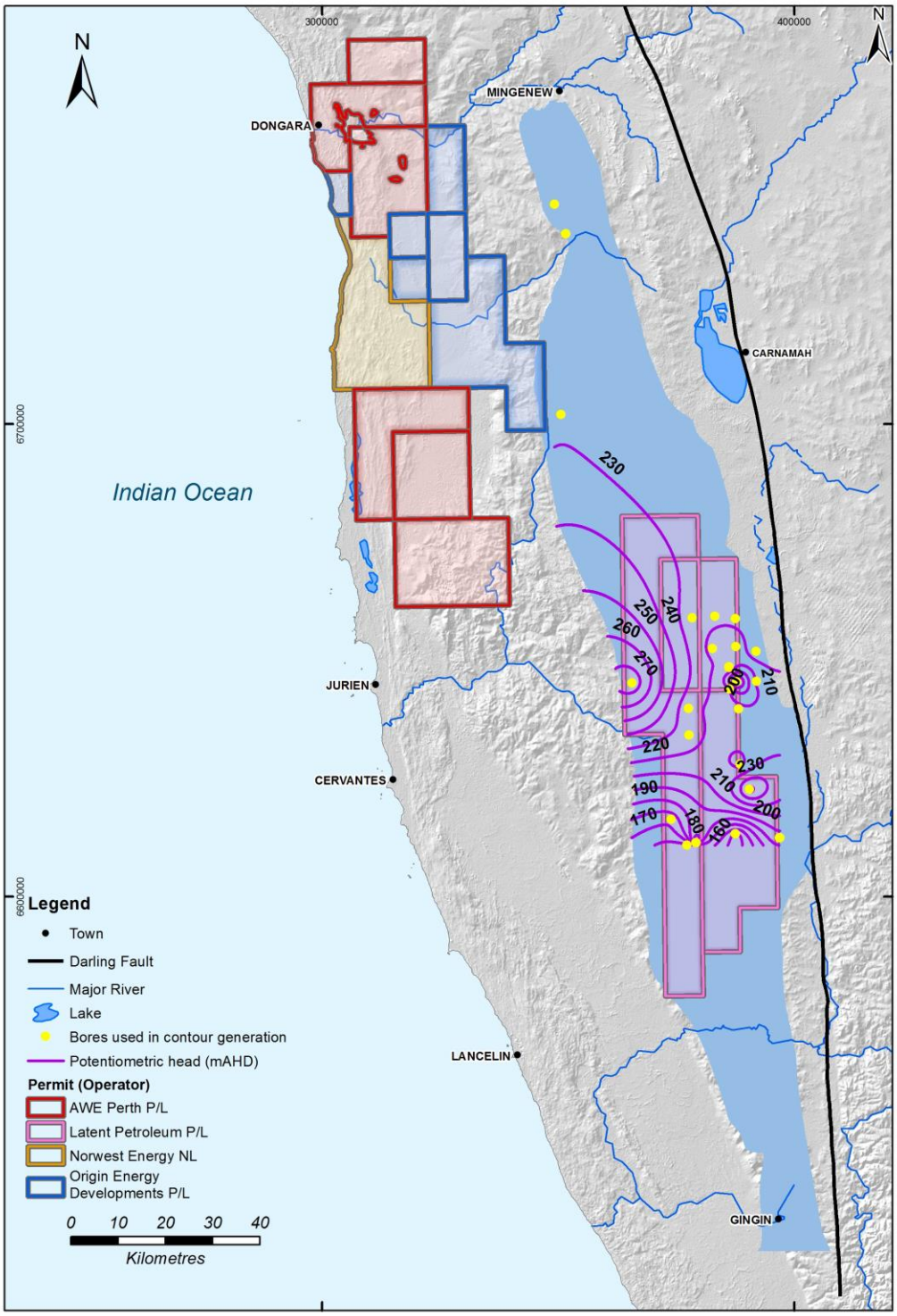


Figure 15 Leederville-Parmelia aquifer potentiometric head for 2010 (CSIRO). Aquifer extent is from Department of Water, 2016.

Yarragadee Aquifer

Bores considered for trend analysis are shown in Figure 16 and water-level trends were compared for four monitoring periods: 2007 autumn, 2010, 2011 and 2015 as shown in Figure 17. Fourteen bores were not monitored during the above monitoring periods. Water-levels of AWE bores for 2010-2015 monitoring periods are also shown in Figure 17.

Similar to Leederville-Parmelia aquifer, during 2007 – 2015, water-levels were almost constant with little fluctuations in all monitoring bores except WL5 (Figure 17). A significant increase in water-level is observed in WL5 during the monitoring periods. At the Latent Petroleum permit area, Department of Water (2016) have reported that groundwater flow is to the west and south-west towards Dongara – Arrowsmith (Figure 18). As with the Leederville-Parmelia aquifer, the consistency in the water-levels indicates the groundwater flow reported by Department of Water (2016) for 2007 autumn period is still valid for area surrounding these bores. The 2010 (CSIRO) contours for the Yarragadee aquifer have a similar number of bores and are broadly consistent with the Department of Water (2016) interpretation. However, there are no monitoring bores in the southern part of the permits areas (Figure 10) for the Yarragadee aquifer. This is due in part to the depth of the aquifer in this area as it is not used for groundwater supply. It is also a gas reservoir and exploration of the gas productivity of the Yarragadee is underway.

The Yarragadee aquifer interval has significant depth and thickness in this area and from petroleum well testing is known to have low permeability and transmissivity. Hence, flow rates are likely to be very low. Nevertheless, consideration needs to be given to the installation of monitoring bores in the Yarragadee aquifer to understand the flow rates and directions. The installation of monitoring bores needs to be evaluated in consideration with the requirement to avoid intersecting a gas zone.

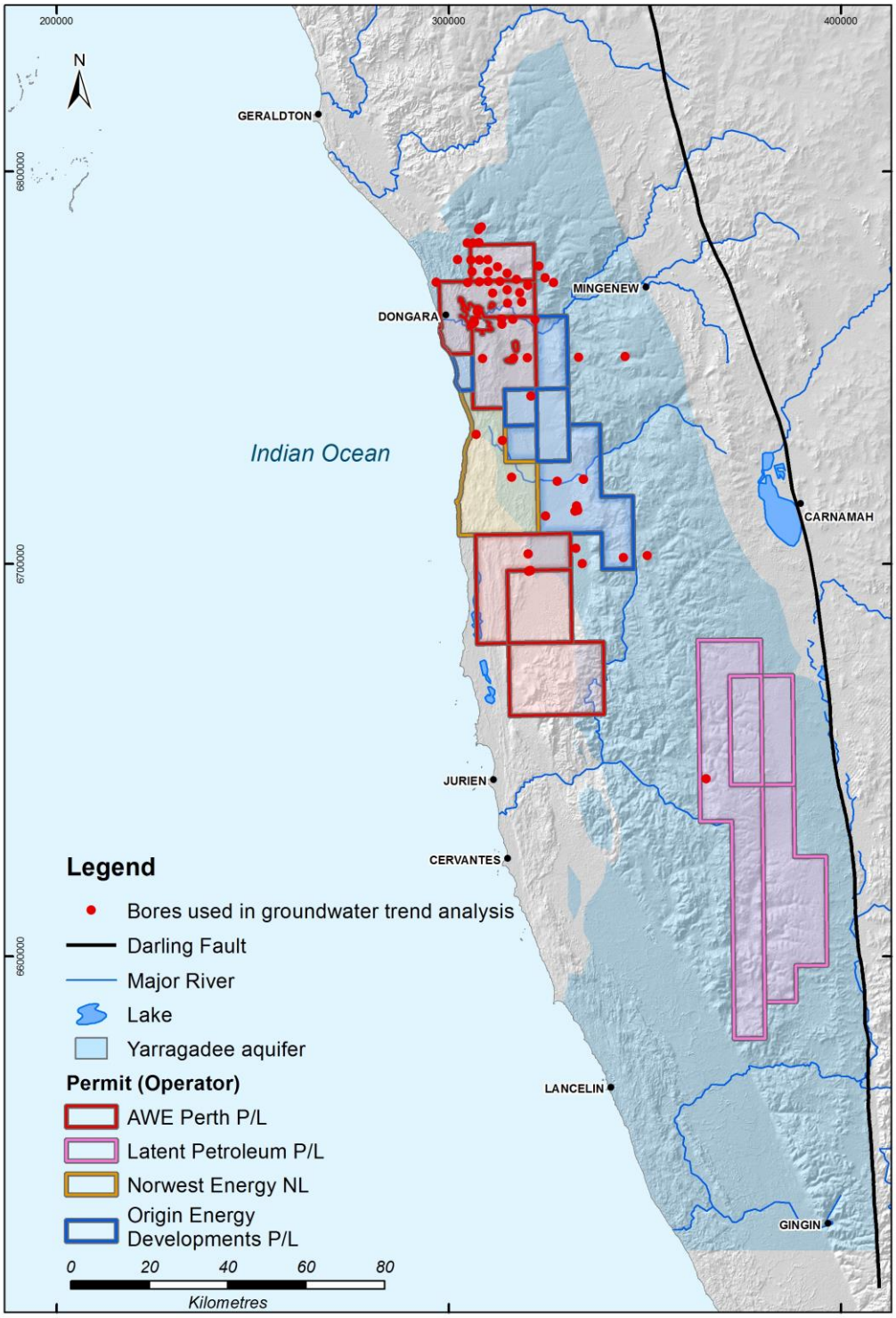


Figure 16 Locations of Yarragadee aquifer bores used for water-level time series

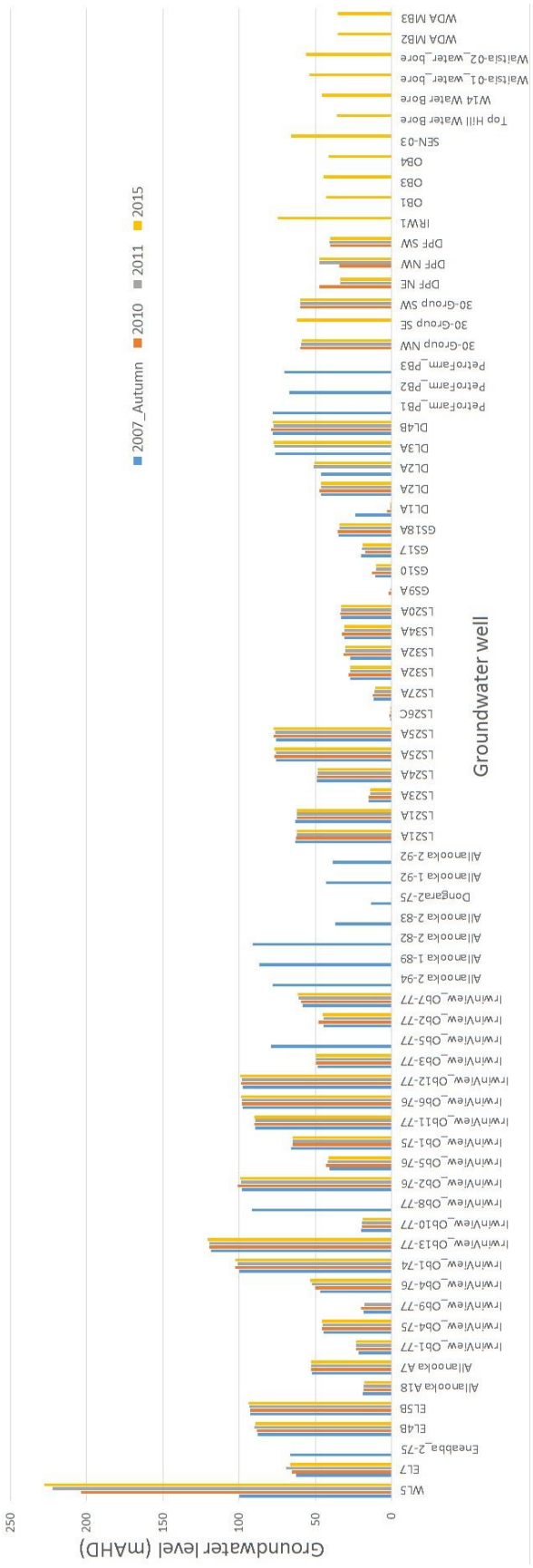


Figure 17 Water-level trends for bores in the Yarragadee aquifer

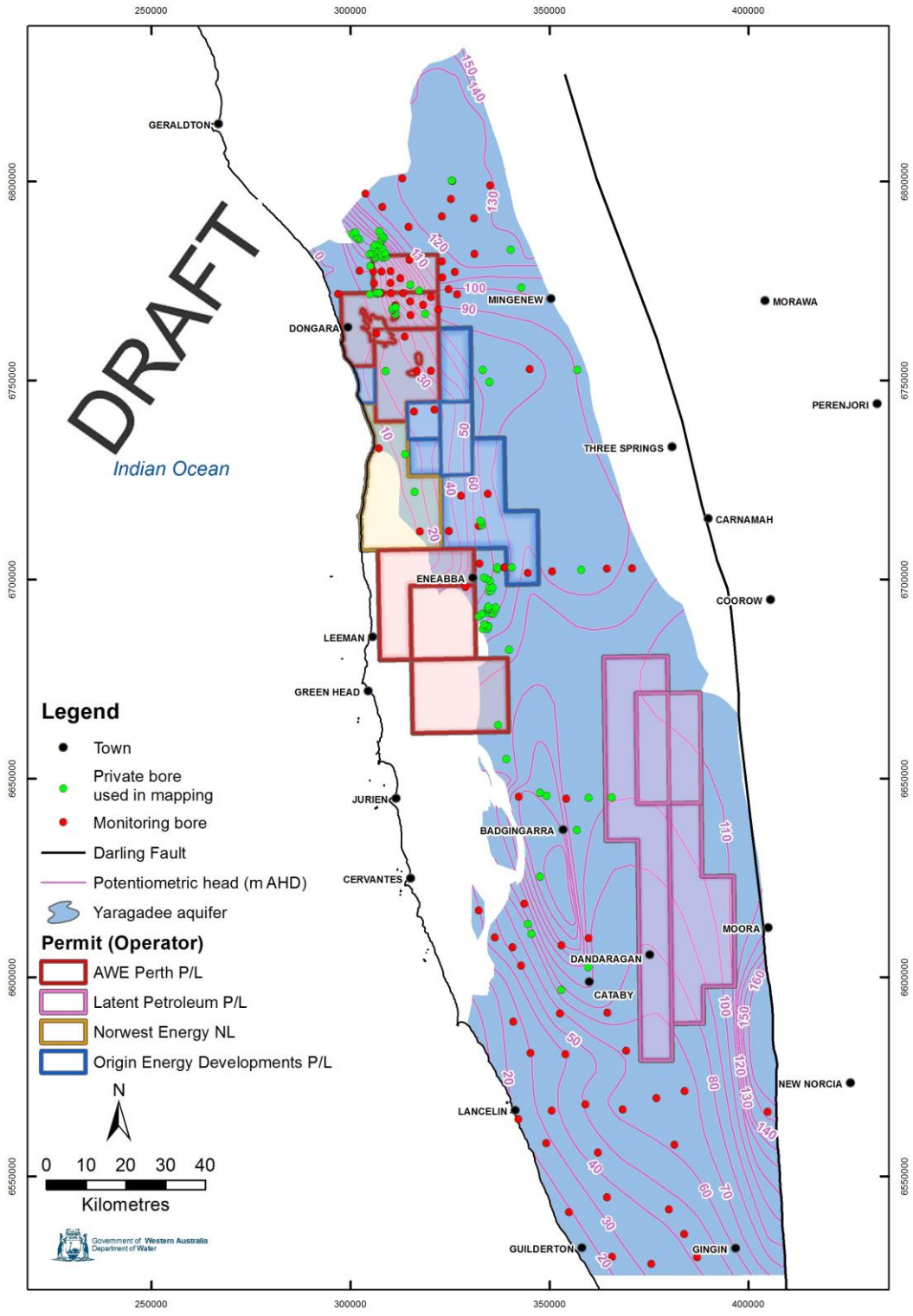


Figure 18 Yarragadee aquifer potentiometric head for 2007 autumn monitoring period (Source: Department of Water 2016)

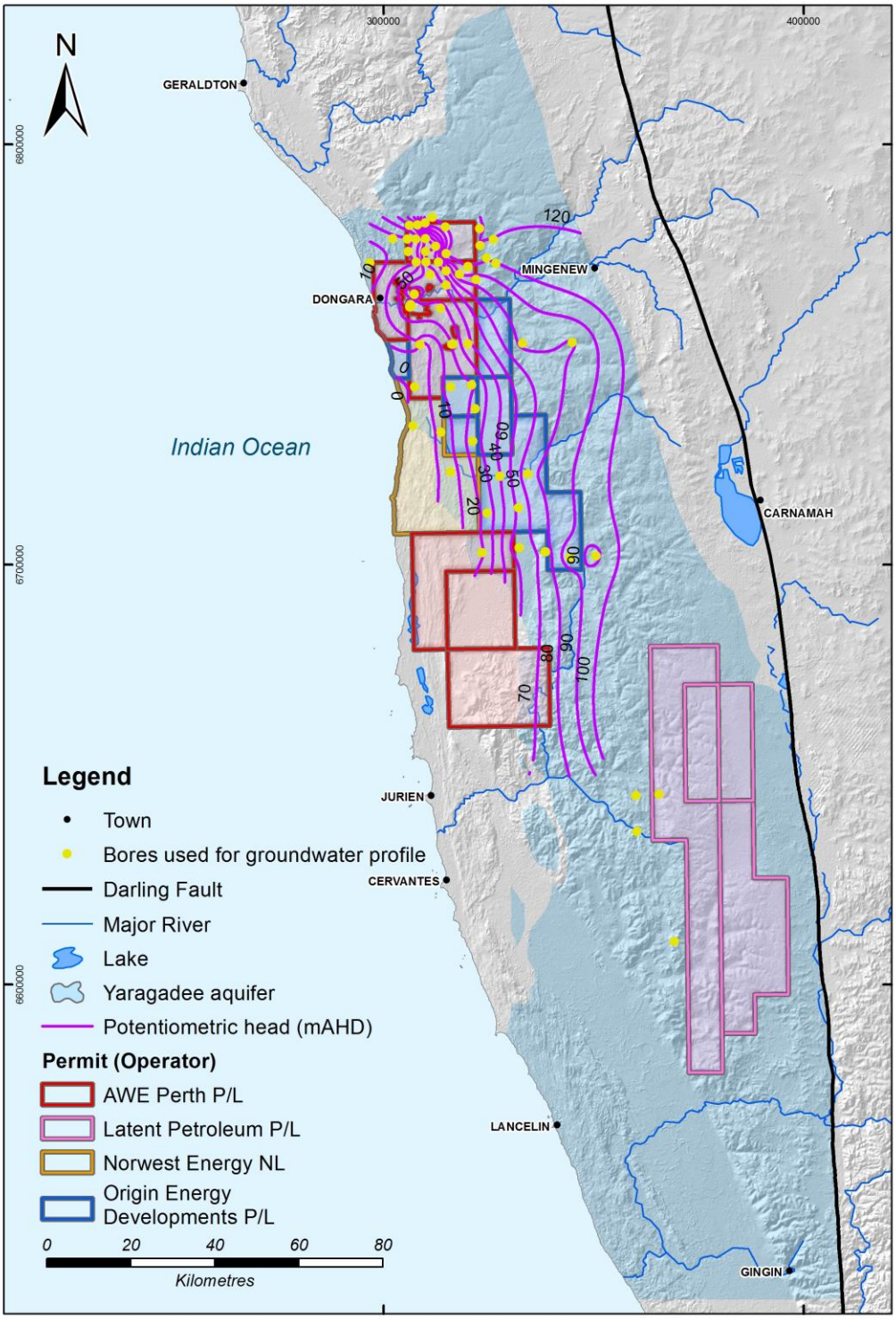


Figure 19 Yarragadee aquifer potentiometric head for 2010. Aquifer extent is from Department of Water, 2016.

2.4 Review of Consortium Member Groundwater Sampling Protocols

Based on CSIRO request for information about the water bores, fluid analyses and chemicals used on their permit areas, consortium members (AWE, Latent Petroleum and Origin Energy) have supplied water-monitoring results for various sampling periods. AWE has also supplied water sampling protocols (developed by contractor Gemec Environmental Consultants), chemical disclosure information and hydrocarbon reservoir data for various well sites. The water data and protocols from each consortium member were compared to current regulations and guidelines referred below, to ensure consistency and best practice.

- Australian and New Zealand Environment and Conservation Council (ANZECC) / Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), October 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- Department of Mines and Petroleum, August 2016, Guideline for groundwater monitoring in the onshore petroleum and geothermal industry
- Department of Environment Regulations, December 2014, Assessment and management of contaminated sites, Contaminated Sites Management Series
- Standards Australia, Australian/New Zealand Standard AS/NZS 5667.1:1998, Water Quality – Sampling, Part I: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples
- Standards Australia, Australian/New Zealand Standard AS/NZS 5667.11:1998, Water Quality – Sampling, Part II: Guidance on sampling of water

The field analysis and water quality parameters measured by the consortium members were compared with the list of parameters prescribed in the Table 2 and Table 3 of DMP (2016) groundwater monitoring guidelines for onshore petroleum and geothermal industry. AWE's field and water quality parameters were consistent with the guidelines. The water quality parameters supplied by Latent Petroleum were consistent with the DMP guidelines, however the field analysis parameters were not supplied to CSIRO.

AWE water sampling protocols (developed by Gemec Environmental Consultants) are also consistent with the current guidelines and regulations. In absence of any information on the water sampling protocol followed by the other consortium members, CSIRO could not make any comments.

2.5 Conclusion

The original objective of the groundwater study was to update the regional flow model presented in Department of Water (2016) with local data from the WIR database and the consortium members. Based on the structural and base elevation contours provided by the DoW, a geological model was developed in ArcGIS and, using records from the DoW WIR database, was used to assign aquifers to water bores with monitoring data, but without a designated aquifer in and around the permit areas.

Using these new datasets, water trends for 2007 – 2015 period were developed and a constant water-level was observed in the majority of bores located in both the Leederville-Parmelia and Yarragadee aquifers. It can therefore be generally assumed that water flow directions reported by Department of Water (2016) in the permit areas is still valid and there have been no significant changes in the regional flow patterns since then. Due to lack of sufficient salinity information after 2000 in WIR database, no further salinity analysis has been undertaken.

Groundwater parameters measured by the consortium members (AWE, Latent Petroleum and Origin Energy) were compared with the DMP (2016) guidelines. AWE's field and water quality parameters were consistent with the guidelines. The water quality parameters supplied by Latent Petroleum were consistent with the DMP guidelines, however the field analysis parameters were not supplied to CSIRO. The data being obtained by the consortium members represents an important data source to supplement the data currently existing in the WIR. There is however, a lack of current monitoring data, particularly in the southern part of the permit areas around Latent Petroleum's permits.

In conclusion, the regional modelling undertaken by the DoW represents the best available understanding of regional water flow and trends across the northern Perth Basin. However, it is also clear from the analyses above that there is a lack of current monitoring data available in and around the areas of interest to understand local flow regimes and climactic impacts. It is recommended that a survey of current water-levels and installation of water-level loggers across this southern part of the Leederville-Parmelia aquifer may provide a better understanding of the localised flow regime. In contrast, there are no bores in the Yarragadee aquifer in the southern part of the permit areas. Consideration needs to be given to installing monitoring bores in this area, however, this needs to be undertaken with caution as the aquifer is known to be gas bearing and highly cemented, i.e. to have low to extremely low permeability.

3 Mobile Surveys

3.1 Introduction

CSIRO undertook a series of mobile, vehicle based surveys to assess the ambient concentration of methane across the basin. The methodologies and technologies were based on those published by Day et al., 2015 in the Surat Basin, Queensland. Vehicle based surveys to measure near surface concentrations of CH_4 have been used successfully in many places, including the United States and Australia. The method uses a vehicle fitted with a Picarro methane analyser that has sufficiently fast response time to allow the vehicle to be driven at normal speed along a designated transect. As this technique involves a moving sensor rather than a static sensor, it adds another dimension to identifying the source of any emissions detected, and detection will only occur if the vehicle is downwind of the source at the time of the survey. Mobile terrestrial methods performed by CSIRO, however, were able to detect elevated levels of methane in the Surat Basin, Queensland (Day et al. 2013). The sources detected included grazing cattle, CSG production wells and natural seeps. The Perth Basin, as compared to the Surat Basin, is relatively undeveloped, and background levels of CH_4 and the potential for natural seeps and emissions is largely unknown.

However, it is important to recognise that the concentrations of CH_4 at any point are dependant on the source of the CH_4 and the wind direction at the time of measurement. Stationary sources of CH_4 can be traced and identified, but mobile sources, such as cattle can also be detected and must be considered. The survey undertaken in this project was carried out over five days and as such can only be considered as a “snapshot” of the baseline ambient CH_4 levels across the basin.

3.2 Methodology

The measurement system consisted of a G2201-i cavity ring down spectrometer (CRDS) from Picarro capable of precisely and accurately measuring CO_2 and CH_4 concentration from the gas phase. This particular system can also measure $\delta^{13}C$ values for both CO_2 and CH_4. The Picarro system was selected for its very low measurement drift (3 ppb over 1 month for CH_4, peak-to-peak, 50 minute average) and for meeting MIL-STD 810F test standards for shock and vibration.

All of the equipment was mounted onto two wooden boards (900 mm x 600 mm and 600 mm x 300 mm) to facilitate mobilization into and out of the vehicle. The CRDS was placed onto a 70 mm thick piece of foam to minimize vibration. The Picarro CRDS contains a fully functioning computer running Windows XP. To make the system less cumbersome (and eliminate the need to attach a monitor, keyboard and mouse), a wireless router was hardwired to CRDS through an Ethernet cable allowing wireless access through remote

desktop login to the system from a laptop. This allows the passenger of the vehicle to readily monitor in real-time the CRDS readings.

A Garmin GPS 18x was used to record the longitude and latitude data time stamped to coincide with the CRDS measurements and attached to the outside of the vehicle. ¼" PFA tubing from Swagelok is used for all gas sampling lines both inside and outside the vehicle. The intake point was via tubing secured to the antenna mounted on the front of the vehicle to ensure clean air. With the exception of tubing between the vacuum pump and the CRDS (where Picarro's own tubing is used), Swagelok parts are used to connect tubing to appropriate fittings.

(a) (b)

Figure 20 Vehicle set up for mobile survey showing (a) the intake point attached to the antenna of the vehicle and (b) the sensor mounting prior to loading into vehicle

The first mobile survey was undertaken in March, 2015. This survey was short and designed to test the equipment and the methodology. The data reported here was from the final survey, which was carried out between the 23rd and the 27th of November 2015. During this time there was no rain and the average daily temperature was between 13 and 32 °C. The daily route was influenced by the prevailing wind direction. The vehicle was stopped periodically to measure wind direction and speed. At each stopping point a soil gas flux measurement was taken. The CDRS was calibrated with 1 and 5 ppm CH_4 standards daily and a variation of less than 0.01 ppm was observed.

The vehicle travelled at a normal speed along the road, dependant on the conditions, but assumed to be 100km/hour. The time taken for air to travel along the tubing from the intake point to the measurement point is 28 seconds. Therefore, the maximum lag associated with the measurement was of the order of 785 m.

3.3 Results

The route taken by the mobile survey was designed to cover as much area as possible in and around the permit areas. The survey covered approximately 2300 km's over five days in November, 2015 (Figure 21).

The data collected each day is summarised in Figure 22 as a box and whisker plot showing the median, 25th and 75th percentile. The background levels across the area over the five days clusters around 1.77 ppm, with the median concentration varying between 1.764 and 1.776 ppm (Figure 22). These values are reasonably consistent with the CH_4 values reported from Cape Grim during November, 2015 of 1.796 (http://www.csiro.au/greenhouse-gases/).

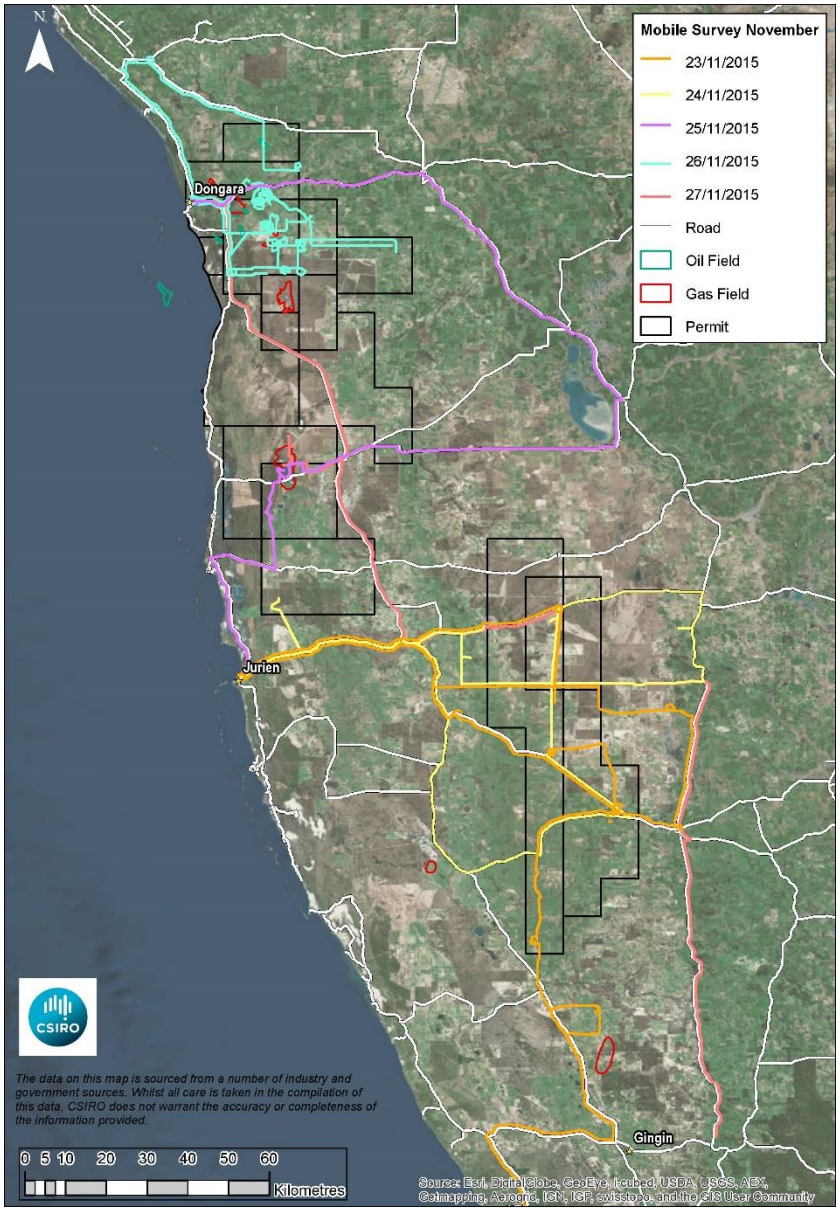


Figure 21 Route taken by mobile survey in November, 2015

The CH_4 concentrations measured along the daily routes are shown in Figure 23 to Figure 27. Although there are numerous small fluctuations, the majority of the data lie close to the mean value of 1.77 ppm. There were several events noted, for example, the higher values measured early on the first day, 23rd November, 2015 (Figure 23) were due to smoke from a bushfire encountered on leaving Perth. The largest concentration measured was on the 27th November, 2015 downwind of the Dongara Production Facility (Figure 27). The

measurements were taken early in the morning, before the wind had risen. The source has not been identified and may be due to higher density CH_4 settling overnight. The measurements were repeated in the afternoon and had returned to background levels. Measurements taken around well sites (roads near the Dongara Production Facility, roads near the Xyris Production Facility, wells at the Woodada Gas Field, Corybas-1, Senecio-2, Senecio-3, Watsia-1, Watsia-2 and Irwin-1) were consistent with background levels.

The original intention was to investigate the usefulness of isotope ratios to understand the source of measured CH_4. Unfortunately the consistently low concentration of CH_4 measured (maximum value was 4.5 ppm) meant that any change was insignificant to isotope ratios after mixing with background atmospheric.

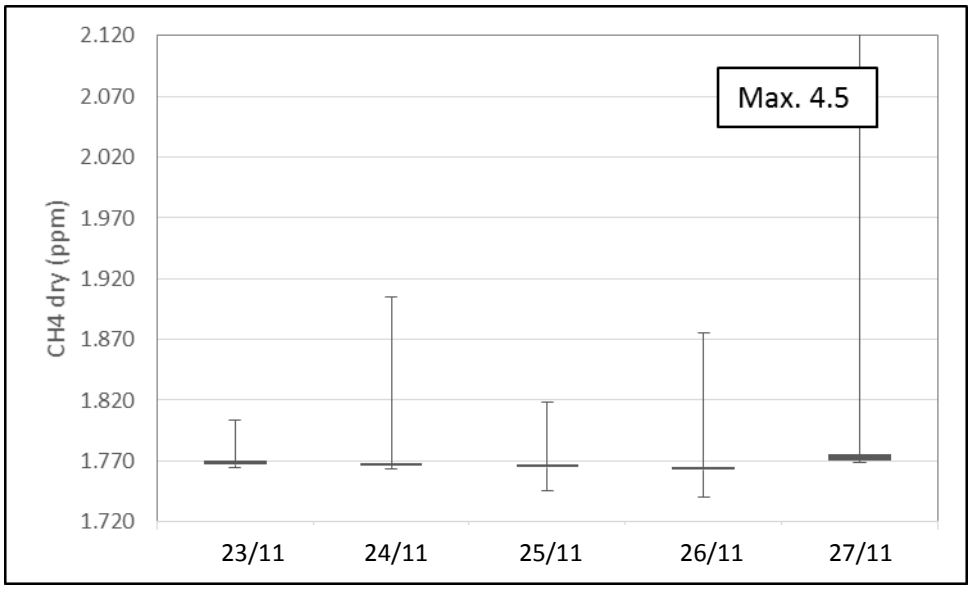


Figure 22 Summary of CH_4 (dry) concentration values measured over the five days of the survey

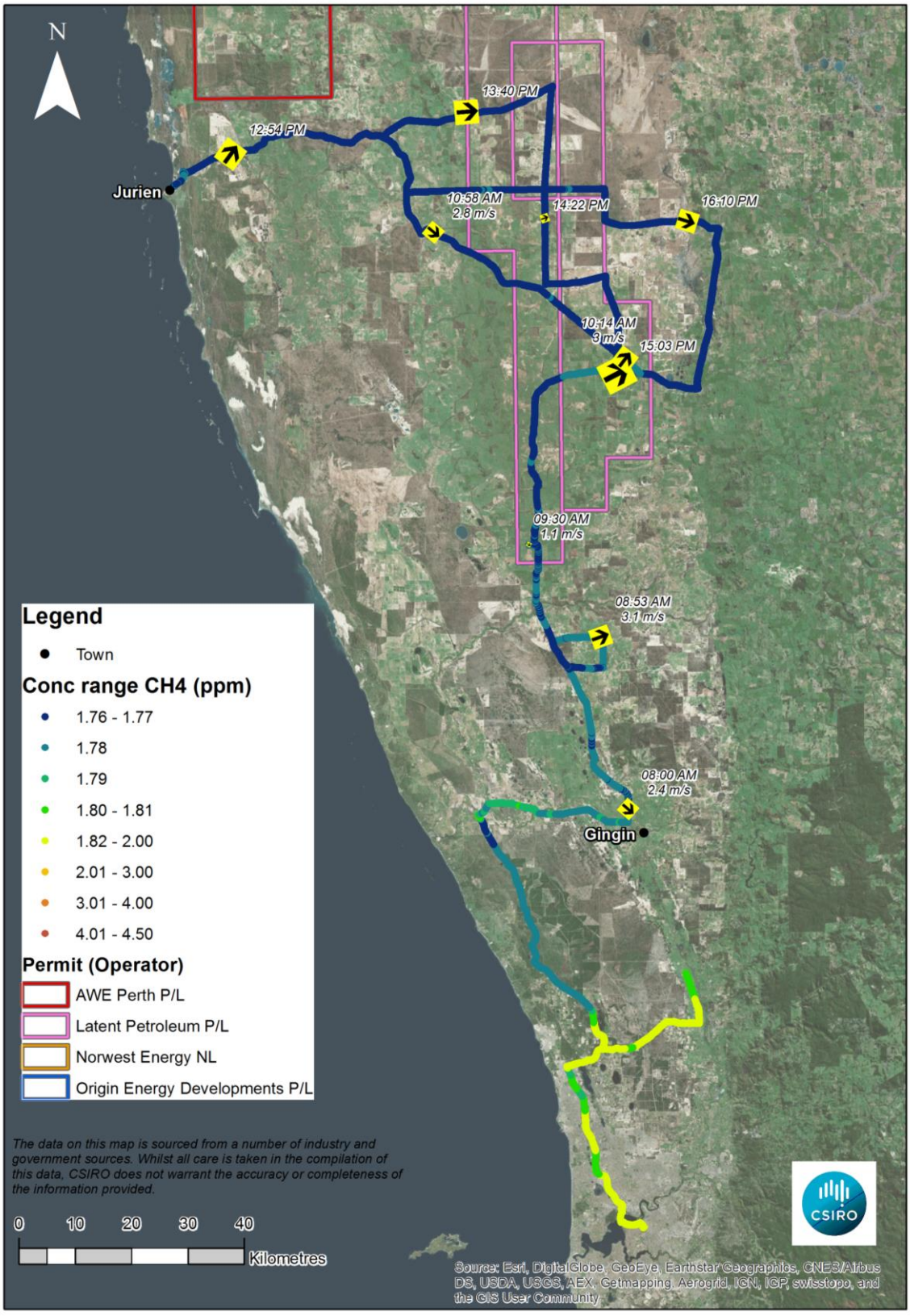


Figure 23 Mobile survey data for the 23/11/2015, showing concentration range and wind direction and speed.

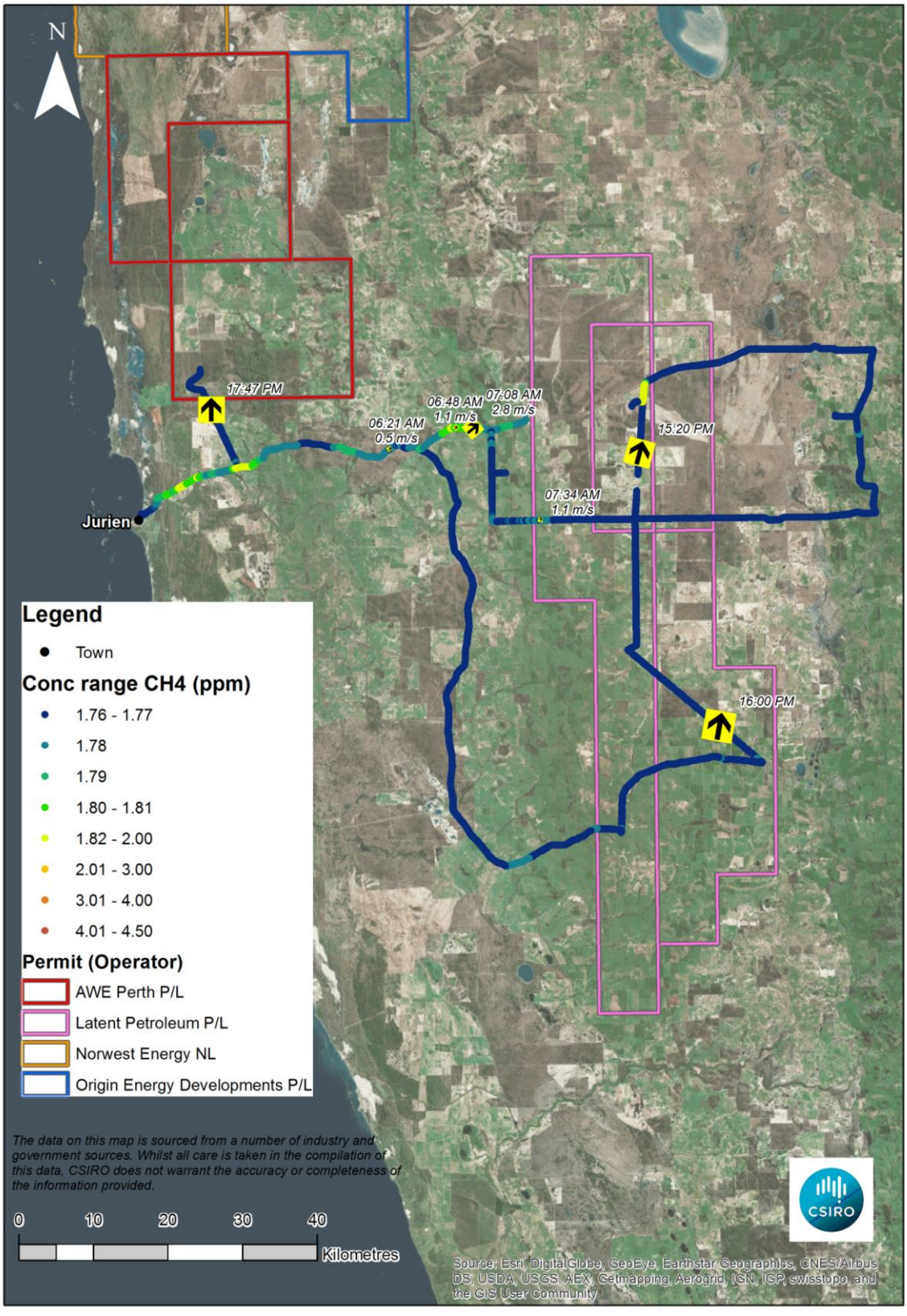


Figure 24 Mobile survey data for the 24/11/2015, showing concentration range and wind direction and speed.

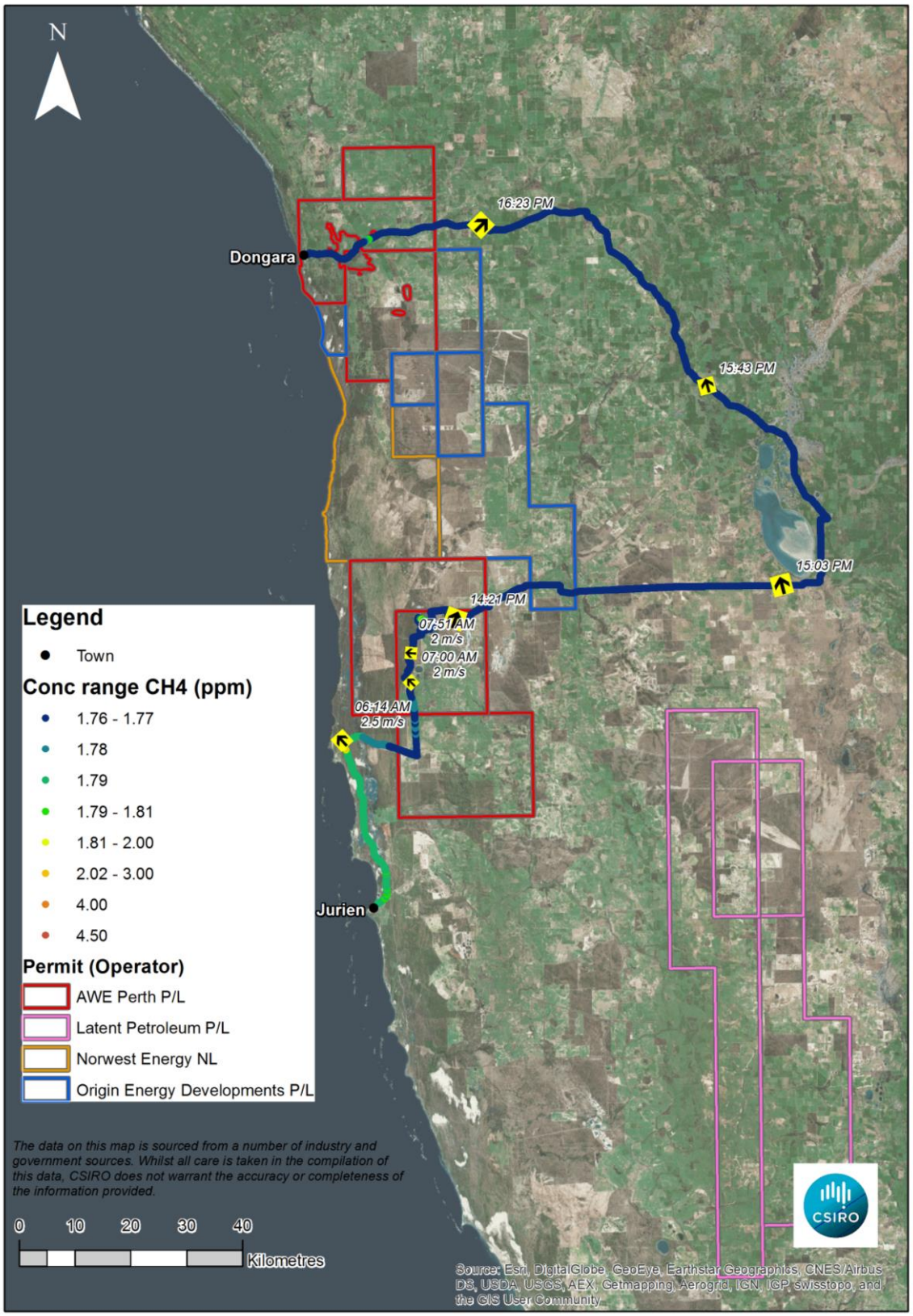


Figure 25 Mobile survey data for the 25/11/2015, showing standard deviation from mean value and wind direction and speed.

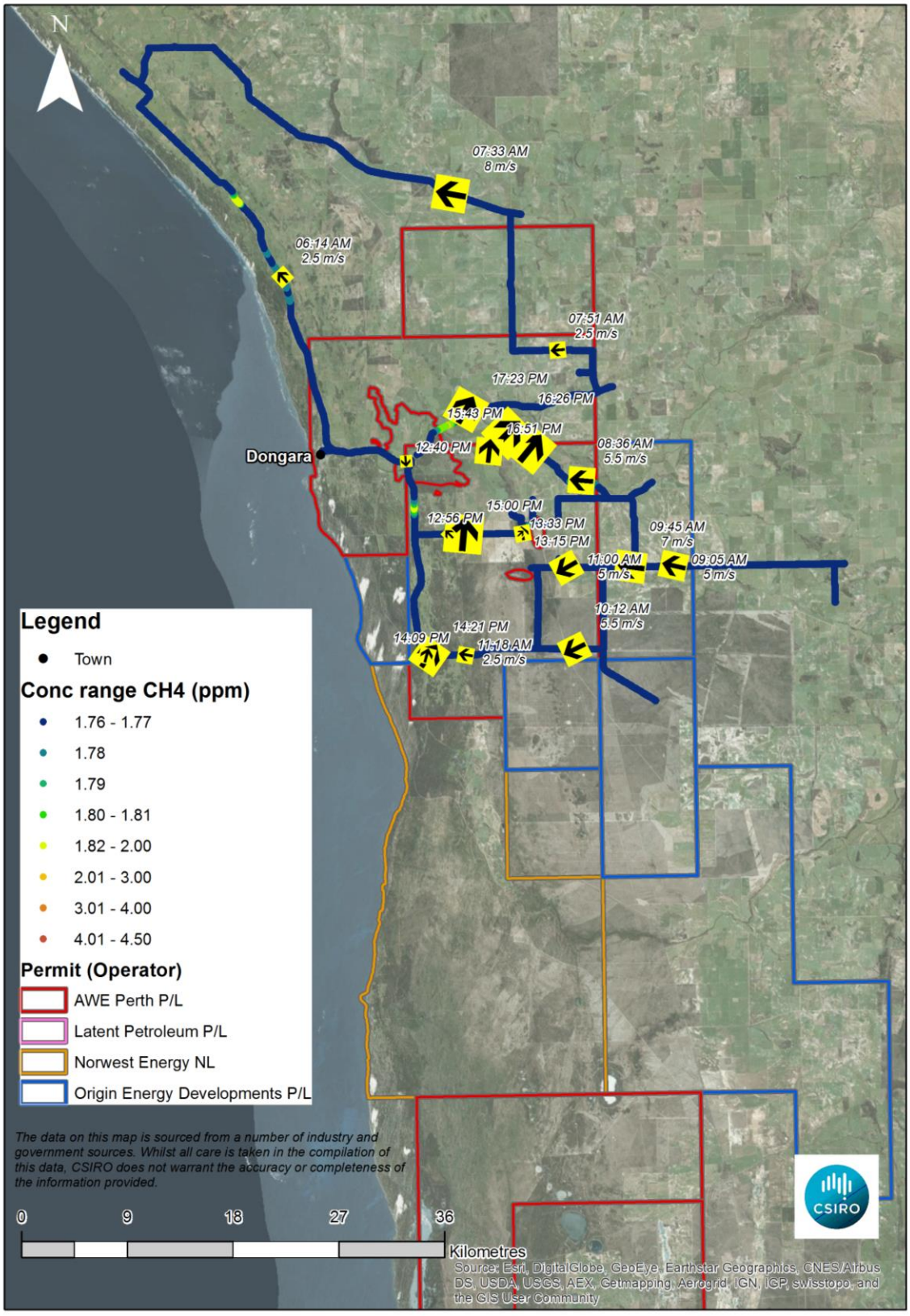


Figure 26 Mobile survey data for the 26/11/2015, showing concentration range and wind direction and speed.

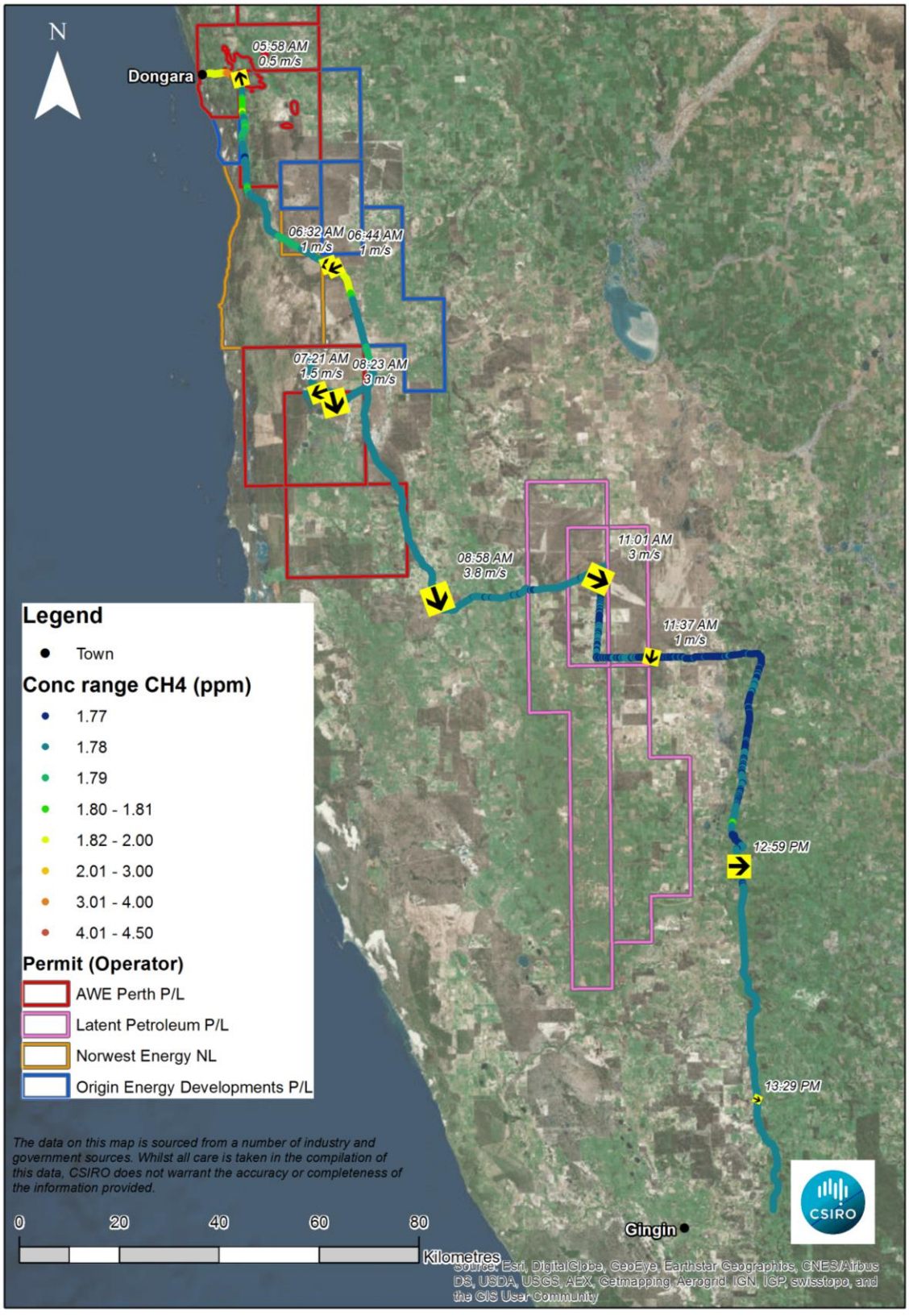


Figure 27 Mobile survey data for the 27/11/2015, showing concentration range and wind direction and speed.

3.4 Conclusion

The results from this initial survey show that the background levels of CH_4 across the area are within the range expected for background atmospheric CH_4. There are numerous small fluctuations which are not always attributable to a source. This method is a simple and effective way to measure methane concentrations across large areas.

The limitation of this method is that it represents a snapshot across the area only at the time of the survey. The Picarro is extremely sensitive, however, the detection of a methane source away from the measurement path is dependant on the methane being carried into the path by the wind.

Future investigations into the application of mobile surveys should be directed at understanding and quantifying the natural variation associated with these measurements. There were several large (up to 4 ppm) events which could easily be tracked to large infrastructure. However, there were a number of other minor events which caused fluctuations in the concentration between 1.76 and 1.79. The significance of these fluctuations and their source should be investigated in future studies.

4 Warro Soil Gas Flux Survey

4.1 Introduction

The project aimed to undertake an assessment of current levels of soil surface CH_4 flux over a spatial scale around the tight/shale gas fields in the Perth Basin prior to any operational activities. The main objective of the CH_4 flux survey was to benchmark the current level of CH_4 flux at specific areas of interested prior to any operation.

Key considerations for selecting the specific areas of interest were:

(i) Identified faults

(ii) Sampling points around existing wells and

(iii) A control site that is not anticipated to undergo any development during the lifetime of the field development.

Sites were located based on available geophysical data and in consultation with rest of the team including the companies involved.

Soil CH_4 gas flux measurement was considered a more robust way to calibrate the processes controlling the ambient concentration of CH_4, compared to transient measurements of gas concentration. However, CH_4 concentrations were also catalogued during the surveys. Along with soil surface CH_4 flux, in order to better constrain the processes controlling CH_4 flux and identify any future anomalous CH_4 response with a higher level of certainly, a suite of relevant soil characteristics were also accounted for. These included: carbon, carbonates, microbial biomass, temperature and moisture (primary abiotic drivers of CH_4 evolution), pH, particle size analysis, bulk density, porosity. This soil physical-chemical-biological monitoring approach was essential for mechanistically understanding the seasonal and spatial variability of soil surface CH_4 flux in order to better identify any future anomalous soil surface CH_4 response.

4.2 Methodology

4.2.1 Soil gas flux survey

The survey points were located based on identified fault and/or anomalous zone, survey points around existing wells and a set of control sites that are not anticipated to undergo any development during the lifetime of the field development. At each location a section of PVC pipe (dimensions: internal diameter 20 cm; height 12 cm; thickness 0.6 cm) serving as a collar for the soil-gas flux chamber was inserted into the surface soil to a depth of about 3-4 cm (Figure 29). This was done 24 hours prior to the commencement of soil-gas flux measurements to allow any soil disturbance effects to settle. The soil gas flux survey was

carried using LICOR survey chamber connected to a LGR ultraportable GHG CH_4/CO_2 analyser. Two campaigns of were conducted during May 2015 and repeated in May 2016. Figure 28 shows the locations of the first survey. Due to time and weather constraints and the difficulty of access, we were not able to get to exactly the same location for several of the sites. In these cases, the second survey point was within approximately 200m of the original.

During these campaigns daytime measurements (morning, afternoon and evening) were taken with the intention of covering a whole daytime cycle. A typical measurement consisted of the chamber being placed over the collar for a period of 3 to 5 minutes and change in CH_4 and CO_2 concentration recorded for calculating the soil CH_4 flux. At each flux measurement point the soil moisture and temperature data is recorded. After the flux measurement is completed, a sample is taken of the top 10 cm of soil within the collar and sealed into a plastic bag for later analysis. Soil samples were refrigerated as soon as possible after collection.

Figure 28 Surface soil survey locations for 2015

Figure 29 Soil gas flux measuring equipment and collar

4.2.2 Soil analysis

Soil carbon and nitrogen content was analysed based on Dumas dry combustion techniques determined by an Elementar analyser (Germany) operating at a combustion temperature of 1000°C resulting in production, purification and measurement when soil C and N is ignited in a stream of O_2. Since the soil samples are quite low in carbonate minerals and charcoal most of the carbon can be assumed as organic carbon.

Soil electrical conductivity was determined based on a 1:5 w/v soil/water extract with air-dry (40°C) by end-over-end mechanically shaking at 25°C for 1 h to dissolve soluble salts then allowed to settle for around 20–30 min and read using a calibrated conductivity cell. While it is realised sparingly soluble salts will contribute to a greater extent at this ratio than at more concentrated ratios, the values of EC are satisfactory for most purposes.

Soil pH was determined using dilute calcium chloride (0.01 M $CaCl_2$) at a 1:5 soil/solution extract with air-dry (40°C) by end-over-end mechanically shaking at 25°C for 1 h to dissolve soluble salts then allowed to settle for around 20–30 min and read by positioning the pH

meter in the unstirred supernatant during measurement. The results obtained using $CaCl_2$ extractant are commonly 0.5 to 1.0 pH unit lower than those obtained in water but pH variability is lower with fluctuation in soil soluble salts, due to seasonal conditions and variation in fertiliser inputs.

Soil particle size analysis was determined using a method involving dispersion and separation of the particles into size groups. This method is a reproducible technique that eliminates factors that may affect field texture such as organic matter content, clay mineralogy, cation composition and the presence of cementing agents. The method comprises two parts: (1) Dispersion and pre-treatment - Pre-treatment of the soil may be needed to remove organic matter and salts such as gypsum. Iron oxides, calcium carbonate and magnesium carbonate should also be removed as they are common cementing agents in Australian soils. Pre-treatment of the soil will allow it to disperse completely. (2) Fractionation: separating each particle size group (sand, silt and clay) from a pre-treated soil and water mixture by allowing the soil particles of different size to settle out of solution at different times (small clay particles take the longest). The fractions are subsequently dried and weighed and the sand, silt and clay must add up to 100%.

Soil microbial biomass consists mostly of bacteria and fungi, which decompose crop residues and organic matter in soil. About half the microbial biomass is located in the surface 10 cm of a soil profile and generally, up to 5% of the total organic carbon and nitrogen in soil is contained in the microbial biomass at any one time. When microorganisms die, these nutrients are released in forms that can be taken up by plants. The microbial biomass was determined based on chloroform ($CHCl_3$) fumigation and extraction method with the rationale that the fumigant lysed the soil microbes and the resulting increase in CO_2 evolution from fumigated soil as compared to unfumigated at 25^oC is directly proportional to the amount of microbial C. The amount of CO_2 released is determined by absorbing in 0.5M K_2SO_4 determined using a total dissolved organic carbon analyser.

4.3 Results

4.3.1 Survey Results for soil surface CH_4 flux

The results of two soil methane surveys conducted during May 2015 and repeated in May 2016 are shown below. For Survey 2 for logistical reasons related to timing and weather, it was not possible to completely duplicate each of the sites measured in Survey 1. Where the original site could not be measured, a new site was chosen as close as practicable to the first, usually within 100-200m. Figure 28 shows the relative locations of Survey sites 1 and 2 and Figure 30 shows the differences between the flux data gathered at each site. In total, there were nine sites where the second survey was not taken and 20 where both surveys were completed. In one case, the second survey could not be completed as the site was now under the cement pad of one of the petroleum exploration holes.

Figure 30 Soil surface CH_4 survey determined during the two surveys and timing details

The soil gas flux values measured at each site are shown in Figure 31. The intensity of the colour reflects the flux, which varies between positive 0.5 to negative 0.05 nmol/sec. The observed fluxes during the two surveys do not show any anomalous flux levels and the current level of background CH_4 is around 1.787 μmol mol^{-1}.

Figure 32 (survey location 28) and Figure 33 (survey location 8) show two examples of the rate of change of CH_4 evolving from the soil for two locations during the flux chamber measurement. At each location, the chamber is closed for a specific length of time (300 seconds in this instance) and the measured data plotted per second. The two scenarios depicted are: 1) when CH_4 rate of change shows a negative flux measurement and the concomitant change in CO_2; 2) when CH_4 rate of change shows a positive flux and the lack of a clear relationship with CO_2, respectively. Figure 36 shows the typical mean soil methane flux observed (0.045 mmols m-2 s-1) across the surveys. The blue line is the 95% confidence level and red line 95% prediction. Overall, it can be seen there is very little variation in the flux across the survey site.

Overall, the daytime soil CH_4 flux measurements have a weak net sink for CH_4 and follow a unimodal pattern, peaking during mid-day and lowest at dawn and dusk. For few observations, especially during early mornings and evening a slight CH_4 source was also observed which was also associated by an absence of strong increase in CO_2.

4.3.2 CH_4 flux at the control sites and well locations

As previously mentioned, the control sites were selected at locations which are not anticipated to undergo any development during the lifetime of the field. The sites were located based on available geophysical data and in consultation with Latent Petroleum. The current levels of CH_4 flux at the control sites is similar to the levels observed at the other survey locations.

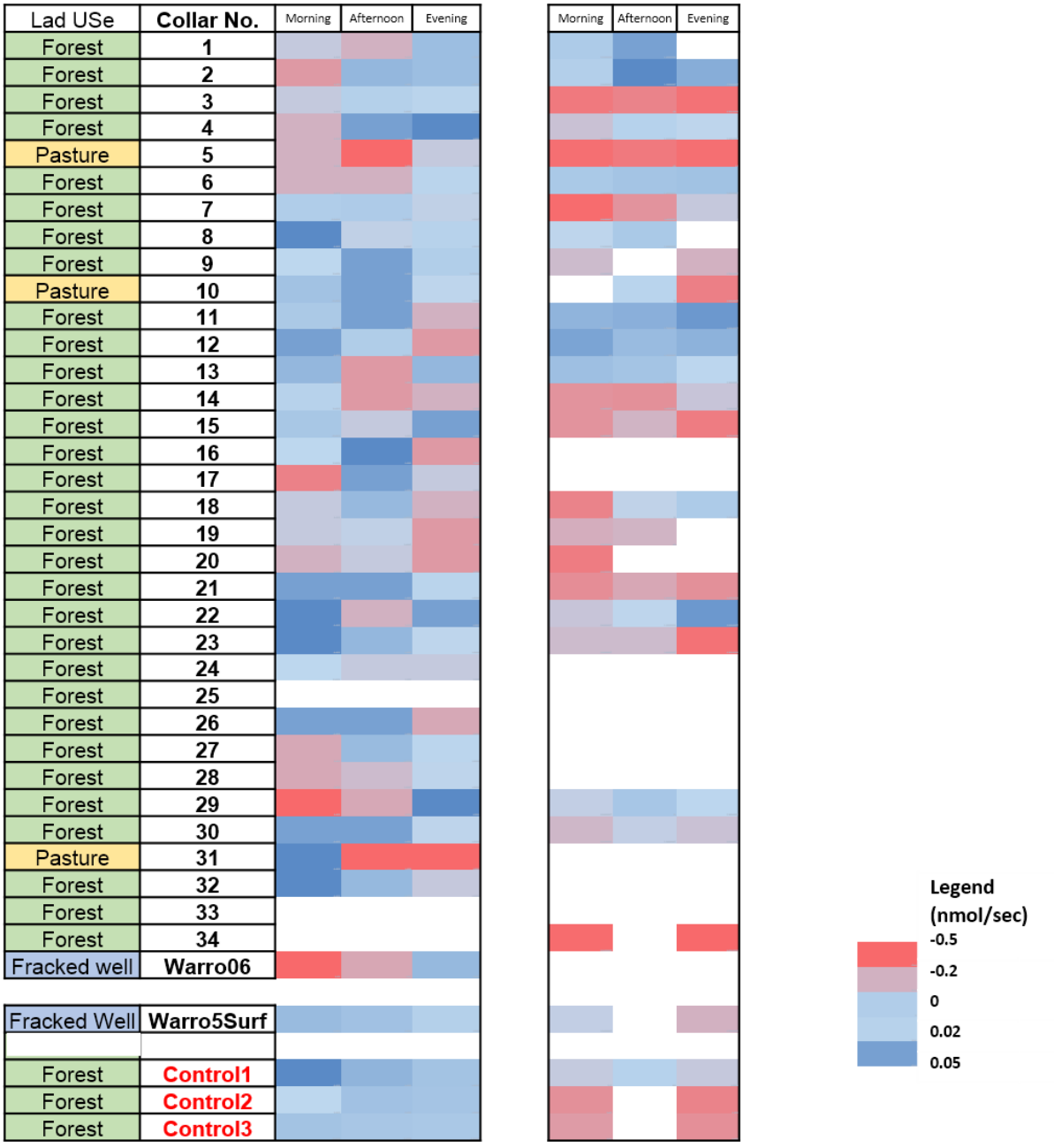


Figure 31 Soil surface CH_4 flux values at each survey location.

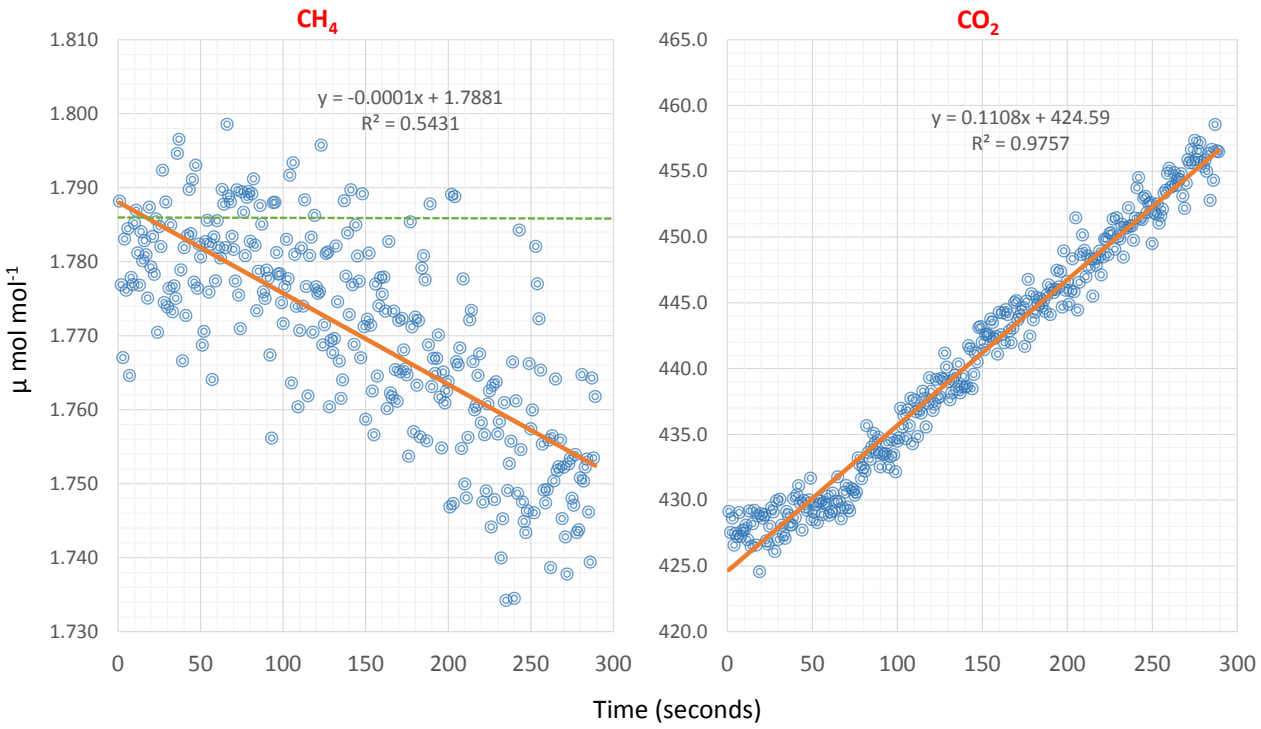


Figure 32 Weak net CH4 sink and associated increase in CO_2 (Survey location: 28). The green dashed line indicates the current level (1.787 µ mol mol^{-1}) of ambient atmospheric CH_4

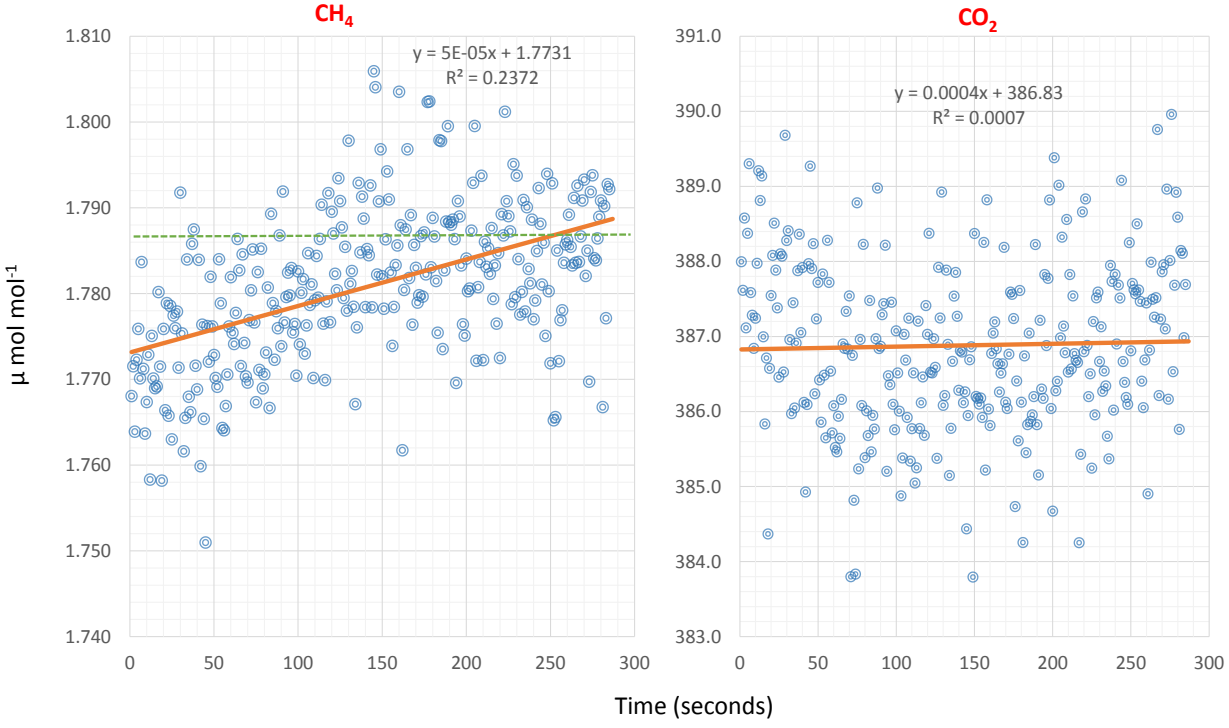


Figure 33 Weak net CH_4 source and absence of strong increase in CO_2 (Survey location: 8). The green dashed line indicates the current level (1.787 µ mol mol^{-1}) of ambient atmospheric CH_4

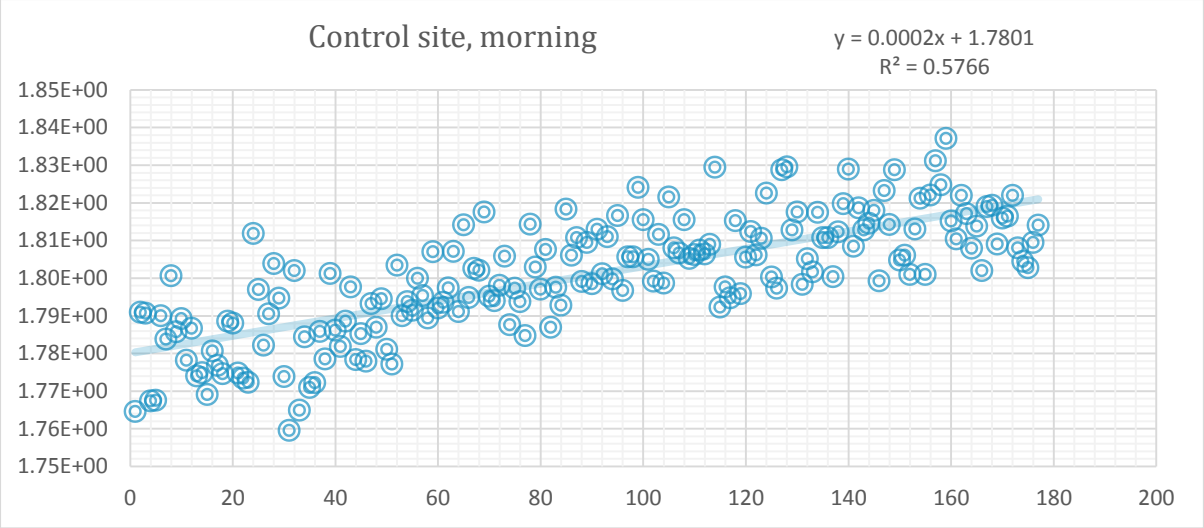


Figure 34 CH_4 flux in the morning, at control site 2

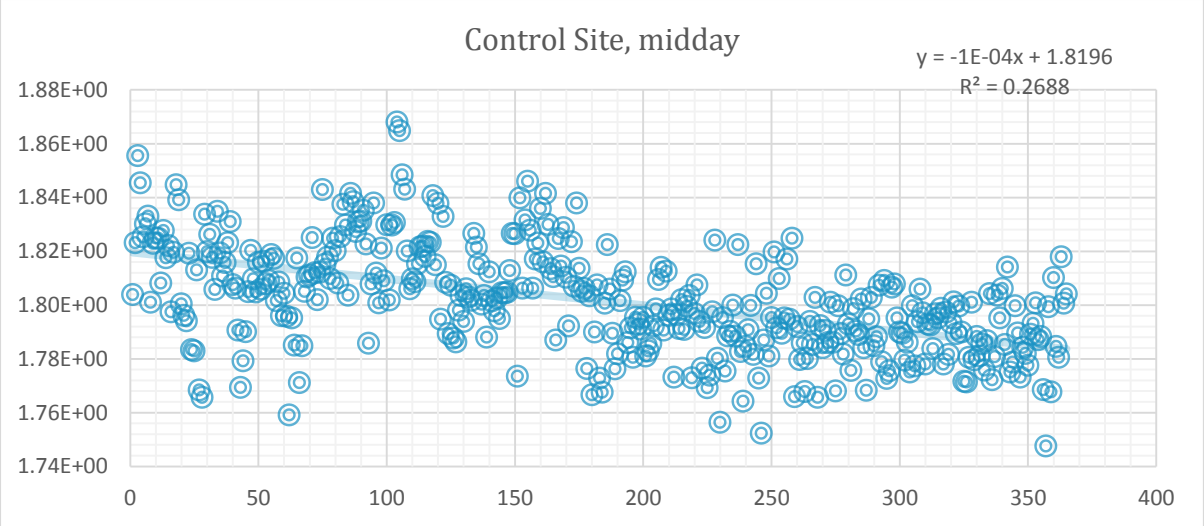


Figure 35 CH_4 flux at midday, at control site 2

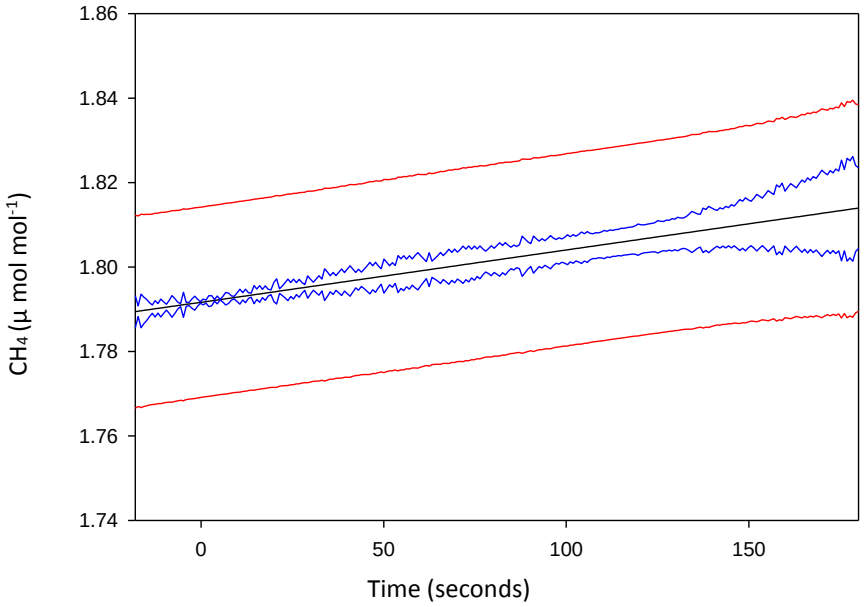
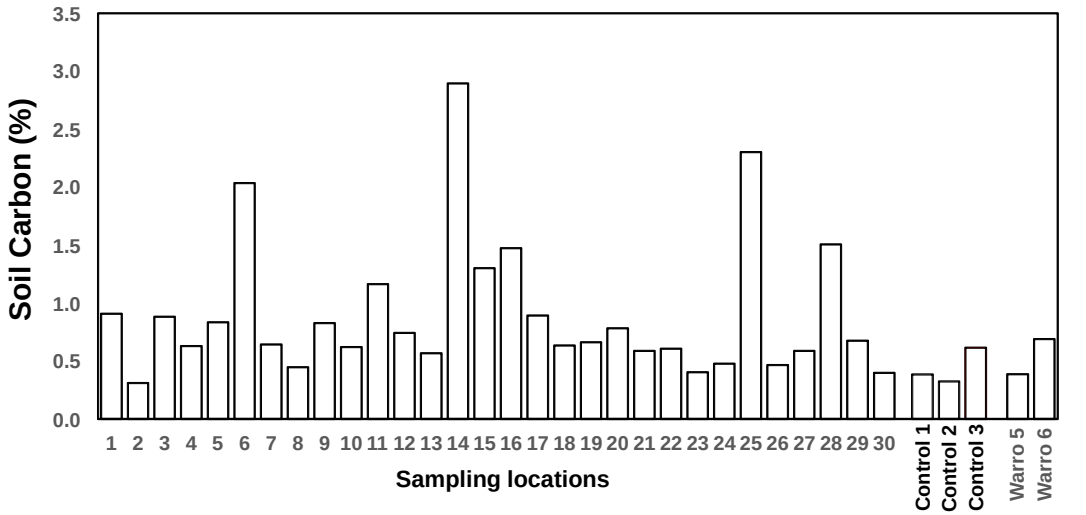


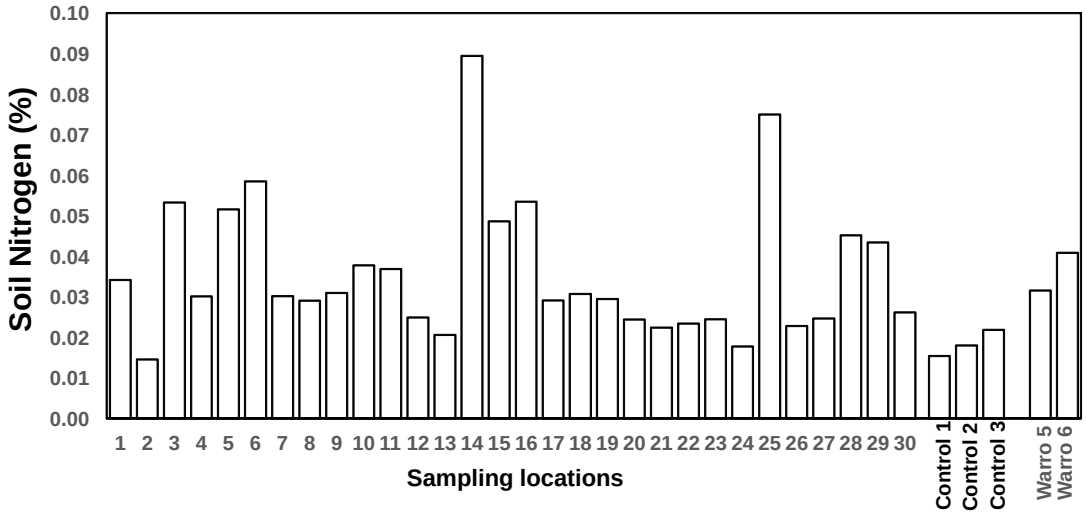
Figure 36 Typical mean soil CH_4 flux observed (0.045 mmols m-2 s-1). The blue line is the 95% confidence level and red line 95% prediction.

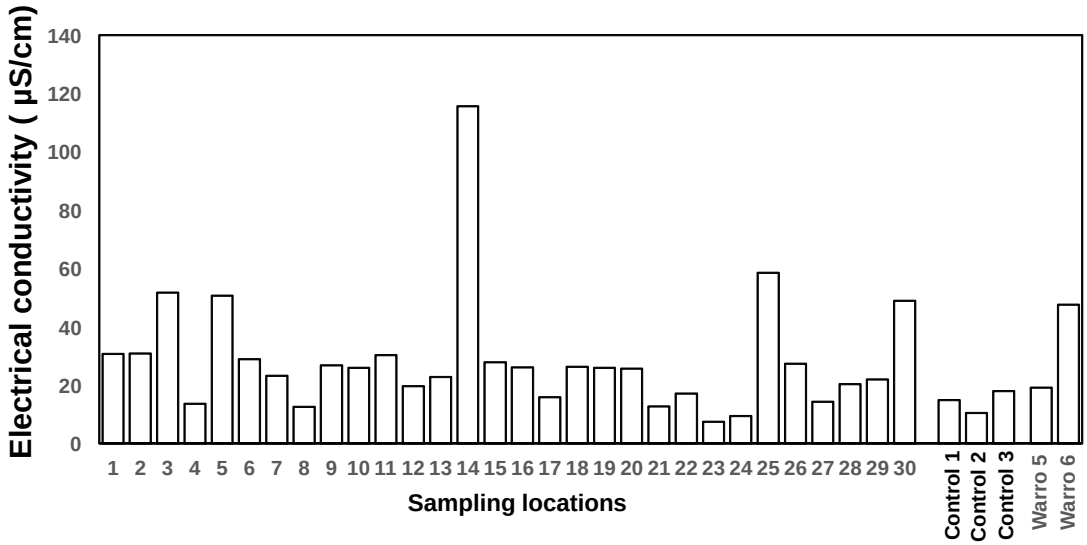
4.3.3 Soil parameters

Even though there is paucity of soil methane flux data from Australia and specifically Western Australia, previous studies have linked soil methane flux to predictor soil properties as potential surrogate soil parameters. A suite of biological and physico-chemical parameters were selected to investigate this relationship: carbon, carbonates, microbial biomass, temperature and moisture (primary abiotic drivers of CH_4 respiration), pH and particle size analysis in order to better constrain the processes controlling CH_4. The results for each parameter analyses are shown below

Average soil carbon 0.84%, standard deviation of ±0.56% and average soil nitrogen values of 0.034 % standard deviation of ±0.016% showed that these values are quite low with little variation at the locations surveyed. Average electrical conductivity values (27.2 µS/cm), $pH_{(CaCl2)}$ (4.2), soil microbial biomass (0.44 µg/g) and dissolved carbon (0.34 µg/g) similarly show a low level of variability for the surveyed locations.


Soil Carbon (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations


Soil Nitrogen (%)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations


Electrical conductivity (µS/cm)
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations

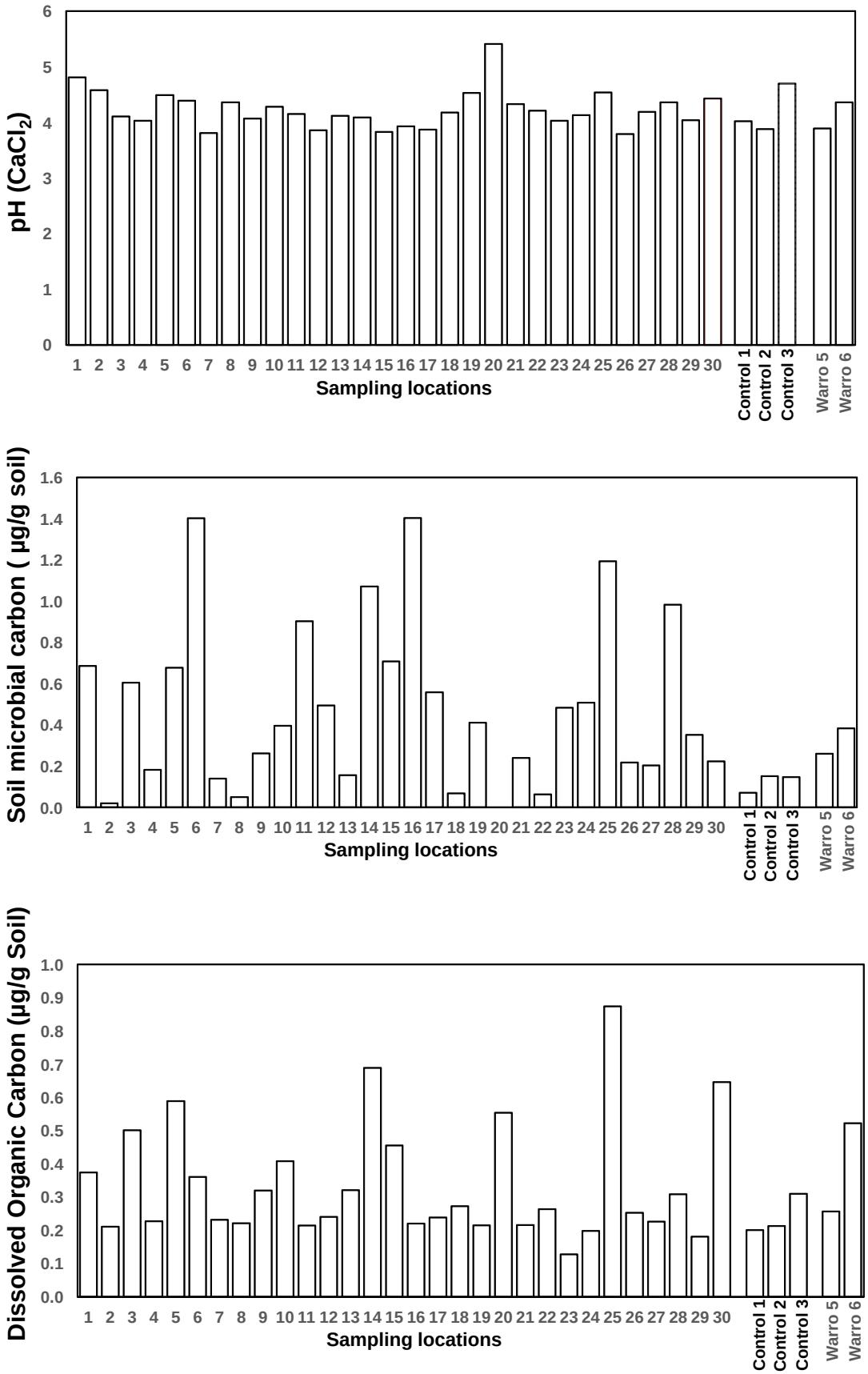


Figure 37 Results for soil sample analysis

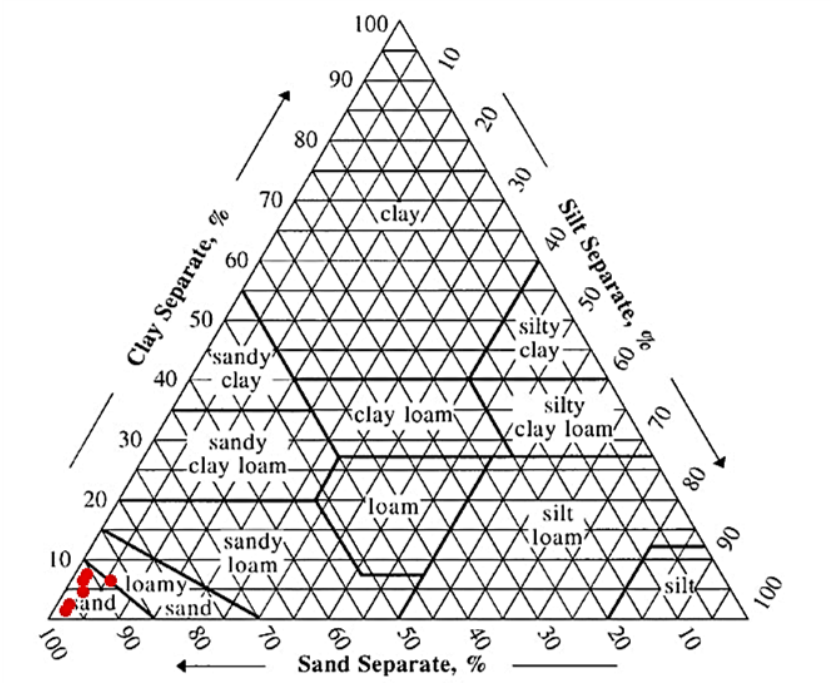


Figure 38 Soil particle size analysis

The soil particle size values showed that the soils are uniformly sandy to sandy loam.

4.3.4 Soil temperature and moisture

Compared to the above mentioned soil parameters, the soil temperature and moisture parameters usually show a higher degree of temporal and spatial variation and thus were recorded at the time of each soil methane flux measurement. Not surprisingly, these values showed variability not only between times of the day but also between the two surveys.

Figure 39 shows the mean soil temperature and moisture values measured at the three periods across the day, morning, midday and late afternoon. On average soil temperature was highest around midday and dropped off again towards afternoon. The soil moisture content was highest in the morning, when the soil was also coolest and dropped off around midday, rising slightly in the afternoon.

Figure 40 shows an increase in CH_4 flux with increasing soil moisture.

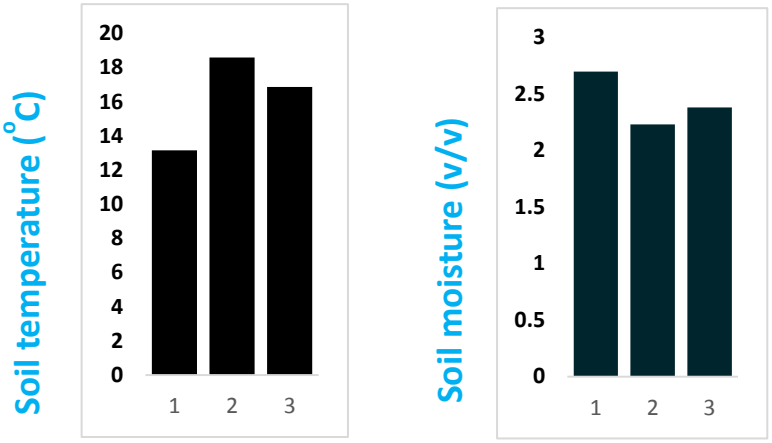


Figure 39 Daytime mean soil temperature and moisture values during the soil surface methane survey (1- morning, 2- mid-day and 3- evening).

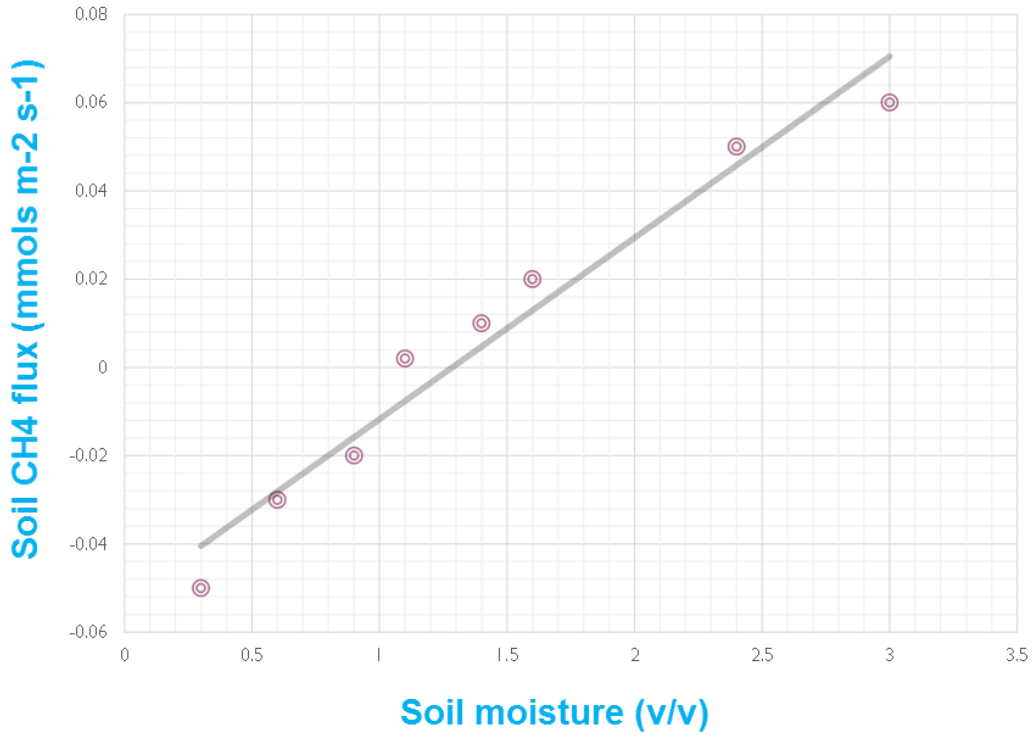


Figure 40 Soil moisture relationship with CH_4 soil flux

4.4 Conclusions

A weak net CH_4 sink was observed probably due to CH_4 oxidation (CH_4+ + $2O_2$ → CO_2 + $2H_2O$) by methanotrophic microbes occurring in aerobic condition which can be observed by a concomitant increase in CO2. For few observations, especially during early mornings and evening a slight CH_4 source was also observed which was also associated by an absence of strong increase in CO_2.

Most of the well-drained soils globally act as sources of the greenhouse gas carbon dioxide, and both sinks and sources of the greenhouse gases nitrous oxide and methane (CH_4), with well-drained aerated soils being one of the most important sinks for atmospheric CH_4. Soil CH_4 uptake is driven by aerobic CH_4 oxidation through methanotrophic bacteria that oxidize CH_4 at atmospheric to sub atmospheric concentrations with soil gas diffusivity being one of the key regulators of soil CH_4 uptake in these systems. Our results show that CH_4 uptake was regulated by soil moisture with uptake rates increasing when soil moisture decreased, which explained the temporal variability in CH_4 at the various sites studied. Soil temperature, soil carbon, soil microbial biomass and soil particle size distribution had a lesser control over this diurnal variation of observed soil surface CH_4.

Based on the two separate surveys, the CH_4 flux measured at the four sites was consistent with expected background levels. In addition, we were not able to detect any anomalous CH_4 concentration values at any of the survey points. The CH_4 concentration measurements taken around the wells were consistent with atmospheric CH_4 levels. CH_4 levels from the more comprehensive survey to determine baseline levels of CH4 within the entire 'anomalous' zone identified on the Warro 3D seismic data at shallow levels and control sites (not anticipated to undergo any development during the lifetime of the field) did not yield any anomalous CH_4.

Additional analyses need to be considered are the stable isotopic signature identification of carbon and soil microbial community studies to confirm the presence and diversity of methanotrophs. Modelling near atmospheric CH_4 on a landscape scale using identified driver variables at selected locations in the Perth Basin is also recommended.

5 Semi-permanent Soil Gas Flux Installation

5.1 Introduction

The soil gas flux survey represents a “snapshot” of the soil gas flux taken at the time of the survey. In order to get an understanding of the seasonal variation in the gas flux in the soil around the Warro field site, we set up a long-term soil gas flux monitoring station. This set-up is unique to the best of our knowledge. There were significant difficulties associated with powering and maintaining the system remotely which required several trips and modifications. Consequently, only a small set of useful data was obtained. However, the system is now considered robust and will be setup locally and undergo further testing before installation at a future site.

5.2 Methodology

The station consisted of a Li-Cor long-term soil gas flux chamber connected to the LGR portable greenhouse gas sensor (described in the previous section). The system was powered by 12 solar panels connected to truck batteries (Figure 41). The Li-Cor was set to measure the soil gas flux every 20 minutes and remained closed for a period of two minutes before opening again (Figure 42). Adjacent to the long term chamber were a soil moisture and a soil temperature probe.

The initial installation did not have telemetry to indicate operational status and required manual restart. During winter there was insufficient sunlight to charge the batteries and solar panels, during summer the system would overheat. In both cases the system would shut down.

These issues have now been addressed through the addition of switches and telemetry to allow us to turn the system on and off remotely, as well as download the data. This modification has had to be made to both sensors, the Li-Cor chamber and the LGR. The LGR system is now on telemetry, however the Li-Cor still needs manual download of the data.

The system as it is now engineered is considerably more stable. The number of solar panels required make it not particularly portable, however, as it is intended to remain at one site for an extended period, that is not necessarily an impediment. The system would be considerably improved by reconfiguring the LGR to enable it to shut down between measurements. Although we had several conversations with the manufacturer who were helpful and enabled us to make some modifications to the system, this particularly modification was not able to be implemented. In future, if the LGR was enabled to shut down between measurements, the power drain on the batteries would be significantly reduced and hence the number of solar panels would also be reduced.

Figure 41 Long term chamber set up, solar panels and telemetry antenna shown

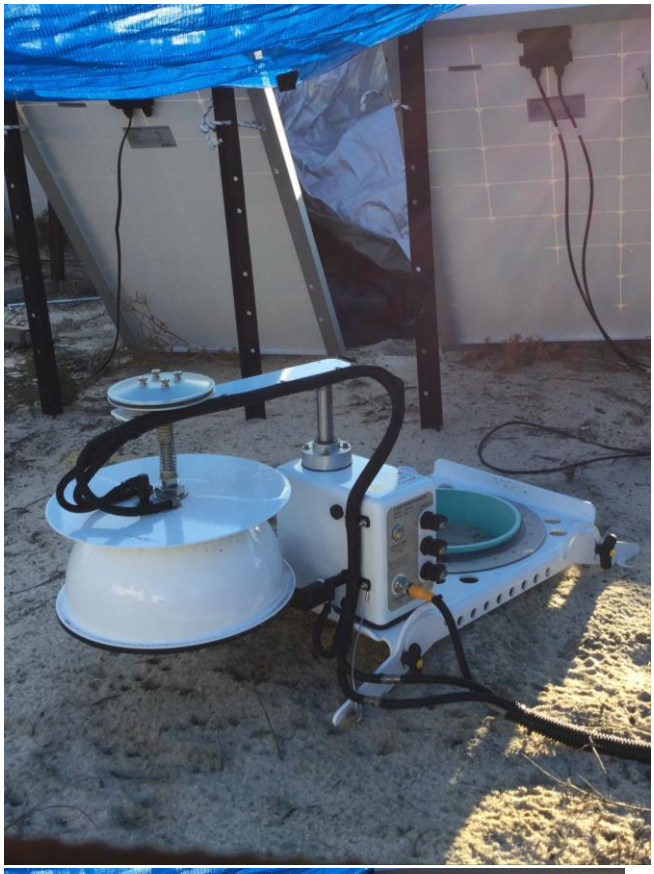


Figure 42 Long term chamber set up (a) open; (b) closed and sampling

5.3 Results

The soil gas concentration data obtained over the period has a number of gaps due to the system instabilities. In total 43 days' worth of data across June, September, October and November were obtained before the sensor failed (Table 8).

Table 8 Dates of useful measurements

Month	Date Range
June	25, 26 and 27
September	23 – 30 (9 days)
October	1 – 31 (31 days)
November	1 and 2

Due to the limited dataset, the gradients were not converted to flux and are presented here as a summary of the rate of change in CH_4 concentration across the sampling period. There was a degree of instantaneous instrument fluctuation during the measurement period which produced anomalous values during the data processing. The resultant gradients for each day have been filtered to show only those between ±0.002 ppm/sec. The gradient data collected daily is summarised Figure 43 as a box and whisker plot showing the median, 25th and 75th percentile for selected days. There were no observable seasonal trends in this preliminary analysis of the data. There are some subtleties in the data obtained, but detailed analysis is outside the scope of this project. No significant anomalies were observed.

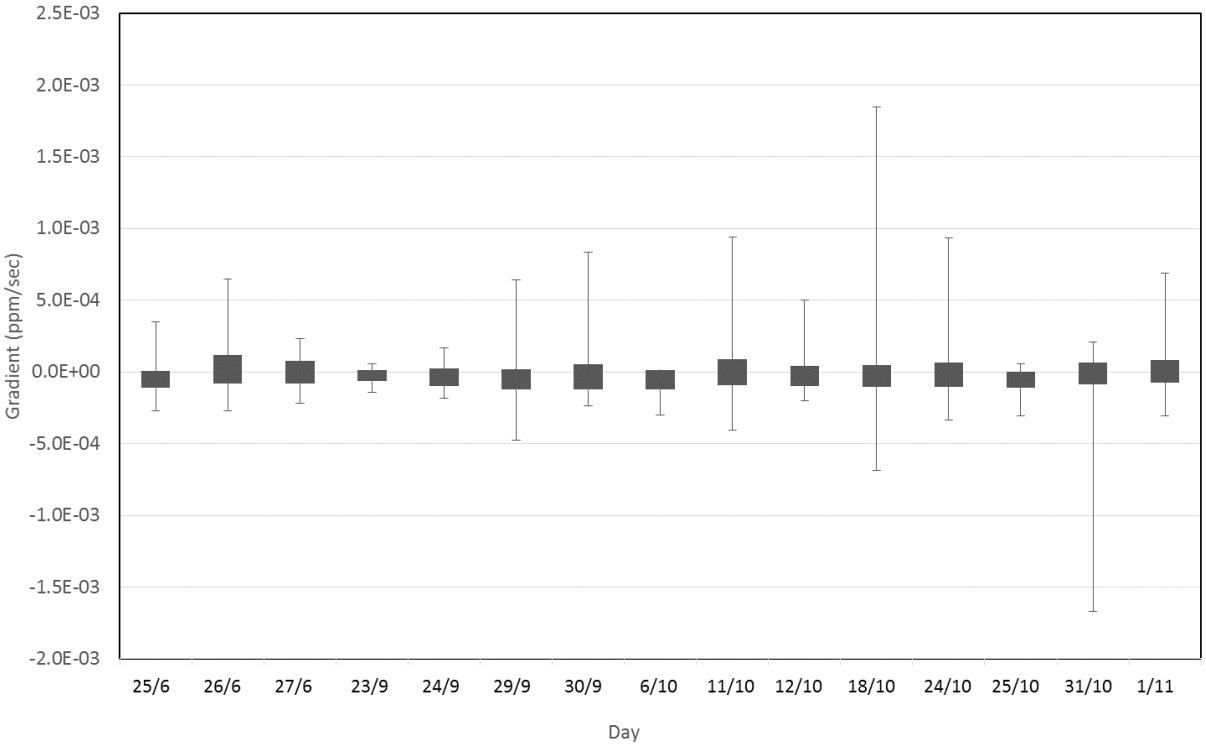


Figure 43 Soil gas gradient from selected days in 2015

5.4 Conclusions

One of the objectives of this component was to set up a long term soil gas flux monitoring station. Although this had a number of unexpected challenges, we were able to engineer a system, using off-the-shelf equipment with a number of modifications. Once the system is stabilised it requires very little maintenance. The sensors do not require regular calibration and are able to accurately measure very low flux values. The system is unique to our knowledge.

The radius of investigation of the soil gas flux surveys is extremely small. The application of a long term monitoring station is potentially useful for two scenarios. It allows the snapshot values of an intensive soil gas flux survey to be put into an annual context, with seasonal variations accounted for. The second potential application is at a point where there is either a known methane flux which needs to be monitored (for example at a near surface fault or leaking well), or at a point of significance where the risk or consequence of an anomalous methane flux is high (for example a well or fault near a water source).

The advantage of this system is that it is relatively self-sufficient, cheap to run, can be set up with telemetry, does not require drilling a well. In addition, it does not require any sampling and therefore any analysis and associated time and costs. We have not yet proven these

advantages, however, we believe we have made significant progress. The system will be setup locally and undergo further testing to be ready for future deployment.

6 Conclusions and Recommendations

There are several conclusions to be drawn from this body of work, the most significant is that this study represents the first attempt to gather ambient concentration values of methane in the near-surface in the northern Perth Basin. In most cases the data gathered in this study represents a “snapshot” of methane distribution across the area at the time of the data gathering.

The project was envisioned as the first step in establishing a Research Program to improve: 1) understanding of suitable methods and protocols for establishing environmental baselines associated with tight and shale gas development, and 2) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact. Understanding the controls and variations of the current environmental baseline is necessary to achieve both of these long term objectives.

With respect to understanding and quantifying ambient near-surface CH_4 concentration, this project has concluded that:

1. Although there exists a good interpretation of regional flow in the northern Perth Basin, at this stage there is inadequate monitoring of the key aquifers for establishing baseline conditions.
2. Ambient levels of CH_4 across the basin were found to be consistent with the expected background concentration. It is recommended that the impacts of stationary sources (facilities, towns, lakes and old petroleum wells) and from mobile sources, such as cattle, be investigated in future studies.
3. The concentrated soil gas flux survey found no anomalous readings and the data indicated the flux was being controlled by microbial action. Additional sampling and modelling is recommended.
4. Long-term monitoring of soil gas flux rates to understand seasonal variations are important to place the soil gas flux surveys in context and may provide the basis to allow predictions of changes in methane flux rates related to changing climatic conditions. During this project a system was developed to provide ongoing, continuous (every 20 minutes) measurements of soil gas flux. Due to ongoing system problems very little useful data was obtained, however, the system is now robust and undergoing further testing ready for future deployment.

References

Day S, Ong C, Rodger A, Etheridge D, Hibberd M, van Gorsel Spencer D, Krummel P, Zegelin S, Fry R, Dell'Amico M, Sestak S, Williams D, Loh Z and Barrett D (2015) Characterisation of Regional Fluxes of Methane in the Surat Basin, Queensland: Phase 2: A pilot study of methodology to detect and quantify methane sources. CSIRO Australia.

Department of Water (2016) Geology, hydrogeology and groundwater resources of the Northern Perth Basin, Western Australia, Department of Water, Hydrogeological Bulletin Series, Report No. HB1.

DoW (2016) Water Information Reporting database. Viewed 1 August 2016, <http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx>.

DMP (2016) Guidelines groundwater monitoring in the onshore petroleum and geothermal industry, Department of Mines and Petroleum, Western Australia.

Issa N, Lumley D, Drew J, Hoskin T and Saygin E, (2016) Final Report: Passive seismic monitoring at the Warr field, Prepared for Baseline Characterisation and Monitoring Protocols for Development of Shale and Tight Gas Resources, Perth Basin Project. Centre for Enegy Geoscience, University of Western Australia, 85pp.

Olierook HKH, Timms NE, Wellmann JF, Corbel S and Wilkes PG (2015) 3D structural and straigraphic model of the Perth Basin, western Australia: implications for sub-basin evolution. Australian Journal of Earth Science: An International Geoscience Journal of the Geological Society of Australia. DOI: 10.1080/08120099.2015.1054882

Rockwater (2013) Warro Project Hydrogeological modelling of potential impacts, Report for Latent Petroluem, Report no. 430.0/13/0

Appendix A

A.1 Data Accuracy

A.1.1 Formation Bases

The formation bases have been generated from structural contours with a 200m interval (MGA50 projection) and use AHD (Australian Height Datum) as the vertical datum.

MGA 50 projection parameters

- *GDA_1994_MGA_Zone_50*
- *WKID: 28350 Authority: EPSG*
- *Projection: Transverse_Mercator*
- *False_Easting: 500000.0*
- *False_Northing: 10000000.0*
- *Central_Meridian: 117.0*
- *Scale_Factor: 0.9996*
- *Latitude_Of_Origin: 0.0*
- *Linear Unit: Meter (1.0)*
- *Geographic Coordinate System: GCS_GDA_1994*
- *Angular Unit: Degree (0.0174532925199433)*
- *Prime Meridian: Greenwich (0.0)*
- *Datum: D_GDA_1994*
- *Spheroid: GRS_1980*
- *Semimajor Axis: 6378137.0*
- *Semiminor Axis: 6356752.314140356*
- *Inverse Flattening: 298.257222101*

Bore Depths

Bore depths start from ground level - this is an SRTM 3 arc second (~ 90m) surface. The original SRTM data has the WGS84 datum.

SRTM Metadata

To use C-band and X-band interferometric synthetic aperture radars (IFSARs) to acquire topographic data over 80% of Earth's land mass (between 60degN and 56degS) during an 11-day Shuttle mission. Produce digital topographic map products which meet Interferometric Terrain Height Data (ITHD)-2 specifications (30 m x 30 m spatial sampling with <=16 m absolute vertical height accuracy, <= 10 m relative vertical height accuracy and

<=20 m absolute horizontal circular accuracy). All accuracies are quoted at the 90% level, consistent with National Map Accuracy Standards

The WGS84 datum parameters are:

- *GCS_WGS_1984*
- *WKID: 4326 Authority: EPSG*
- *Angular Unit: Degree (0.0174532925199433)*
- *Prime Meridian: Greenwich (0.0)*
- *Datum: D_WGS_1984*
- *Spheroid: WGS_1984*
- *Semimajor Axis: 6378137.0*
- *Semiminor Axis: 6356752.314245179*
- *Inverse Flattening: 298.257223563*

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[redacted]

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FOR FURTHER INFORMATION

Energy
Allison Hortle
[redacted]

AWE Perth Basin Operations

Coorow Community Reference Group
Drover-01: Groundwater monitoring

23 July 2015

Overview

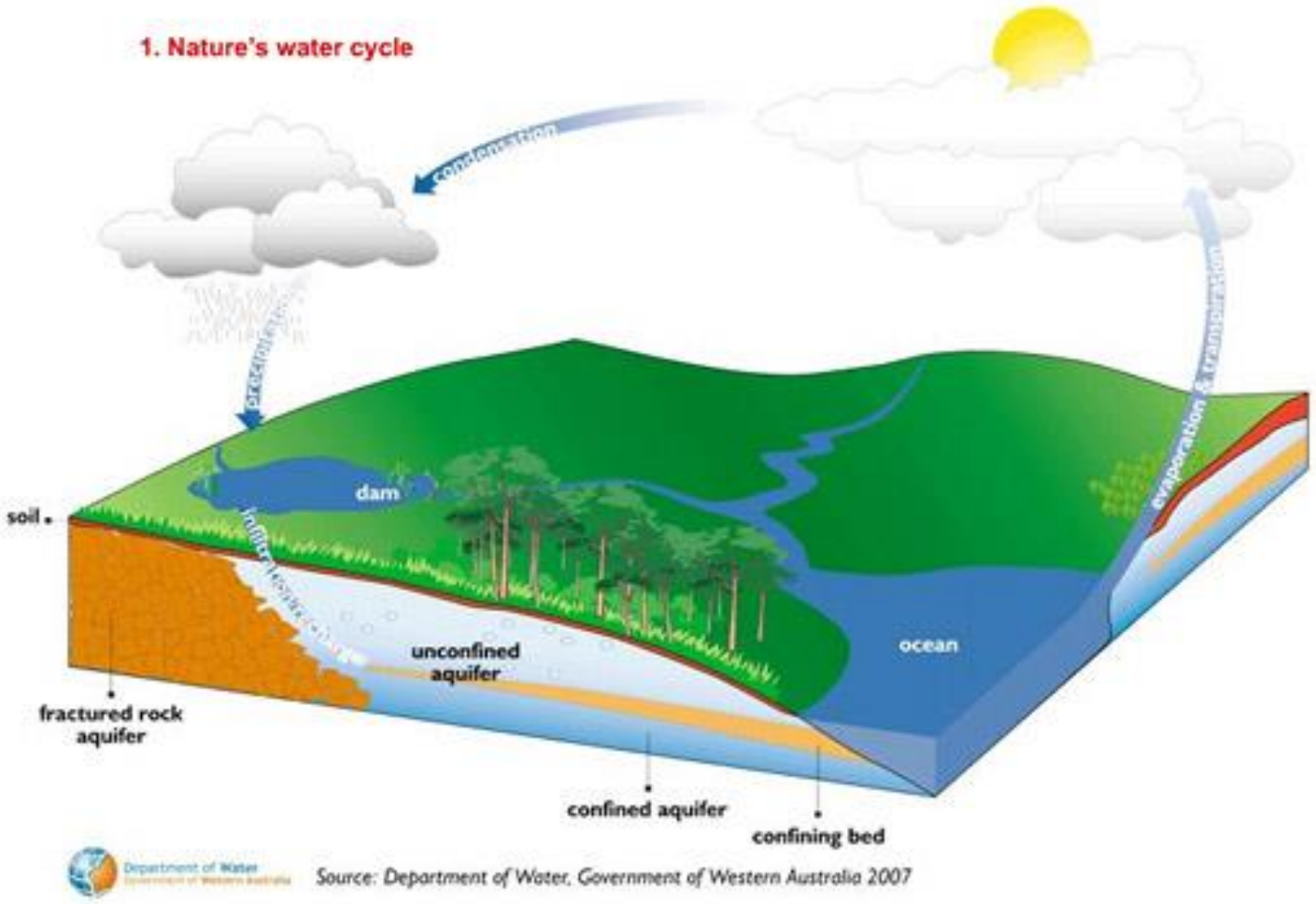
- Setting the scene - Groundwater monitoring basics

- Drover 01
  - Groundwater monitoring details
  - Recent monitoring results

- Next steps

Setting the scene - Groundwater monitoring basics

Groundwater is a reserve of water beneath the earth's surface in pores and crevices of rocks and soil.



Groundwater monitoring program an important risk management tool

Setting the scene - Groundwater monitoring basics

Groundwater monitoring bores are used to:

- determine the nature and properties of soils through which liquids may seep;
- provide access to groundwater for measuring its level, physical and chemical properties; and
- allow groundwater samples to be withdrawn for laboratory analysis

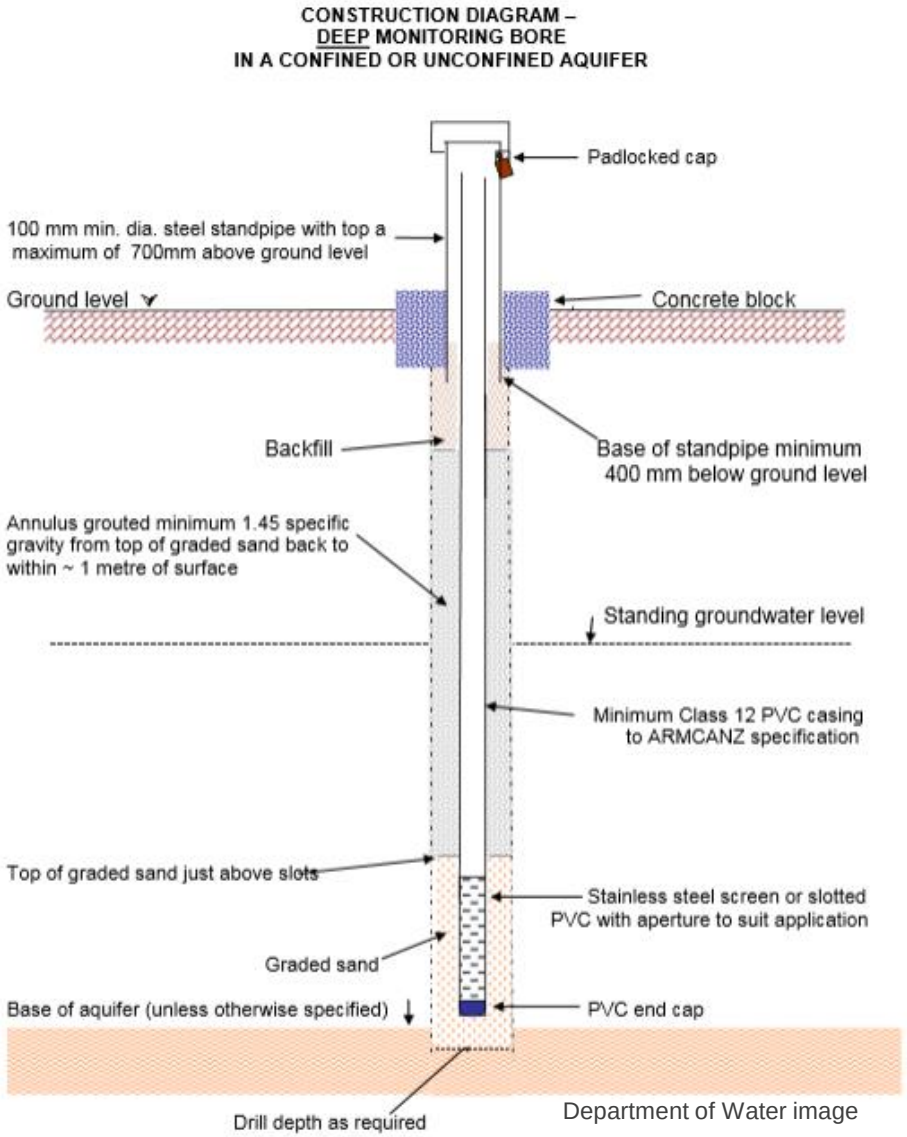
Photo courtesy of DoW (not Drover-1)

Monitoring bores are mainly needed to assess changes to water table levels and groundwater quality

Setting the scene - Groundwater monitoring basics

Factors considered

- Site of monitoring bores
- Bore construction and drilling technique (eg depth, diameter, main casing, completion)
- Water sampling techniques
- Equipment and site hygiene
- Bore drillers required to be qualified and licensed for the aquifer/s at the site



Department of Water image

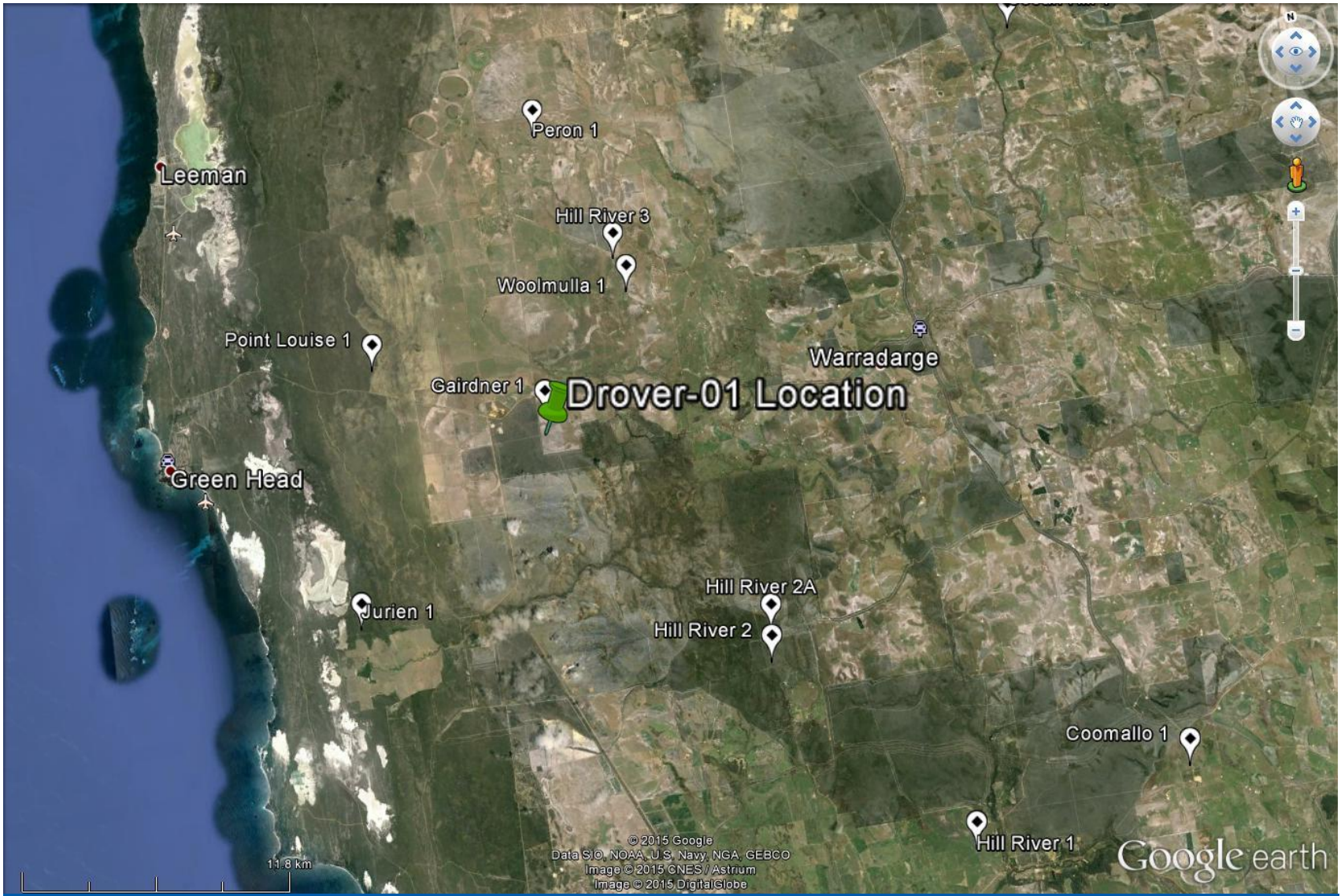
Groundwater monitoring program is tailored to each site and activity

Drover-1

Groundwater Monitoring Assessment and Planning

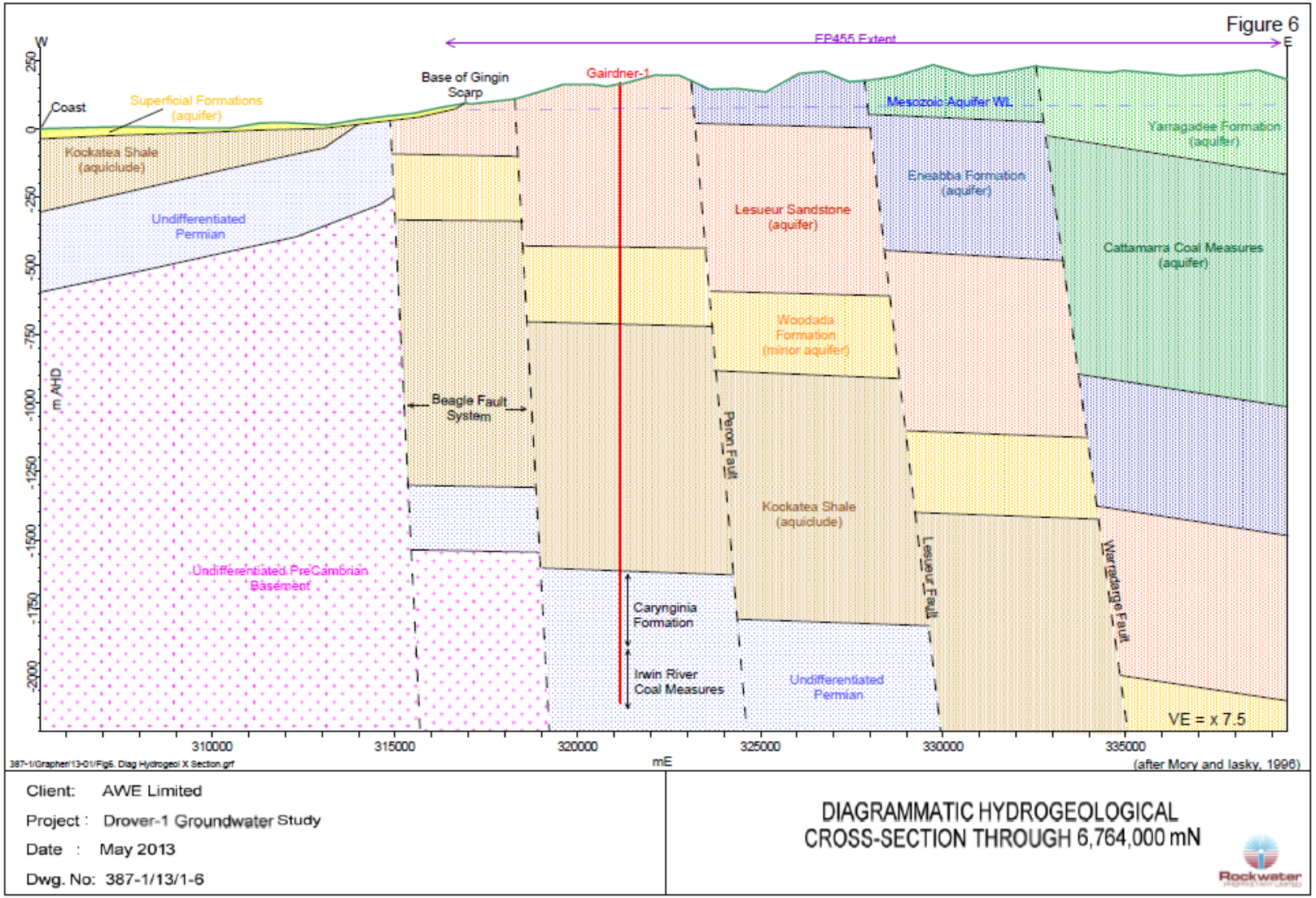
AWE

Exploration wells in the Drover-1 region



Exploration activity has been in the region since the 1960s

Drover-1 Cross Section from Ground Water Study



Hydrogeological assessment undertaken during Drover-1 planning phase drew on historic data

Drover -1 Regulatory assessment

Approvals process for the proposed Drover-1 well included review and assessment by:

- Department of Mines and Petroleum (DMP)
- Department of Water (DoW)
- Department of Parks and Wildlife (DPaW)
- Environmental Protection Authority (EPA)
- Appeals Convenor

Risk management controls

- DoW identified highest risk to water resources was from possible surface spillage of chemicals/diesel fuel
- DoW estimated that if any spill was not contained or remediated, it would take hundreds of (up to 800) years to travel the distance to Mt Peron borefield, which is approximately 4 km away.
- Depth to groundwater is 100 m. This gives ample time for containment and clean up of any surface spillage.
- If there was any surface spillage, AWE would promptly implement spill containment and clean up measures to prevent it from seeping offsite and into subsurface water.

In its response, the Department of Water recommended the adoption of a monitoring program and a contingency plan to the EPA to reduce this risk.

Groundwater monitoring program an important risk management tool

Drover-1 Groundwater Monitoring Advice

Independent consultants

- Designed the monitoring program (Rockwater) reviewed by DoW
- Monitoring bore installed by licensed water bore driller (?)
- Conduct monitoring on a six-monthly basis (Gemec)

DoW reviewed proposed monitoring program

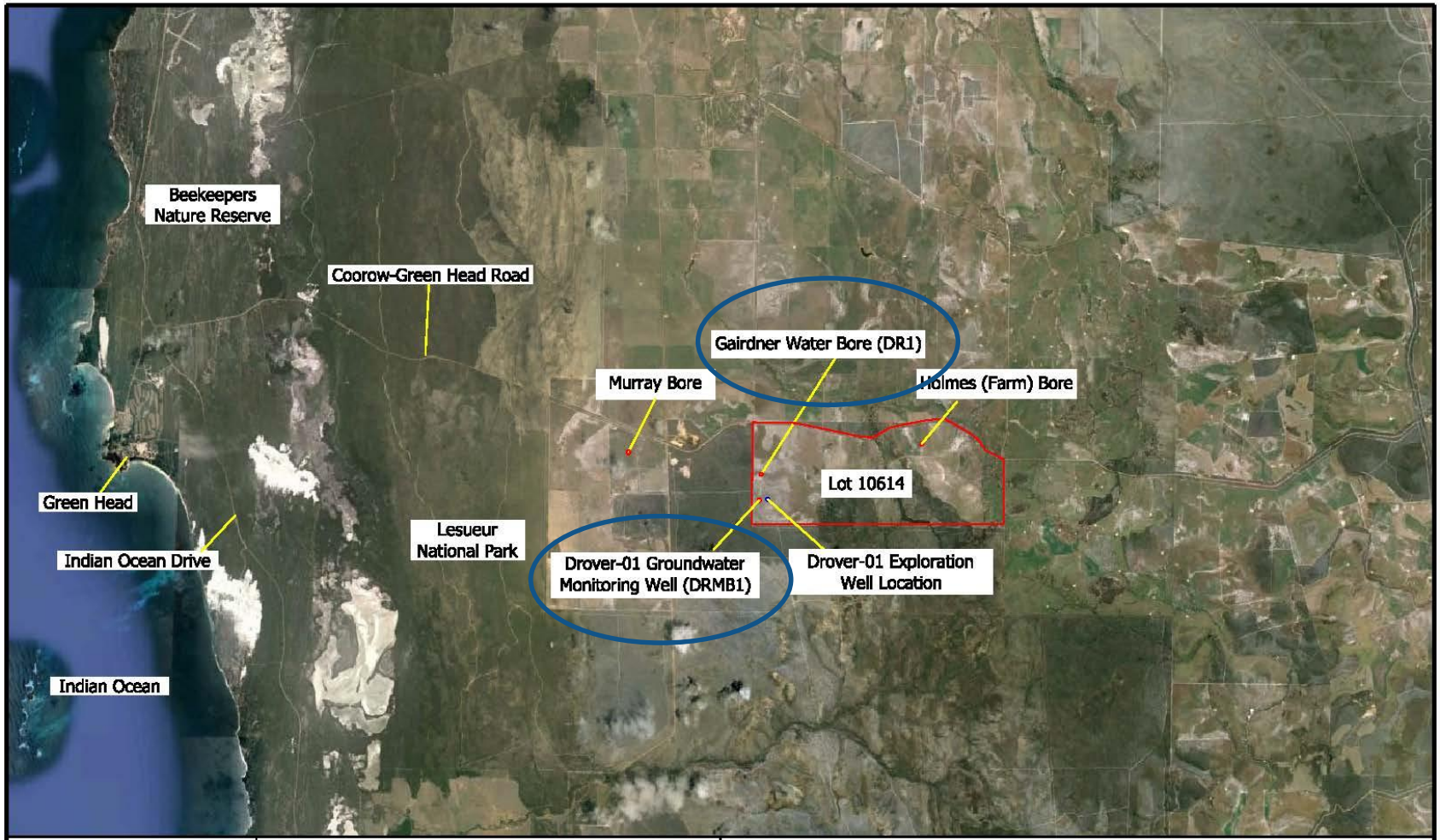
- Advised installation of a monitoring bore downstream
- Approved bore location and design based on site specific groundwater depth and flow
- Review monitoring results routinely

Drover-1

Groundwater Monitoring Details

AWE

Drover-01 bore locations



gemec
ENVIRONMENTAL CONSULTANTS
PO Box 89
Melville W.A. 6956
T: +61 8 9339 8449
F: +61 8 9339 0073
W: www.gemec.com.au

Water bore location
Lot boundary

0 1 2 3
Scale (km), approx.

Assumed Groundwater Flow Direction - Rockwater 2013

Regional Aerial Photograph (October 2013) Showing the Drover-01 Exploration Well & Groundwater Abstraction Bore Locations

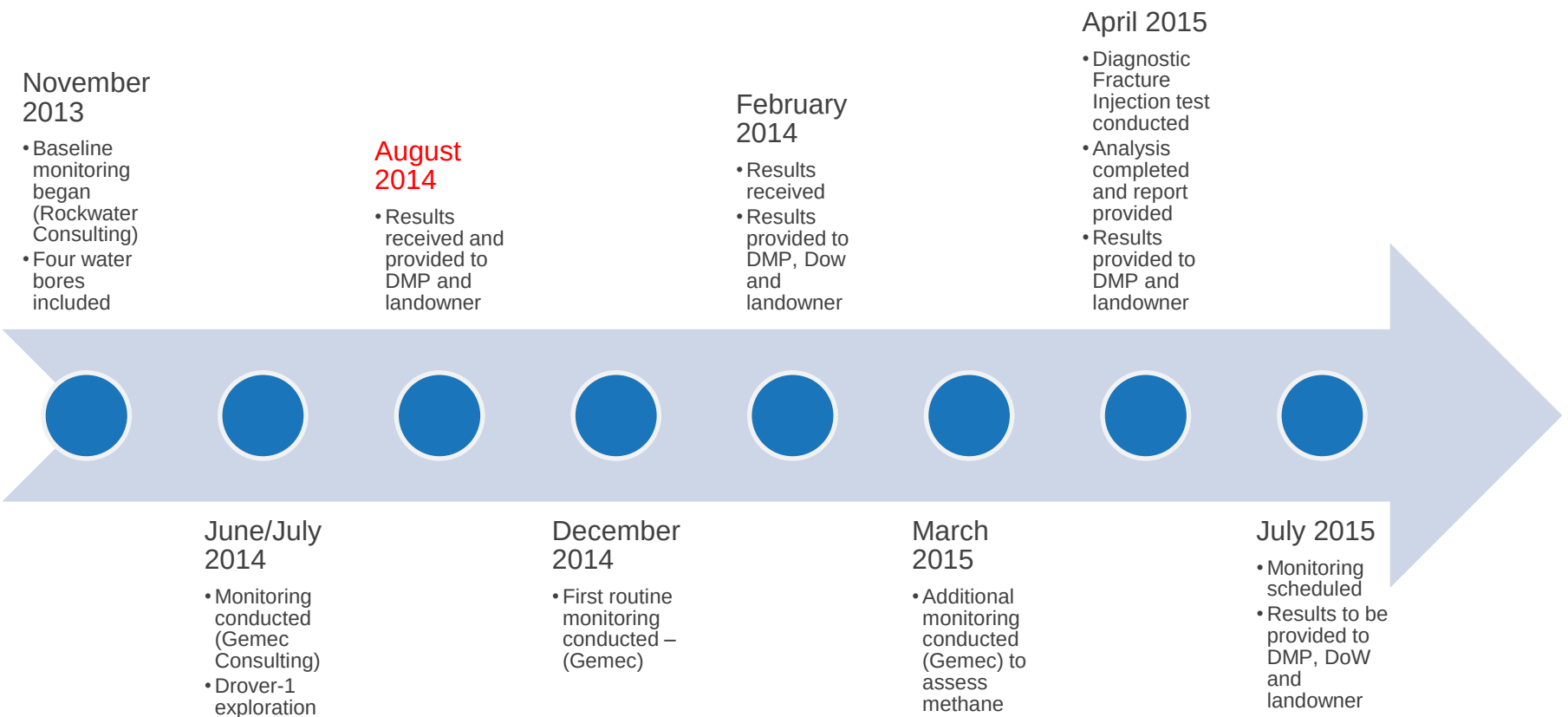
SOURCE: *Google Earth*

AWE Limited - Drover Site

Lot 10614 (9287) Coorow-Green Head Road, Warradarge, Western Australia

Drawn: SL	Date: 27.03.15	CHECKED RB	APPROVED RB	DRG No.	Figure 1
Scale: As Shown					

Drover-01 Groundwater Monitoring



Sampling consistently prior to drilling and following

Drover-1

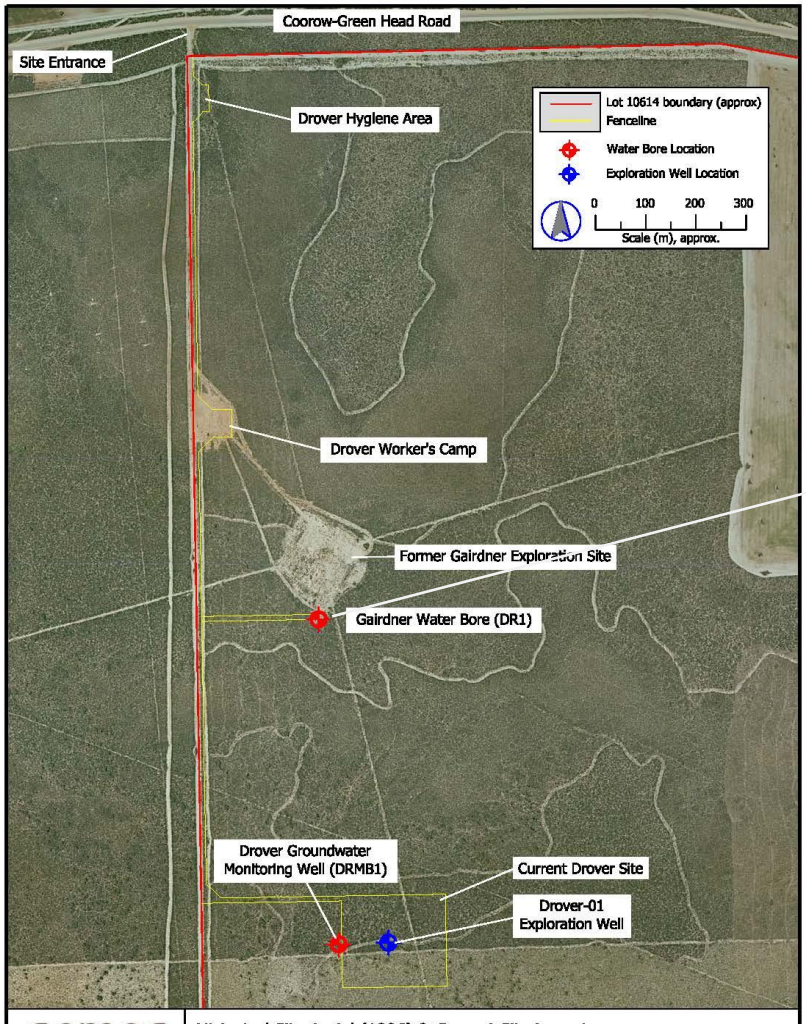
Recent monitoring results

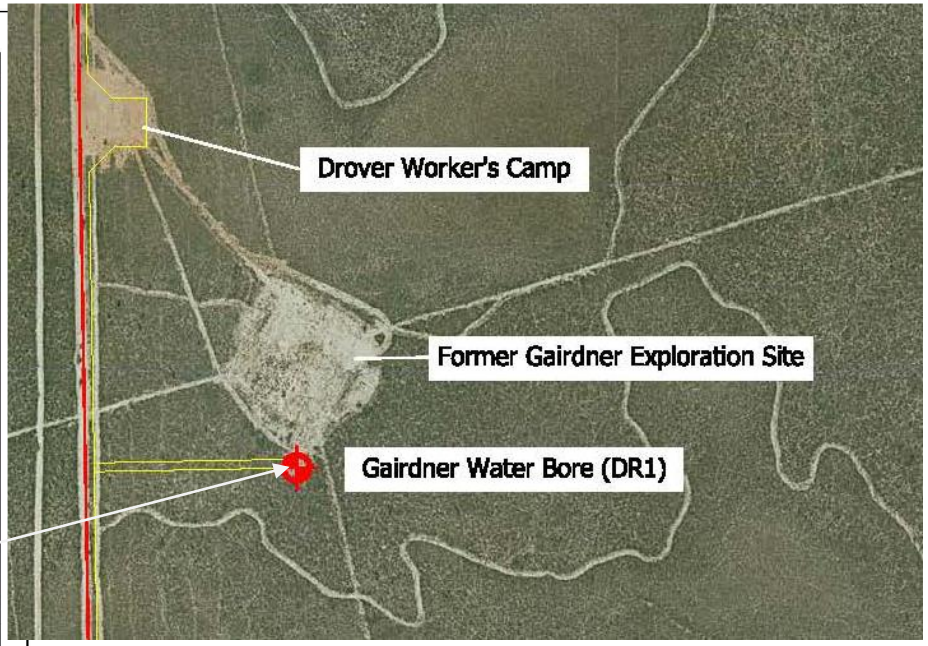
AWE

Recent Monitoring Results

- Preliminary results were provided in early February to AWE
- Most components tested at the four bores were in accordance with the baseline and previous monitoring results
- Results from two bores were different
  - Elevated concentrations of methane found
    - DR1 (4 mg/L)
    - DRMB1 (0.5 mg/L)
- AWE promptly advised DMP, DoW and the landowner of the initial results
- Independent consultant resampled the bores
- Analysis (stable isotopic) undertaken by University of Queensland to help identify the methane source and better understand the initial results
- Both bores were resampled March 2015

Potential Source





- Discussion with landowner (March) highlighted Gairdner-01 well mud sump as a possible source of hydrocarbon contaminants.
- Landgate aerial photo (1996) reveals well site immediately north of Gairdner water bore (DR1)

Methane isotope analysis

Background:

- Gemec commissioned University of Queensland (UniQuest) to undertake methane isotope analysis of samples collected from both bores.
- Dissolved methane can be of inorganic, microbial or mixed origin with the distinction made primarily on the basis of the stable isotope compositions of methane and associated groundwater.
- The carbon isotope differences between methane and CO2 and the hydrogen isotope difference between methane and associated groundwater may provide a better indication of the origin of the gases than the absolute carbon and hydrogen isotope values.

Methodology:

- Carbon, hydrogen and oxygen stable isotopic analyses were conducted using gas source isotope ratio mass spectrometry (IRMS) in The University of Queensland (UQ) Earth Sciences Stable Isotope Geochemistry Laboratory (UQ-SIGL).

Conclusions

- The methane found within DR1 and DRMB1 is of microbial origin
- The methane sources for each bore are not related, although both are linked to the biodegradation of hydrocarbon
- The source of TRH (Total Recoverable Hydrocarbons) within DRMB1 has been identified as from the drill muds and casing glue
- The TRH source within DR1 appears to be a result of the Gairdner exploration well activities, possibly an unlined mud sump buried on site

Based on the additional studies, Gemec concluded that:

The presence of hydrocarbons is not considered a result of AWE activities in relation to the drilling of Drover-01 exploration well.

Future plans

- Advise other stakeholders (ie CRG and Shire) of report findings
- Based on results and discussions with regulators, no further methane isotope analysis planned
- Continue six-monthly monitoring, including methane levels, at Drover-01 as per Environment Plan commitments
- Discuss any further steps when, and if, required

Supporting slides

As required

AWE

Results

DR1 - Methane concentrations similar to previous ~4,000 ug/L.
DRMB1 – Increase to 500 ug/L.

GROUNDWATER MONITORING EVENT
AWE LIMITED - DROVER-01 LOCATION
LOT 10614 (9287) COOROW-GREEN HEAD ROAD
WARRADARGE, WESTERN AUSTRALIA
MARCH 2015

Table 1: Historical and Current Groundwater Analytical Results - BTEXN, TRH, MTBE & Methane

Sample ID	Date	SWL (m btoc)	PID (ppm_v)	BTEXN						TRH				MTBE	Methane
				Benzene	Toluene	Ethylbenzene	m+p Xylenes	o-Xylenes	Naphthalene [1]	C6-C10 less BTEX	>C10-C16 less naphthalene	>C16-C34	>C34-C40		
DR1	13.11.13 [2]	103.880	NP	<1	**18**	**77**	**172**	**47**	<5	**150**	**120**	**390**	<100	<5	**15**
			Silica Gel Cleanup								<100	**290**	<100		
	10.02.14	104.084	-	<0.5	**2**	**21**	**18**	**9.5**	<0.5	**93**	**110**	<500	<500	<0.5	NT
	10.06.14 [3]	-	-	<1	**2**	**6**	<2	**3**	<1	<10	<50	<100	<100	<1	**48**
	17.12.14	104.086	0.0	<1	**6**	**13**	**20**	**7**	<1	**40**	**150**	**140**	<100	<1	**4000**
	11.03.15	104.227	2.9	<1	**9**	**37**	**71**	**20**	<1	**100**	**180**	<100	<100	<1	**3800**
	Dup 1			<1	**9**	**34**	**64**	**18**	<1	**93**	**160**	<100	<100	<1	**3500**
	RPD			NA	0	8	10	11	NA	7	12	NA	NA	NA	8
	Split 1			<1	**10**	**40**	**70**	**23**	<1	**67**	**90**	<100	<100	<1	**4000**
	RPD			NA	11	8	1	14	NA	40	67	NA	NA	NA	5
DRMB1	12.06.14	103.748	12.6	<1	<1	<1	<2	<1	<1	**360**	**150**	**120**	<100	<1	<5
			Silica Gel Cleanup								<50	**110**	<100		
	16.12.14	103.533	0.0	<1	<1	<1	<2	<1	<1	**210**	**220**	**190**	<100	<1	**160**
	11.03.15	103.558	-	<1	<1	<1	<2	<1	<1	**250**	**200**	**120**	<100	<1	**500**
Holmes (Farm) [3] Bore	21.10.13 [2]	-	NP	<1	<2	<2	<2	<2	<5	<20	<100	<100	<100	<5	<10
	10.06.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	**10**
	19.12.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	<5
Murray Bore [3]	21.10.13 [2]	-	NP	<1	<2	<2	<2	<2	<5	<20	<100	<100	<100	<5	<10
	19.12.14	-	-	<1	<1	<1	<2	<1	<1	<10	<50	<100	<100	<1	<5
Domestic Non-potable Use (NPUG)				10	25 [4]	3 [4]	20 [4]		NE	NE	NE	NE	NE	12 [4]	NE
Long-term Irrigation Water (LTV)				NE	NE	NE	NE	NE	NE						
Stock Watering (SW)				NE	NE	NE	NE	NE	NE						
Groundwater HSL-D (sand)				5000	NL	NL	NL	NL	NL	70					
Laboratory Limit of Reporting - MPL				1	1	1	2	1	1						
Laboratory Limit of Reporting - SGS				0.5	0.5	0.5	1	0.5	0.5						
Laboratory Lim															

Notes: all concen
77 sha
'NA' denotes not a
'NE' denotes scree
'NP' denotes data
'NL' denotes scree
'NT' denotes 'not
'RPD' denotes rela

1. nap
2. sam
3. grou
4. aes
5. con

DRMB1 – TRH concentrations chromatograms indicate source to be: Liqui-Pol (drilling mud) and Pipe master (PVC pipe cement)
DR1 – Possible source of TRH identified as Gairdner drilling mud sump.

Note: The sampling methodology has varied across the 5 GME's as outlined below:
13.11.13 – Airlift and bailer
10.02.14 – Low flow pump (methane not tested)
10.06.14 – Sampled directly from PVC pipe outlet at freshwater pond
17.12.14 - Low flow pump
11.03.14 - Low flow pump

Methane isotope analysis results

- Results indicate the dissolved methane in both wells is of microbial origin and linked to the biodegradation of hydrocarbon.

- The very different concentrations of BTEXN, C6-C36 TRH and methane in the two wells, together with the methane carbon and hydrogen isotope systematics indicate the presence of methane in the two wells is unrelated.

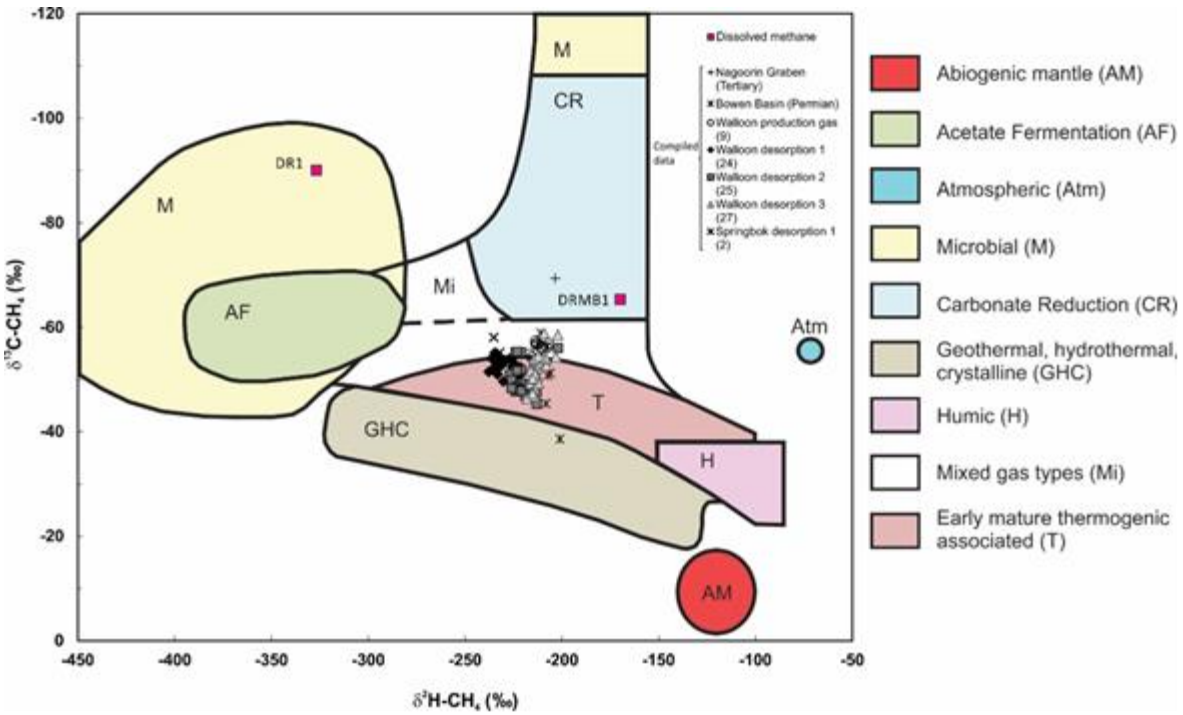


Figure 4. $\delta^{13}C$ vs $\delta^{2}H$ plot of CH_4 stable isotope compositions for dissolved methane samples DR1 and DRMB1. Results from coal measures in Queensland are included for comparison. Walloon Subgroup production gas data are from Draper and Boreham (2006). Walloon and Springbok desorption data from Hamilton et al. (2014). Bowen Basin production gas data are from Draper and Boreham (2006) and Kinnon et al. (2010). Nagoorin Graben data are from Draper and Boreham (2006). Fields on plot modified from Draper and Boreham (2006) after Whiticar et al. (1990) and Whiticar and Schaefer (2007).

Source: Groundwater methane isotope analysis, UniQuest, University of Queensland, 5 May 2015.

Drover-1 Shire of Coorow Community Reference Group

DMP: Community Partnership Awards

The journey of the Drover-1 Shire of Coorow Community Reference Group: from a place of mistrust, frustration and cynical attitudes to a position of trust, respect and finding common ground between the coastal towns of the Coorow community and AWE Pty Ltd. A humbling and fascinating story on how community empowerment in any project can be beneficial and rewarding for all stakeholders and projects.

"This community process was an eye opener. It was a great experience"

Bev Port-Louis (CRG Yued Aboriginal representative)

2016

Joint Submission: Drover 1 CRG and AWE Limited Pty Ltd

Submission Highlights

Foreword

At the outset, I was very sceptical about the then proposed **Drover-1 Shire of Coorow Community Reference Group (CRG)**. In the end, I was very pleased with the many positive outcomes achieved by the group. As a Shire councillor and community member, I served as a Steering Group member for the CRG from the first meeting in November 2014 until the end of 2015.

There were many things I liked about the CRG process. Firstly, the CRG gave us an independent, community body which allowed us to have our say about the Drover-1 Exploration Project (Project) and explore the key issues. Secondly, we were provided an independent resource which helped us design, facilitate and run the process of the CRG. This was invaluable as it enabled us to focus on the Project rather than the administration of the CRG. Finally, the outcomes. The unique process we adopted to run the CRG enabled us to learn about the Project through open, non-threatening dialogue with AWE and the various government agencies (DMP, DoW, DoH, CSIRO). This enabled us to identify and seek answers to key questions as well as obtain clarification and certain commitments concerning the Project.

We certainly did have our share of disagreements – especially in the early meetings. After all, we were dealing with a highly emotive issue – potential fracking. We also didn't solve everything in our journey and we didn't get everything we would have liked. But we absolutely had community empowerment and importantly we managed to have a significant positive influence on the Project as well as government department processes. This is something I did not think we would achieve before we started this journey.

I believe that the CRG process created real benefit and value for our community. I give enormous credit to AWE and the community for sticking with the CRG process and working together in a collaborative and empowering manner. Credit must also be given to the various government departments who sent guest speakers to inform the CRG on matters such as departmental policy and assurances to the community, risk assessment and their views of the science and engineering relating to Drover-1. I believe our CRG set a great example to future projects on how to place the community at the heart of a project and have open, two-way communication that fosters trust and respect between all parties.

I am very pleased to have been involved in the journey that was the Drover-1 Shire of Coorow CRG and I welcome a shared nomination with AWE for the DMP Community Partnership Award.

Guy Sims

(Coorow Shire Councillor, Drover-1 Shire of Coorow CRG Steering Group member)

Submission Highlights

CRG: Building Trust and Respect

2014 – Our beginning

"I was very anxious before the first meeting. I didn't know what to expect"

Bev Port-Louis (Traditional Owner representative)

"There was zero trust with AWE and there was a bit of emotion and heat at the first meeting"

Guy Sims (Coorow Councillor)

"I had initial doubts about the CRG process. I thought it was too touchy feely"

David Guise (AWE Regional Manager)

"I was very suspicious of most people at my first meeting. I tried to keep an open mind"

Tim Gilbertson (Community member)

"***When I heard that a CRG was being established, I found AWE scary and I was negative towards them"***

Jenny Griffiths (Community member)

2015 - Final thoughts

"The CRG process created value to our community and enabled it to grow. I take my hat off to AWE"

Bev Port-Louis (Aboriginal representative)

"We got the real facts from the process. The CRG created real value for the community"

Guy Sims (Coorow Councillor)

"The CRG process worked. We developed strong relationships and trust with the community"

David Guise (AWE Regional Manager)

"Top marks. Well informed. People had their say. We should use this process in the future. It's hard for anyone to hijack the CRG. DMP and DoW provided powerful information"

Tim Gilbertson (Community CRG member)

"We would definitely use this CRG process in the future for community engagement"

Jenny Griffiths (Community CRG member)

Submission Highlights

Summary

Drover-1 Exploration Project

The Drover-1 exploration well site is located on private, agricultural land in the Shire of Coorow, adjacent to the Lesueur National Park and near the Mount Peron Water Reserve (refer map). It is approximately 220 km north of Perth.

The well site was prepared for gas exploration in mid 2014 following initial stakeholder consultation undertaken in late 2013. The well site was successfully drilled in mid-2014 without any significant health, safety or environmental incidents.

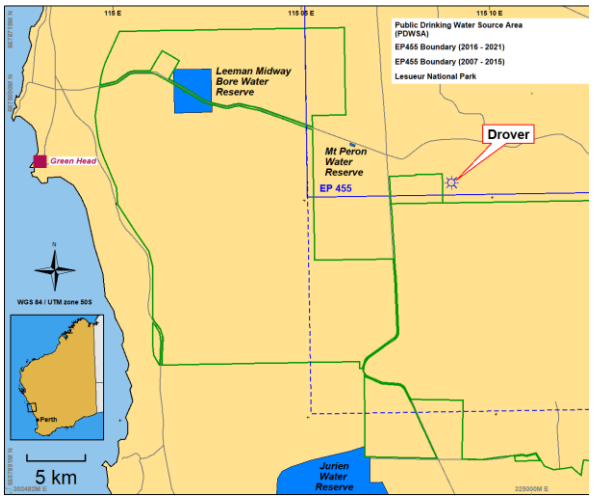


Figure 1: Location of Drover-1 (Source: AWE, April 2016)

Further information about the Project can be found here http://www.awemidwest.com.au/what-we-do/drover-1-exploration/

Following a series of tests between 2014 and April 2015, it was concluded that Drover-1 was unlikely to have a sufficient commercial flow rate of gas. As a result, the well site has been decommissioned and the site will be rehabilitated by mid-2016.

Community Reference Group (CRG)

Prior to the CRG being established, AWE had received all necessary approvals for the Project. However, due to a spike in community concerns arising in August 2014 around drinking water protection for the coastal towns of Green Head and Leeman, the approvals processes and potential lifestyle changes, an independently facilitated Community Reference Group (CRG) was established in late 2014 and met through to the end of 2015.

The purpose of the CRG was to place local community members at the centre of the consultation process with a clear line of communication between AWE and other stakeholders. The CRG also was designed to help reestablish trust and respect between community, industry and government.

All interested community members living and/or working or with other interests in the Shire of Coorow were welcome to attend meetings. This included Traditional Owners or their representatives with a current and/or historical connection to land in the Shire of Coorow. Meeting venues were shared between coastal towns within the Shire of Coorow at Green Head and Leeman.

Although independently facilitated, the CRG (refer Figure 2) was governed by a community selected Steering Group. Representation on the Steering Group included: local community and business owners (mainly from Green Head and Leeman), Traditional Owner (Yued), Shire of Coorow (staff and council) and NGO groups.

The independent resource was used by the Steering Group to assist in the design, facilitation and background administration of the CRG. This was helpful as it enabled community members to focus on the Project rather than the processes involved in running the CRG. The CRG funding was provided by AWE but not tied in any way to outcomes. The community was the monitor of independence of

the facilitator.

Once established, the CRG was open to invite input from external organisations as relevant. This included AWE, Conservation Council of WA, state government agencies such as Department of Mines and Petroleum, Department of Water, Water Corporation, Department of Parks and Wildlife, Department of Health and also academics and/or third party consultants to address technical or specialist questions.

Figure 2: Drover-1 Community Reference Group 2015 (Photo: with permission CRG)

Although uncommercial results from the exploration program led to AWE deciding to decommission the well site, post-CRG interviews with participants indicated that the CRG process was an overwhelming success and created real value for the community (Source: Independent Lessons Learned Report: Appendix A). Furthermore, all parties would definitely use this process again – they felt heard and respected and genuine human connections were made.

AWE

AWE is a medium size Australian energy company. AWE, and its predecessors, have been operating in the Mid West since the 1960s. All of AWE's operations staff live in the communities in which they operate. AWE does not employ FIFO employees in its Mid West operations.

Figure 3: Mid West AWE facilities employees

The Drover-1 well site is an exploration site in the Shire of Coorow located 17 km to the east of Green Head (Refer Figure 1). The well site was established to find more gas resources in the Mid West in order to complement those that the company already owns. Further information about the Project can be found here: http://www.awemidwest.com.au/what-we-do/drover-1-exploration/.

Selection Criteria

1.0 Selection Criteria: Leadership/Innovation in Engagement

1.1 How and when did the partnership come about?

Prior to the CRG forming, AWE had undertaken project planning that included stakeholder engagement activities for the Project. This had involved meetings with the Coorow council as well as council staff in 2013. AWE also hosted an open community information session, with assistance from the Coorow Council, and then circulated flyers and project update letters to shire residents at key project milestones. During this time, no significant concerns were raised about the proposed Project.

Leeman and Green Head are small coastal towns on the edge of a predominately agricultural shire. Green Head has a high demographic of retirees and holiday home owners. Both communities get their drinking water supply from the Mt Peron Water Reserve. Exploration has been occurring in the project area since 1978, however there has been limited resources activity in the Coorow Shire since 1990.

Following media focus on a group of concerned residents' views about potential contamination of their drinking water by the Project, a late agenda item was then raised at the August 2014 Council meeting. Council subsequently carried a resolution, which resulted in developing a Petroleum, Mining and Extractive Industries Policy, which specifically covered hydraulic fracture stimulation within the Shire. Meanwhile, further discussions were occurring between AWE, the Shire of Coorow and some community members. From this, AWE offered to fund an independent CRG *process* to identify and work through shared community concerns about the Project in the Shire of Coorow.

The independent CRG option was explored during a community meeting held in Greenhead on 8 October 2014 and a decision was made by those present to proceed with the offer. The first formal CRG was held on 5 November 2014 and the final official meeting held 9 September 2015. Informal relationships are continuing as rehabilitation of the well site progresses.

An independent facilitator was funded by AWE to design and facilitate the CRG process. The role of the facilitator was not tied to ensuring achievement of any particular outcome or agenda.

1.2 How did parties interact to promote inclusive dialogue and relationship building?

Formal Interactions

The CRG met to discuss progress against key issues and at key project milestones. From the beginning, all participants believed open dialogue was an important part of working through issues involving the Project. As such, invited guests such as AWE, Department of Mines and Petroleum, Department of Water, Department of Health and CSIRO were asked to come to certain meetings to listen to and understand the views of the community and respond to their queries. This exchange of information often involved presentations and the occasional use of physical materials to help demonstrate operational practice.

Conversations during each meeting were captured on a white board by the facilitator at the front of

the meeting using 'spider mapping' technique. This technique helped enable the threads of the conversation to be better tracked and for participants to see how their issues were being tracked and recorded. Points of difference were also captured during the meeting along with outstanding actions.

The initial meetings were focussed on establishing the CRG with AWE briefly introducing the Project and initial engagement activities. As meetings progressed and topics were discussed in more detail, AWE and other presenters were invited to stay for longer periods of time. Ground rules were established early in the CRG process based on respect and inclusion. The CRG participants welcomed Shire non-residents although they discouraged people from using the forum for their own purposes.

Draft minutes were prepared and distributed for comment by the independent facilitator to everyone attending meetings or wishing to be on the mailing list (Refer Figure 4). More than 200 people were on the distribution list which covered a wide range of organisations and locations. Final minutes with agreed corrections were then sent out, which enabled progress on key issues to be tracked.

The independent facilitator and the community also established a small Steering Group that could work and plan scheduling, preparation for, and notifying people about future CRG meetings. There was enormous power in the local community acting as a unified group for the CRG.

Figure 4: CRG relationships

Informal Interactions

CRG members advised that one of the most powerful relationship building mechanisms during the journey of the CRG was the informal meetings (Refer Appendix A). For example, site tours (refer Figure 5), post meeting catch-ups and afternoon teas were critical in developing human connections and understanding each other's point of view. These sessions significantly contributed to building trust and respect.

Supporting documentation

Supporting documentation such as minutes, ground rules, maps are available on request.

Figure 5: Site tours helped with relationship and trust building

1.3 How did the engagement practices demonstrate leadership, or an improvement to or establishment of innovative approach?

Classical Community Consultation

Classical community consultation in Western Australia has often placed the company at the centre of the consultation process. Under these consultation models, the company controls the project information and how it is communicated. It tends to be a one way flow of information. For example, often, a public meeting is held where the agenda has been set by the company without effective prior consultation with people who are most likely to be affected by the proposal. Such consultation prevents the community from effectively collaborating together to identify common issues and concerns as well as potential community benefits. This can lead to the community feeling like that they are isolated, voiceless and part of an administrative "tick and flick" exercise. This leads to everyone feeling frustrated.

Drover-1 Shire of Coorow CRG – a different approach

The Drover-1 Shire of Coorow CRG approach placed the community at the centre of the engagement process. It enabled the community to come together in a non-threatening environment to form a united collective and to articulate the important issues and what additional information they wanted about the Project.

The community was also resourced with an independent facilitator to help organise, design and facilitate the process. This enabled meetings to have an independent voice to keep the meetings on track and to hold all participants to account. It also prevented interest groups from manoeuvring the meeting agenda.

This innovative approach required a "leap of faith" by AWE and the community and required trust and respect between all parties in order to work.

In the oil and gas industry in Western Australia, such comprehensive consultation and resourcing for a single well exploration project is unusual and unprecedented. However, the extra effort given to this Project was in response to community interest in groundwater management aspects and reflects a genuine desire by all participants to improve the understanding of everyone's views.

1.4 How were the community's values integrated into the business operations?

Key community values and questions were identified early in the CRG meetings (Refer Table 1). These items led to a number of commitments being made by AWE and government agencies to

ensure that community values were being addressed by the Project. Examples of community values being heard and implemented into the project included (sourced from minutes):

Table 1: Community Values and Resolutions

Community Value	Resolution	Responsible	Status
Community empowerment around being heard on issues of concern	Offer and acceptance to support independently-facilitated and resourced Community Reference Group – Oct 2014	AWE/community	Agreed and implemented
Fracking concerns and perceived impacts on water supply	No hydraulic fracture stimulation of Drover-1 Well before April 2015 – Nov 2014 Presentations on fracking from DMP, DoW, DoH	AWE Government	Agreed Ongoing
Water supplies assured	Leeman and Green Head potable water supplies assured – Nov 2014	Department of Water	Agreed
Site Access	Agreed public access to site (subject to safety requirements) – April 2015	AWE	Agreed
Available information, trusted information	Agreed timely access to monitoring results - April 2015 Appointment of independent scientist – agreed but not pursued by CRG (not required) Information from government agencies	AWE CRG Govt agencies	Agreed Agreed Agreed
Future protection of sensitive water areas	AWE agreed to facilitate a CRG meeting with DMP and DoW to determine if Mt Peron water supply could be permanently removed from future exploration leases.	CRG	Meeting held

2.0 Selection Criteria: Benefits of the collaboration

2.1 What initiatives arising from the partnership have benefited the community?

This process benefited the community and AWE because it allowed the Project to be better shaped to match community expectations.

Dealing with Community Questions

The CRG process enabled the community to develop and track a list of questions that were specific to their needs and interests. For example, the following questions were asked and answered in the first CRG meeting in November 2014.

- How are leases assigned to companies like AWE to drill wells like Drover-1?
- What is AWE entitled to do at Drover-1 under its current lease or equivalent?
- What factors were considered by whom in the lead-up to and during the approval process for Drover-1?

New questions from the community continued to be identified and tracked via minutes of subsequent meetings. If questions were not addressed, then attempts were made at the subsequent meeting to respond.

Working towards commitments

The CRG process enabled the community to articulate and seek from AWE and the government a number of key commitments concerning the Project. Many of these commitments helped to shape the Project (Refer Table 1).

2.2 What are the specific beneficial outcomes for the community?

There were many beneficial outcomes that the community and AWE were able to obtain by participating in the collaborative CRG process. Many of these benefits are captured in Appendix A. Some of the significant benefits included:

- The community was able to establish a formal group that empowered them to have a high level of influence on the Project (refer section 2.1)
- The community was able to use an independent facilitator as a resource to design, organise and run its meetings. This enabled the community to focus on the Project rather than the administration of the CRG. This saved the community considerable personal time
- A high level of trust and respect was established between the community and AWE
- Stronger relationships and friendships were built within the community as a result of the CRG process
- The community was able to learn more about the broader onshore energy industry especially the regulatory processes involved
- AWE and government agencies were provided an opportunity to listen to the community in a non-threatening environment and were then able to provide tailored information based on the community concerns and issues
- At a regional and state level, AWE and government agencies were able to better understand the key community issues around the onshore energy industry. For example, a community top 10 questions list was developed for use in the Mid West region so that future projects can better understand and tailor their consultation to answering these 10 questions.

2.3 How was consensus reached on the value of such projects?

The CRG process generated a list of common questions and various commitments sought through consultation with the community. Each outstanding question and commitment was tracked throughout the CRG process (Refer 1.4).

3.0 Selection Criteria: Commitments to providing sustainable and enduring outcomes

3.1 How has the partnership made a positive sustainable difference for the community?

The CRG process has reconnected the community, government and AWE. At the heart of the process, human connections have been made with the core outcomes being mutual respect and trust. This is an outstanding achievement given the highly contentious issue of "fracking" in some sections of society. Other communities in the area are now considering using a similar CRG framework in relation to future industry projects and use the lessons learned (refer appendix A) and top 10 questions to enable community empowerment in any project.

The model applied at the Drover-1 Shire of Coorow CRG has been accepted as a new method for empowering community in project development. The same successful model is being considered for another AWE proposal in the Shire of Irwin in 2016. There have also been discussions for a broader Mid West regional CRG forum as a result of the Drover-1 CRG work.

The process was also the first time that many of people in the local community had an opportunity to work with and hear the views of a Yued Traditional Owner. The Yued Traditional Owners also felt that they had a voice and ownership in the process, which was a welcome outcome.

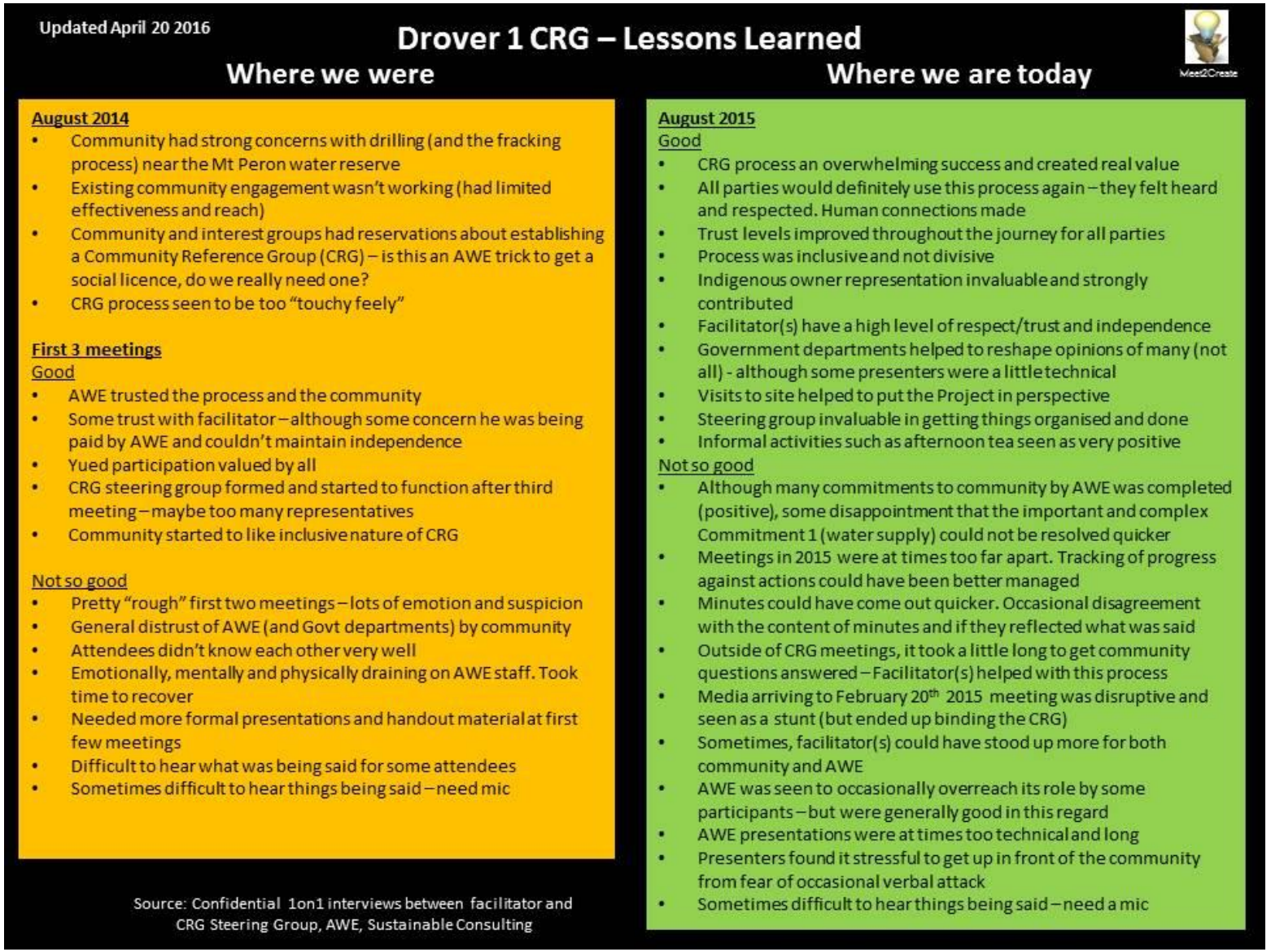
3.2 How will the collaboration benefit the community beyond the life of the resource project?

The CRG has set a benchmark for collaboration and community empowerment. In the future, it is highly likely that other resource companies will be encouraged to undertake a similar method of community engagement in the Mid West region.

Beyond the life of this Project, the CRG has set the scene for AWE's next exploration phase in the recently renewed permit area. The goodwill and trust that has already been established between community, AWE and government departments will facilitate engagement for further exploration activities AWE may propose to undertake.

3.3 How does the project extend beyond normal requirements and obligations?

In mid 2014, AWE had already received approval to commence its exploration activities associated with the Project. The company was not legally obligated to undertake any further community consultation processes. However, when there was a spike in community concerns in August 2014, AWE offered to place the community at the centre of the consultation process through establishing an independently facilitated CRG process. This "extra" community consultation is not traditionally part of an onshore energy exploration project. However, this step proved to be extremely beneficial to all stakeholders with relationships that are lasting beyond the timeframe of the project.


Updated April 20 2016
Drover 1 CRG – Lessons Learned
Where we were
Where we are today
Meet2Create
August 2014
• Community had strong concerns with drilling (and the fracking process) near the Mt Peron water reserve
• Existing community engagement wasn't working (had limited effectiveness and reach)
• Community and interest groups had reservations about establishing a Community Reference Group (CRG) – is this an AWE trick to get a social licence, do we really need one?
• CRG process seen to be too "touchy feely"
First 3 meetings
Good
• AWE trusted the process and the community
• Some trust with facilitator – although some concern he was being paid by AWE and couldn't maintain independence
• Yued participation valued by all
• CRG steering group formed and started to function after third meeting – maybe too many representatives
• Community started to like inclusive nature of CRG
Not so good
• Pretty "rough" first two meetings – lots of emotion and suspicion
• General distrust of AWE (and Govt departments) by community
• Attendees didn't know each other very well
• Emotionally, mentally and physically draining on AWE staff. Took time to recover
• Needed more formal presentations and handout material at first few meetings
• Difficult to hear what was being said for some attendees
• Sometimes difficult to hear things being said – need mic
Source: Confidential 1on1 interviews between facilitator and CRG Steering Group, AWE, Sustainable Consulting
August 2015
Good
• CRG process an overwhelming success and created real value
• All parties would definitely use this process again – they felt heard and respected. Human connections made
• Trust levels improved throughout the journey for all parties
• Process was inclusive and not divisive
• Indigenous owner representation invaluable and strongly contributed
• Facilitator(s) have a high level of respect/trust and independence
• Government departments helped to reshape opinions of many (not all) - although some presenters were a little technical
• Visits to site helped to put the Project in perspective
• Steering group invaluable in getting things organised and done
• Informal activities such as afternoon tea seen as very positive
Not so good
• Although many commitments to community by AWE was completed (positive), some disappointment that the important and complex Commitment 1 (water supply) could not be resolved quicker
• Meetings in 2015 were at times too far apart. Tracking of progress against actions could have been better managed
• Minutes could have come out quicker. Occasional disagreement with the content of minutes and if they reflected what was said
• Outside of CRG meetings, it took a little long to get community questions answered – Facilitator(s) helped with this process
• Media arriving to February 20th 2015 meeting was disruptive and seen as a stunt (but ended up binding the CRG)
• Sometimes, facilitator(s) could have stood up more for both community and AWE
• AWE was seen to occasionally overreach its role by some participants – but were generally good in this regard
• AWE presentations were at times too technical and long
• Presenters found it stressful to get up in front of the community from fear of occasional verbal attack
• Sometimes difficult to hear things being said – need a mic

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Baseline Characterisation and Monitoring Protocols for Development of Shale and Tight Gas Resources, Northern Perth Basin

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Report Number: EP167555

Final Report for the Northern Perth Basin Consortium

CSIRO
AWE Perth Pty Ltd
Latent Petroleum
Norwest Petroleum
Origin Energy
WA Department of Mines and Petroleum

10 May 2017

THE UNIVERSITY OF WESTERN AUSTRALIA

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Executive summary

The northern Perth Basin is highly prospective and offers significant potential for the development of shale and tight gas resources. This development requires stimulation methods involving fracturing gas-bearing, low permeability strata. Experience in shale and tight gas exploitation globally, particularly North America, has suggested that in some cases fugitive methane from the reservoir may migrate into near-surface environments including ground water or even atmosphere. While this occurrence is not typical and can be mitigated by good engineering practices, Australian communities, regulators and resource companies are aware of these potential outcomes.

As such, CSIRO, in collaboration with UWA and four onshore gas explorers (Latent Petroleum, AWE Perth Pty Ltd Limited, Origin and Norwest), and the WA Department of Mines and Petroleum (DMP) have established a coordinated Research Program into methods of establishing baseline values of environmental indicators and of monitoring techniques for these indicators prior to and during the development of tight and shale gas resources. The goals of this Research Program are to improve: 1) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact, and 2) understanding of suitable methods and protocols for establishing environmental baselines associated with tight gas development. The Research Program will consider monitoring aspects in four environmental domains: deep subsurface, shallow sub surface, surface and near-surface atmosphere.

The work described in this report represents the first project of the proposed Research Program. The most significant outcome is that this study represents the first attempt to gather ambient concentration values of methane in the groundwater and the near-surface in the northern Perth Basin. In most cases the data gathered in this study represents a "snapshot" of methane distribution across the area at the time of data gathering.

With respect to the higher level goals of the proposed Research Program, this project has concluded that:

1. Although there exists a good interpretation of regional flow in the northern Perth Basin, at this stage there is inadequate monitoring of the key aquifers for establishing baseline conditions.
2. Ambient levels of CH_4 across the basin were found to be consistent with the published values from atmospheric CH_4 monitoring stations. It is recommended that the impacts of stationary sources (facilities, towns, lakes and old petroleum wells) and from mobile sources, such as cattle, be investigated in future studies.

3. The concentrated soil gas flux survey found no anomalous readings and the data indicated the flux was being controlled by microbial action. Additional sampling and modelling is recommended.
4. Long-term monitoring of soil gas flux rates to understand seasonal variations are important to place the soil gas flux surveys in context and may provide the basis to allow predictions of changes in methane flux rates related to changing climatic conditions. During this project a system was developed to provide ongoing, continuous (every 20 minutes) measurements of soil gas flux. Due to ongoing system problems very little useful data was obtained, however, the system is now considered robust and following further testing will be ready for future deployment.

1 Introduction

Recovery of shale and tight gas in Australia offers significant new potential for both large and small resource companies. The process of extraction of gas from shales and tight reservoirs requires stimulation methods involving fracturing gas-bearing, low permeability strata. Experience in shale and tight gas exploitation globally, particularly North America, has suggested that in some cases fugitive methane from the reservoir may migrate into near-surface environments including ground water or even atmosphere. While this occurrence is not typical of shale and tight gas development and can be mitigated by good engineering practices, Australian communities, regulators and resource companies are aware of these potential outcomes. Western Australia's natural gas from shale and tight rocks industry is currently in the early stages of exploration and evaluation. As such, it is timely to initiate studies to understand the baseline levels of CH_4 that may be present across the northern Perth Basin. This will provide the initial data required to understand the controls on the system and develop monitoring systems to effectively and efficiently monitor changes that may occur over time.

As such, CSIRO, in collaboration with four onshore gas explorers (Latent Petroleum, AWE, Origin and Norwest), and the WA Department of Mines and Petroleum (DMP) have established a coordinated Research Program into methods of establishing baseline values of environmental indicators and of monitoring techniques for these indicators during the development of tight and shale gas resources. The goals of this Research Program are to improve: 1) understanding of suitable methods and protocols for establishing environmental baselines associated with tight and shale gas development, and 2) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact. The Research Program will consider monitoring aspects in four environmental domains: deep subsurface, shallow sub surface, surface and near-surface atmosphere.

The Project described herein represents the initial phase of this Research Program. The objective of this Project is to examine the three shallower domains of the subsurface: (groundwater), surface (soil gas) and the near-surface atmosphere. A sub-project involving a passive seismic survey is published as a separate report (Issa et al, 2016). The outcomes of this project will provide the basis for refining data collection and analysis methods for future projects aimed at achieving the high level goals of the Research Program.

The study consisted of four components and was intended to build on work undertaken by CSIRO in the Surat Basin through GISERA and other programs. The four areas of study and the objectives are:

i) Groundwater: a desktop study intended to understand the current state of knowledge of the hydrogeology within each of the permit areas and a review of the analyses and methodologies used by each

ii) Mobile CH_4 Survey: a mobile survey of background levels of methane across the study area

iii) Soil Gas Flux Survey: an intensive survey taken across one of the permit areas to measure the CH_4 flux

iv) Long-term Soil Gas Flux measurement: a semi-permanent installation to complement the soil gas flux survey by measuring the soil gas flux over an annual cycle.

The methodologies used in each component and the results are discussed below.

1.1 Study Area

The study area was constrained by the extent of the permit areas of the four consortium members (Figure 1). The permit areas attributed to AWE within the study area are all operated by AWE, however permits L1/L2 are jointly owned by AWE 50% and Origin Energy 50%. The permit areas were correct at the time of the study. The study area includes several small towns, including Dongara and Jurien Bay. The study area also includes several oil and gas fields and the Dongara Processing Facility (DPF). The land use is predominantly farming and scrubland and includes national parks and several lakes.

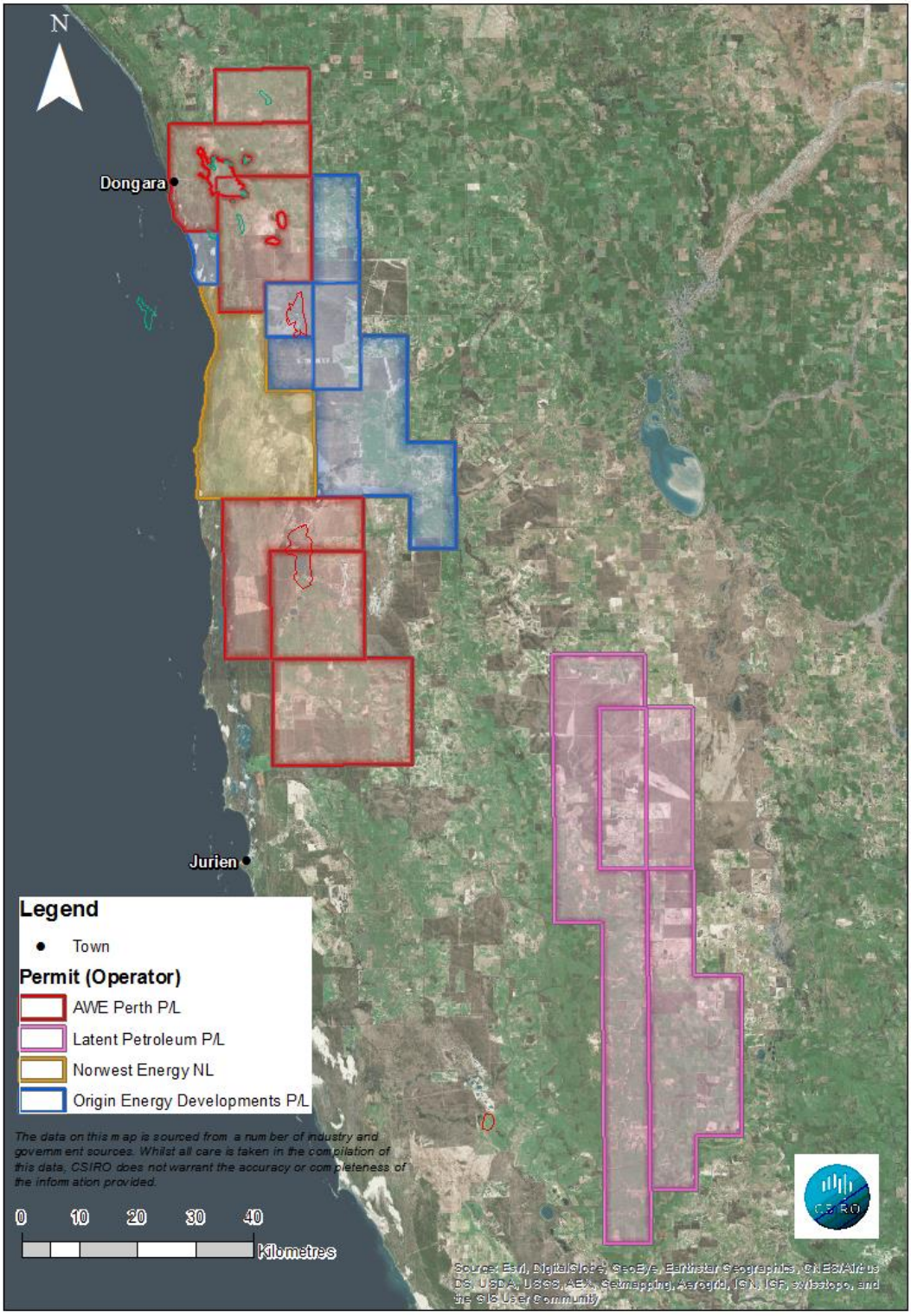


Figure 1 Study area constrained by the permit areas of the Consortium Members

2 Groundwater

2.1 Introduction

The objective of this component of the project was to review the current state of knowledge of the groundwater of the northern Perth Basin and to integrate where possible the regional hydrogeological interpretation with local data and with data being obtained by the consortium members. The study focused on groundwater data available within a 5 km radius of the permit areas. A working knowledge of the aquifers within this area is assumed.

2.1.1 Regional Information

The WA Department of Water (DoW) requires that all bores have a work approval and are registered, regardless of the intended purpose. Under WA's *Rights in Water and Irrigation Act 1914, Rights in Water and Irrigation Regulations 2000 and Water Services Act 2012*, a water access licence is required to extract water for all consumptive purposes except for stock and domestic purposes. The data from these bores is maintained in an online database, the online Water Information Reporting tool (WIR), including site details, water-level and water quality. In addition, the DoW is finalising a report on hydrogeological and groundwater resources for the northern Perth Basin (Department of Water, 2016), with the objective of compiling and analysing hydrogeological information and knowledge reported in various public and private reports and databases. Under a restricted access license agreement, the DoW has supplied CSIRO with ArcGIS files of the figures reported in the northern Perth Basin Bulletin and permitted use of these figures in the current report. However, these ArcGIS files cannot be distributed to any third party without further licensing from the DoW. The datasets used for generation of figures in the northern Perth Basin report have undergone rigorous screening and analysis by DoW and represent the best available interpretation of the groundwater regime of the northern Perth Basin, Autumn, 2007.

CSIRO conducted a search of the WIR online database (DoW, 2016) and identified 1896 registered bores located within 5km of the permit areas of the consortium members (Table 1). A hydrogeological study requires water-level and salinity data and each data point must be associated with an aquifer to be useful. Of the bores identified within the area of interest, 1383 have either water-level data (1080), salinity data (1193) or both (896). Of these, only 231 have a designated aquifer. However, a significant number of the remaining bores had construction data available (i.e. either screened interval depth or bore total depth). A methodology was developed to assign the data in these bores to an aquifer. The methodology is described below and resulted in an additional 890 bores being assigned a designated aquifer. Figure 2 and Figure 3 demonstrate the distribution of bores with water-level or salinity data, respectively, after the application of the methodology.

According to the WIR, the current status of these bores is largely unknown. Of the original 1896 bores, only 153 are designated as “Operational”, while the status of 1736 bores is “Unknown” (Table 2). The construction date associated with these bores also varies from 1900 (likely a default value) to 2014. The uncertainty associated with the status of these bores illustrates the difficulty of maintaining such a large database and demonstrates why a rigorous QC system is required to analyse the datasets.

Table 1 Summary of bores with useful data (source: WIR database)

	Number of records
Bores located within 5 km distance	1896
Bores with water-level, salinity data or both	**1377**
Bores with known aquifer information	231
Bores with construction data	890
Total Number of bores available for analysis	**1121**
Bores with no aquifer and insufficient depth data	256

Table 2 Status of groundwater bores (source: WIR database)

Status of bores	Number of records
Abandoned	1
Decommissioned	1
Non-functional	4
Not operating (historical)	1
Operational	153
Unknown	1736

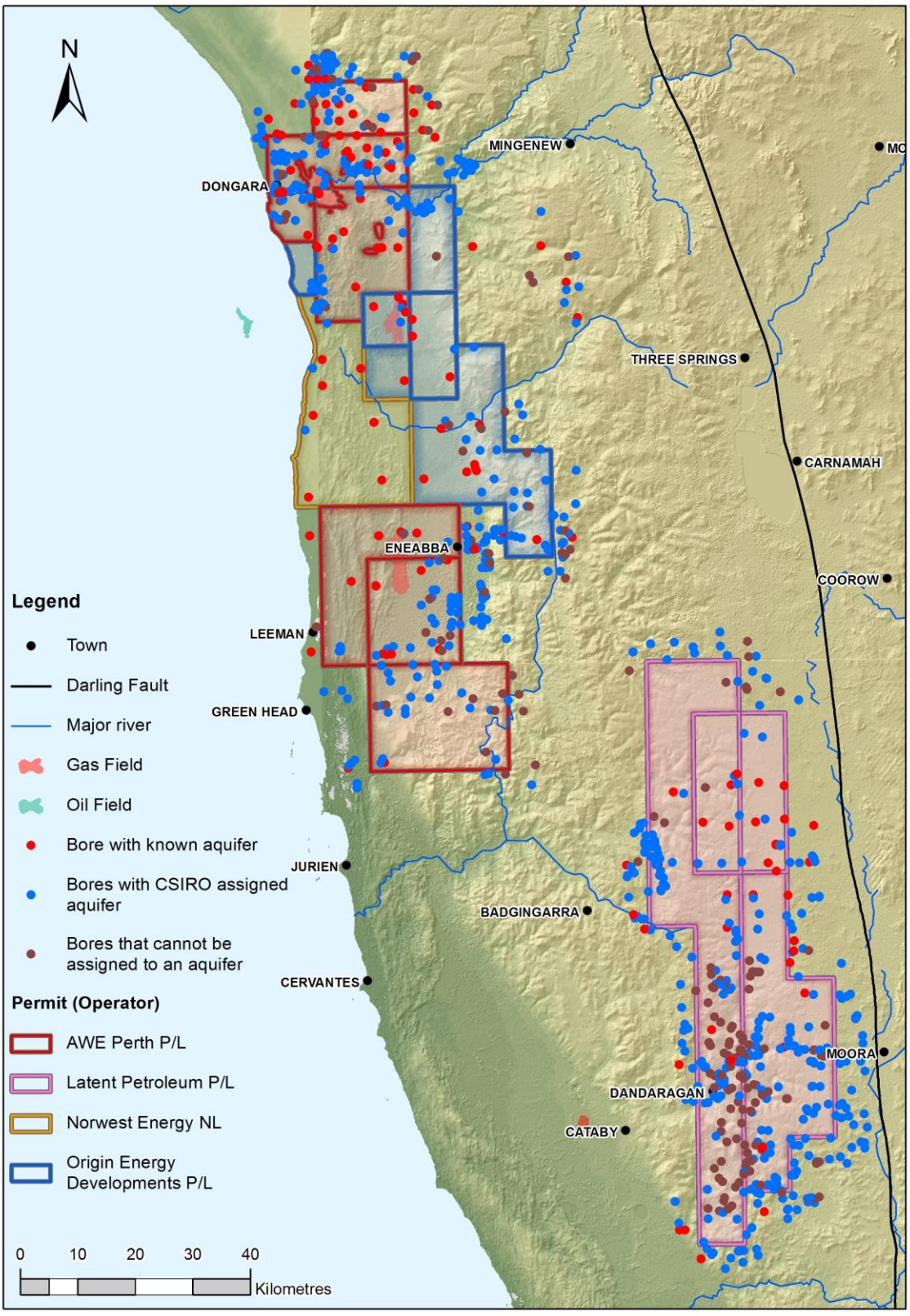


Figure 2 Location of groundwater bores in WIR database with water-level records within 5 km radius of permit areas.

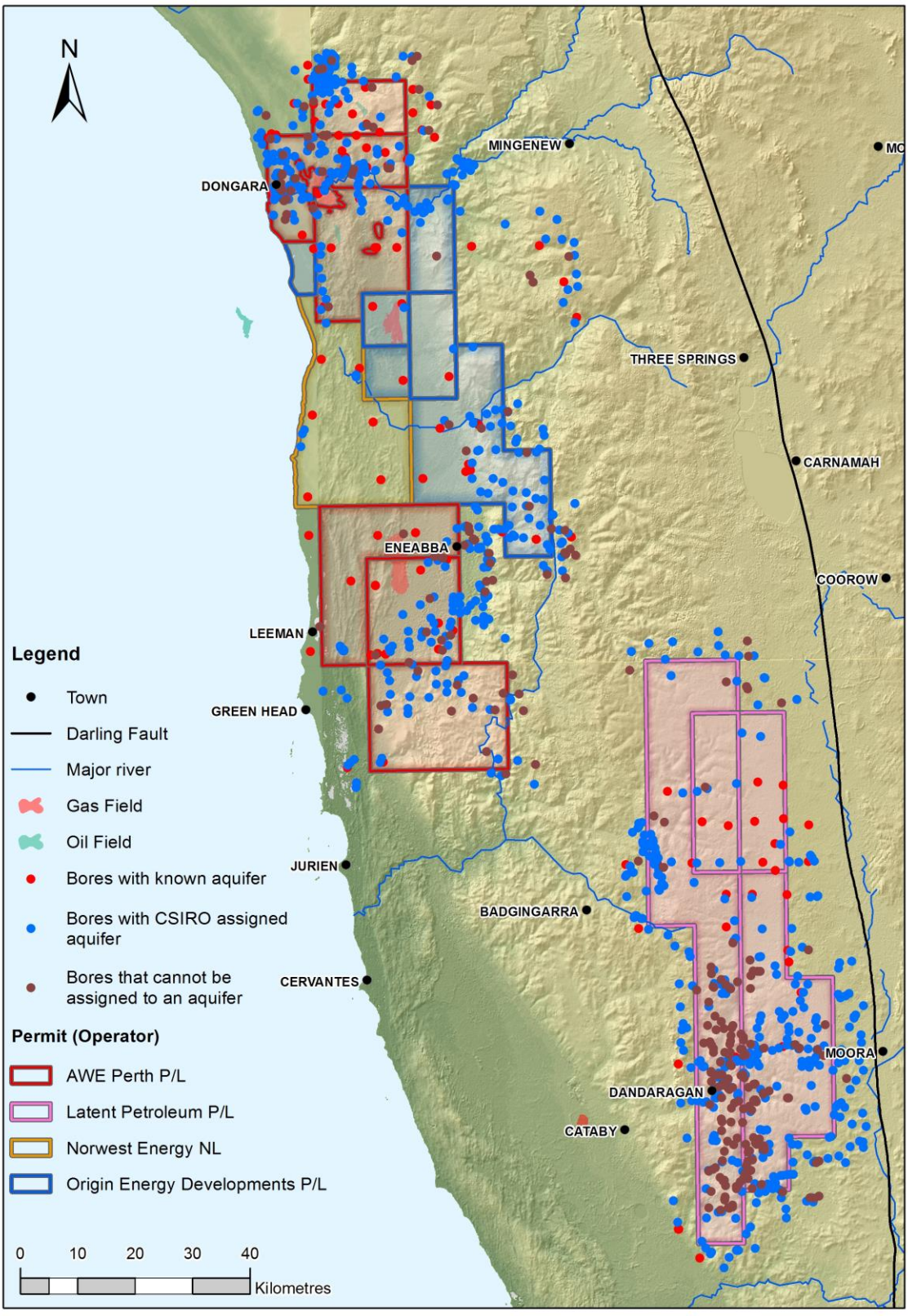


Figure 3 Location of groundwater bores in WIR database with salinity records within 5 km radius of permit areas

2.1.2 Localised data from consortium members

In the WIR database there are 10 groundwater and 7 salinity readings from 15 groundwater bores within the permit areas (2 AWE bores, 1 Latent Petroleum bore, 1 Norwest Energy bore and 11 Origin Energy bores) were available (Table 3). Figure 4 shows the locations of the consortium members (AWE and Latent) groundwater bores.

Data was supplied by AWE, Origin Energy and Latent Petroleum. In addition, Latent Petroleum provided a report commissioned from RockWater (2013). In the report, a MODFLOW groundwater model was developed to assess the potential impacts on the groundwater systems from the Warro Project activities and to inform a groundwater monitoring system. The results from the report indicate that there will no impact on the Yarragadee aquifer and a minor impact on the Parmelia aquifer due to Latent Petroleum's planned activities at the Warro Project area.

Unfortunately, we considered there was insufficient data to undertake a review of sampling protocols and reporting with respect to current regulations, as originally proposed. As an alternative, we carried out a review of the current state of the wells and monitoring data within the permit areas from the DoW database.

Table 3 Summary of monitoring data supplied by consortium members

Consortium Member	Number of bores	Reported Aquifer(s)	Groundwater-levels monitoring period	Salinity monitoring period
AWE	25	Yarragadee (19 bores); Eneabba (1 bore); Lesueur (3 bores); Bores with no co-ordinates (2 bores)	2008-2015	2007 - 2015
Latent Petroleum	14	Leederville – Parmelia and Yarragadee (based on RockWater, 2013)	No information	2014
Origin Energy	19	No information	No information	2011-2014

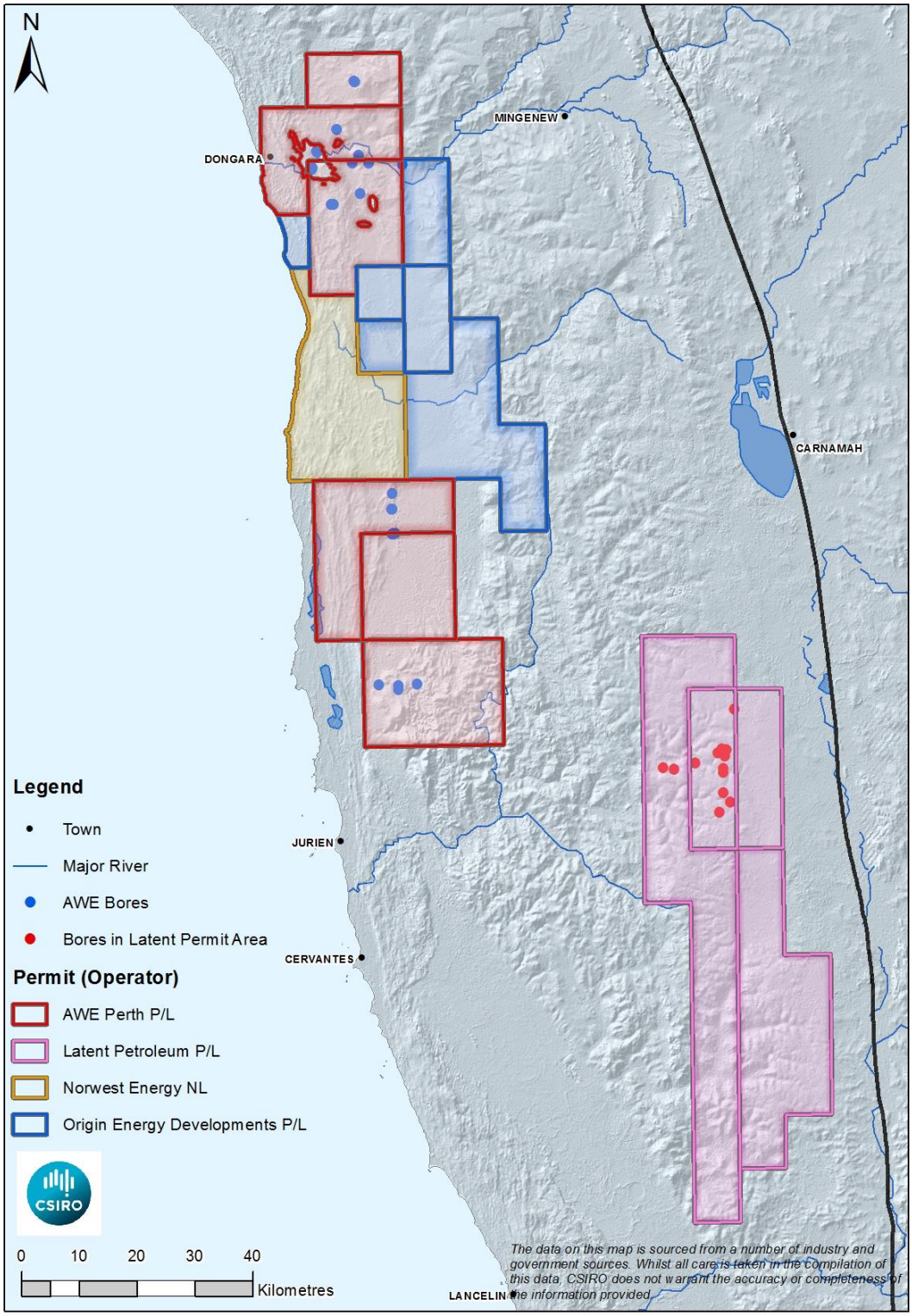


Figure 4 Location of consortium members permit areas and groundwater bores where data was supplied

2.2 Methodology

2.2.1 Methodology to assign aquifers

The methodology to assign an aquifer to bores with water-level and/or salinity data compared the total depth (or screened interval) of a bore relative to the nearest overlying aquifer surface (Figure 5). Therefore, the first step in the methodology was to create surfaces of each key interval from the available information and the second to run the comparison and assign the aquifer according to a set of parameters described below.

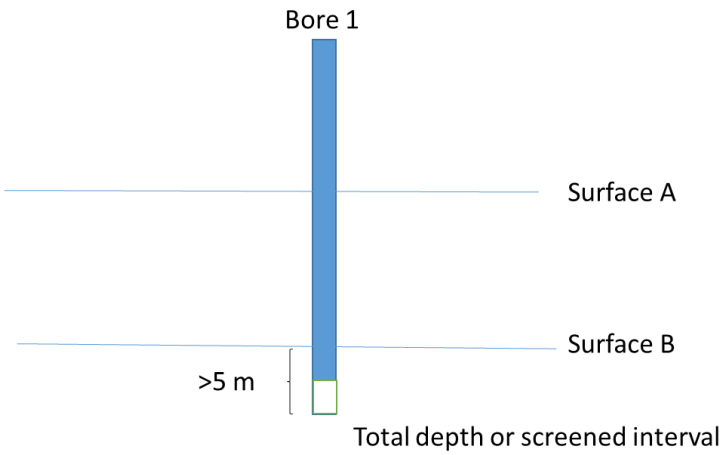


Figure 5 Schematic representation of methodology to assign aquifers

Geological Model Building

The DoW provided basal elevations and structural contours (isopachs) for 14 geological formations. These were used to create surfaces for each formation using various geoprocessing tools available in ArcGIS (version 10.3) software, as described below (Figure 6). It is assumed that reader has some familiarity with ArcGIS software. Details about the accuracy of the data are provided in Appendix A.1.

The base elevation/structural contours for a given formation (e.g. Yarragadee) were added to ArcGIS along with the fault networks present at the northern Perth Basin area. The contours were examined for continuity and to reflect any faulting in the area. Where discontinuities in the contours due to faults were observed the contours were split into individual fault blocks (Figure 6 (1)) for further processing. Once all the contour blocks were created, a rectangular raster surface for each formation was generated using *Topo to Raster* tool in ArcGIS (Figure 6(2)). The base polygon (Figure 6(3)) which covers the extent of the contours was split along the lines of the contour blocks and each individual polygon converted into a raster mask using *Polygon to Raster* tool (Figure 6(4)). The raster mask is then used to clip the generated formation surface to match the base polygon (Figure 6(5)), in order to generate an accurate extent of the contour block. After generation of the

surfaces for the individual contour blocks, formation surfaces are then mosaicked together (Figure 6(6)) using the *Mosaic* tool in ArcGIS software.

The generated surfaces were stacked based on the geological age as reported by Davidson (1995).

Table 4 presents the geological surfaces generated using the base elevation datasets provided by DoW.

Table 4 Geological surfaces generated using the DoW datasets

Stratigraphy	Represented in model	Represented as single layer or combined with other layer
SRTM/DEM	**Yes**	**Single layer**
Superficial formation	No	Single layer
Molecap Greensand	**Yes**	**Single layer**
Henley Sandstone	No	Single layer
Coolyena	No	Single layer
Leederville formation	**Yes**	**Single layer**
South Perth Shale	No	Single layer
Gage Sandstone	No	Single layer
Warnbro group	No	Single layer
Otorowiri formation	No	Single layer
Parmelia Group	**Yes**	**Single layer**
Yarragadee Formation Unit A	**Yes**	**All the four layers are combined as single layer in model**
Yarragadee Formation Unit B	**Yes**	
Yarragadee Formation Unit C	**Yes**	
Yarragadee Formation Unit D	**Yes**	
Lesueur Sandstone	No	Single layer

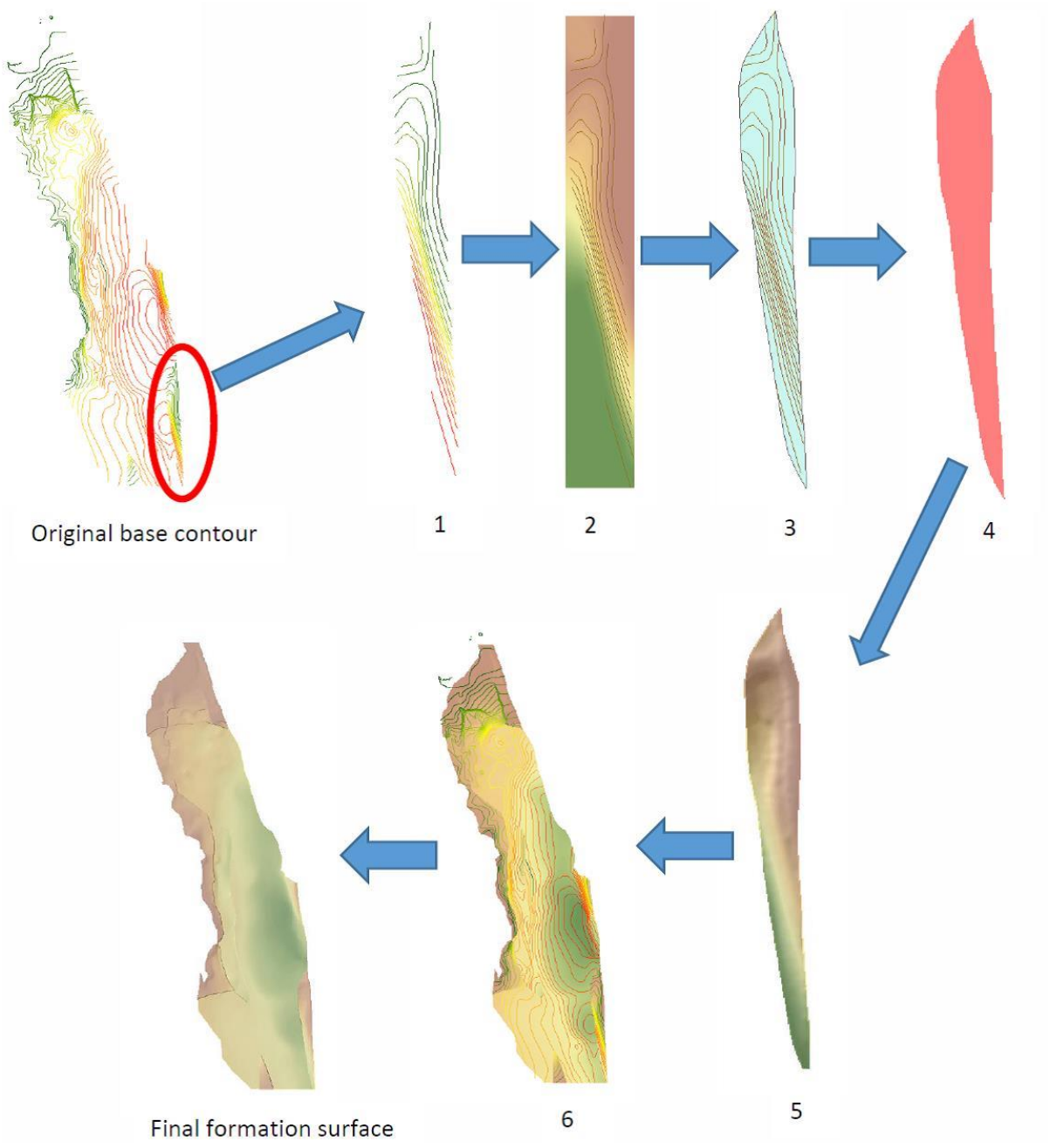


Figure 6 Methodology to generate formation surfaces

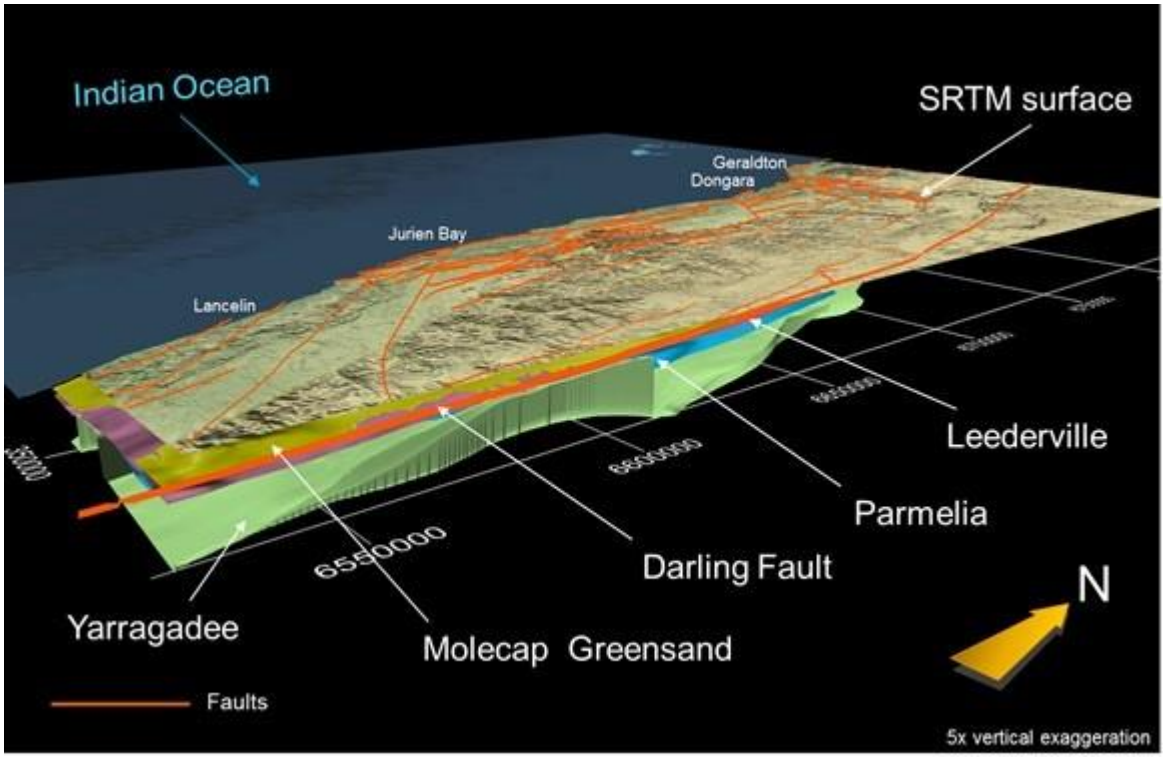


Figure 7 3D view of stratigraphic model generated for the northern Perth Basin

Assigning aquifers to the additional bores

The methodology was only applied to those bores with construction information (either screened interval or total depth) and water-level or salinity data. For each bore, an aquifer was assigned according to the following assumptions:

1. If there is no screened interval length, it is assumed to be 5 m and located at the bottom of the total depth of the bore
2. any bore with a screened interval (reported or assumed) penetrating a mapped formation/aquifer more than 5 m is extracting the water from that aquifer, and
3. any bore penetrating a mapped formation/aquifer less than 5 m is assumed to be extracting the water from both formations and not used in the analysis

The assumptions may not hold in all cases, so the classification is indicative, rather than definitive. Note that a longer interpretation of the screened interval or a requirement of a penetration greater than 5m will reduce the number of bores.

Nevertheless, application of the methodology significantly increased the number of bores with an assigned aquifer from 231 to 1,121. The distribution of bores within each aquifer unit is shown in Table 5 and Figure 8. The method was applied to each of the five aquifers, however, only the key Leederville-Parmelia (Figure 9) and the Yarragadee aquifers (Figure 10) are discussed here as they are the target aquifers for the AWE and Latent Petroleum

tight gas exploration activities. The aquifer extent in both figures is as defined in Department of Water (2016).

The additional bores identified in the Leederville – Parmelia aquifer are distributed largely to the east of the permits areas, but extend both north and south. The additional bores in the Yarragadee aquifer are concentrated primarily to the north and west of the permit areas. There are no additional Yarragadee bores in the south east part of the study area.

Table 5 Reclassification of groundwater bores

Aquifer	Number of bores		Number of bores having potentiometric head records	Number of bores having salinity records
	WIR database	After GIS analysis		
Superficial and Base of Superficial formation	44	423	313	363
Leederville – Parmelia	47	217	185	179
Yarragadee	93	407	349	339
Cattamarra- Eneabba-Lesueur	47	74	57	50
Total	231	1121	904	931

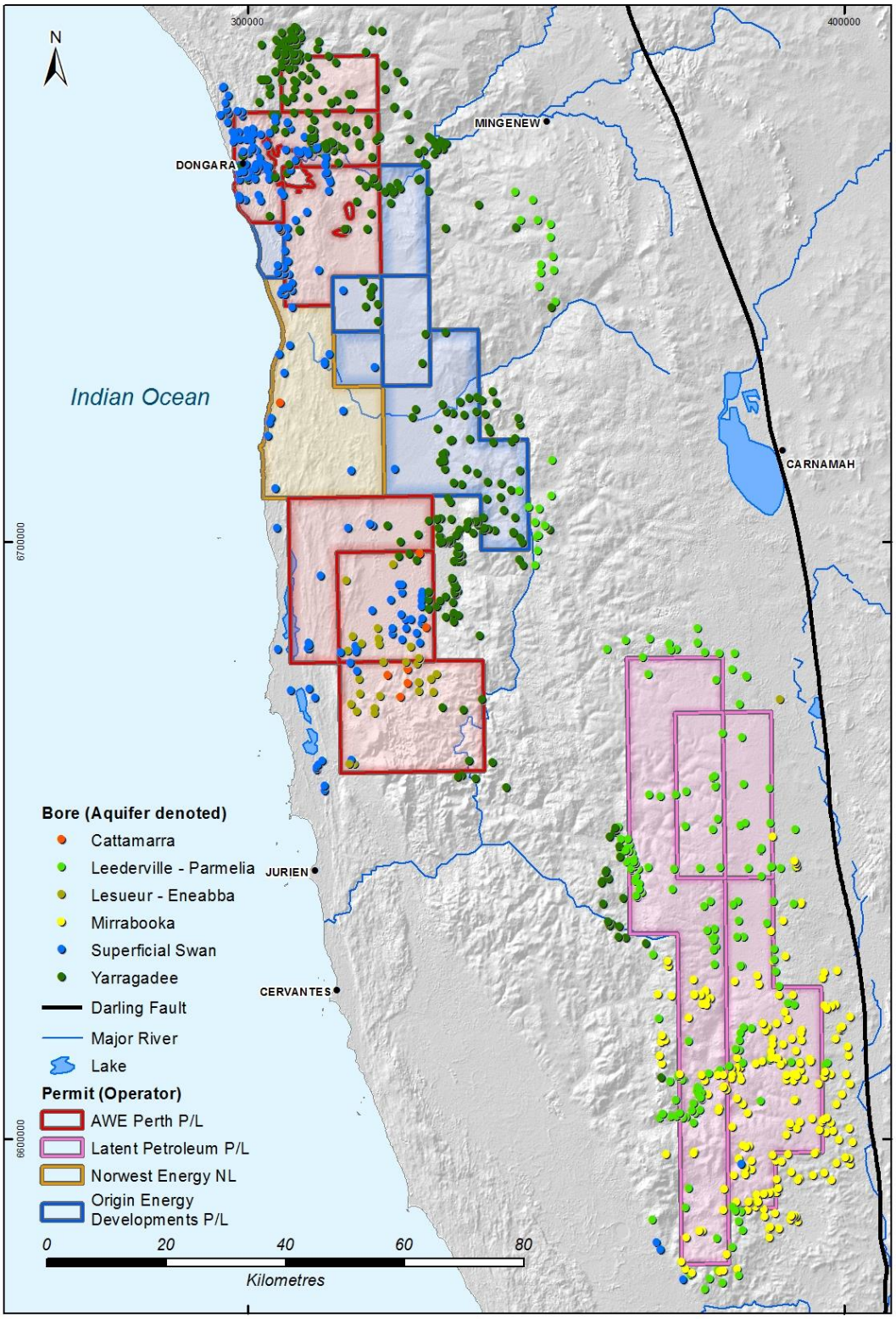


Figure 8 Distribution of bores within each aquifer

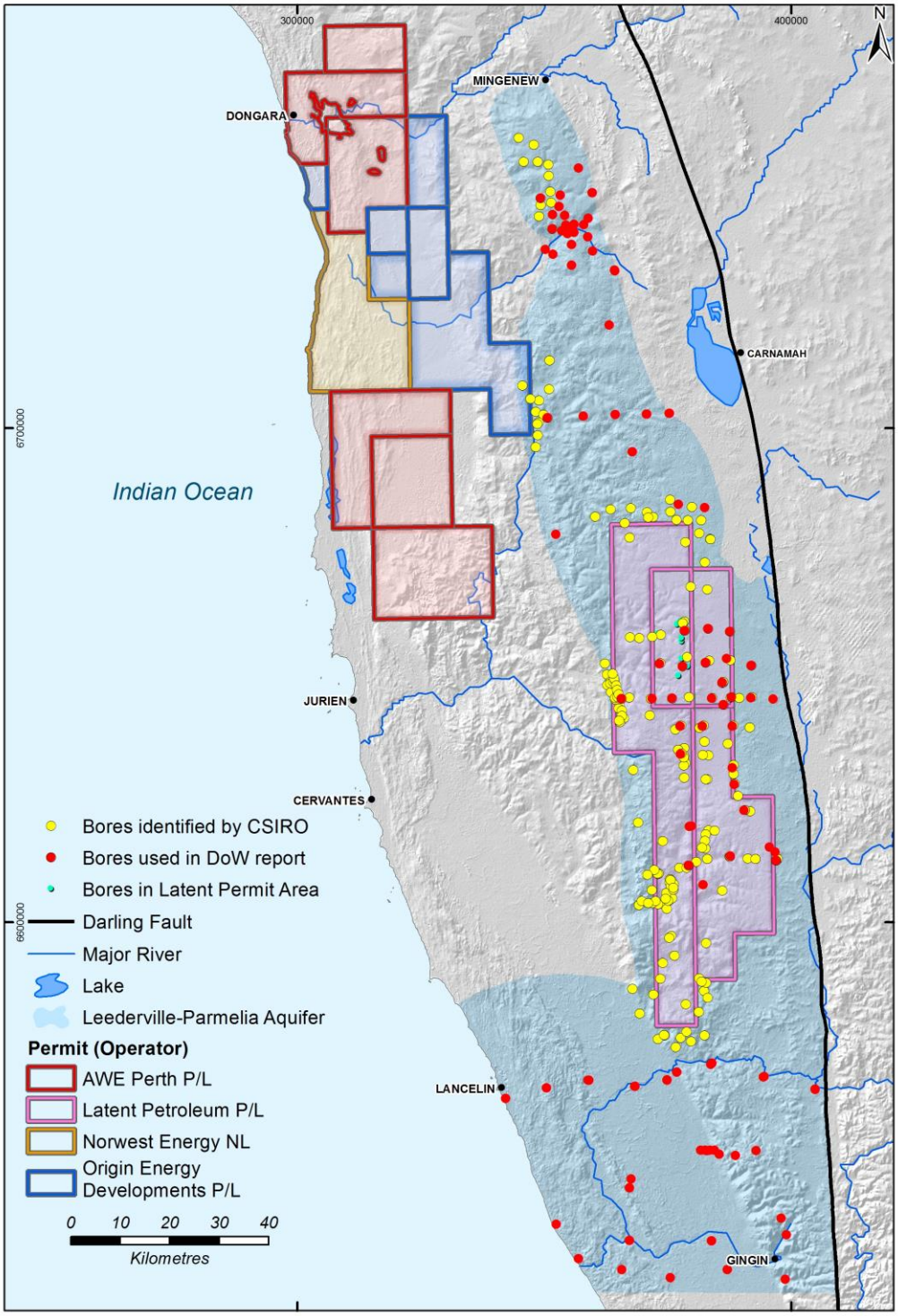


Figure 9 Bores located in the Leederville – Parmelia aquifer

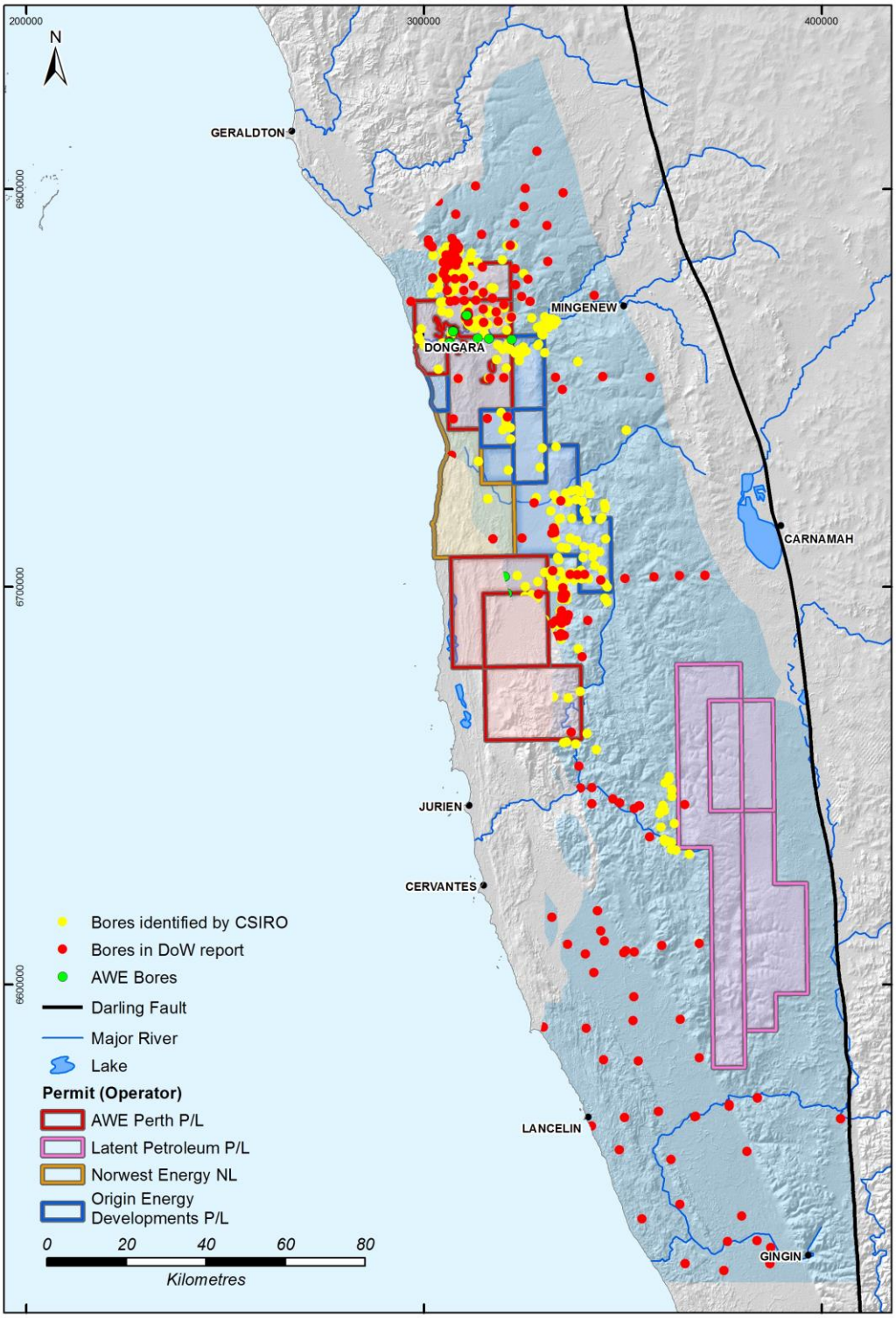


Figure 10 Bores located in the Yarragadee aquifer

2.2.2 Potentiometric head calculation and contour generation

There were four types of water-level measurement types recorded in the WIR database. For this data to be useful all measurements must be relative to a consistent datum, standard meters above Australian Height Datum (mAHD). Once in this format, the data can be used for trend analysis and for conversion to potentiometric head data. The potentiometric head data is then used to generate contours to determine the rate and direction of groundwater flow.

The four water-level measurement types and their application are:

i) static measurements from water-level measurement instruments; these were converted to mAHD (metres relative to Australian Height Datum) using the topography generated through the 3D modelling and used in the analysis

ii) water-levels reported in terms of mAHD; these records were used directly as reported

iii) Standard Level Elevation (SLE); this data format was used until 1998 and was discarded after 1998. There were 3812 groundwater-level records from 30 bores reported with respect to local (historical) datum, Standard Level Elevation (SLE). SLE is a non-standard datum and was used in past to avoid negative groundwater-level values. It requires local (site) topographic knowledge to converting these values to a standard datum value (mAHD). Conversion of SLE to mAHD is outside the scope of this project, therefore, these groundwater-level readings (3812) and the associated bores were not considered for the analysis

iv) datalogger readings reported as daily minimum, maximum and mean values. Only the only daily mean values were considered. During 2001-2016, there were 86,916 monitoring records obtained from data loggers, of these 28,972 were daily mean values.

The preferred method to present and analyse trends is to consider seasonal trends, i.e. the data should reflect both the minima (end of summer) and the maxima (end of winter) values. However, in this case there were insufficient monitoring records to produce meaningful results. Instead, the data from each bore for a specific year was averaged to create a yearly mean value. The yearly mean value was then used in the analysis. The data varied from one to two measurements for all bores in Leederville-Parmelia aquifer, with an exception of one bore which had 346 monitoring records for the 2015 monitoring year. For bores in the Yarragadee aquifer, monitoring records varied from one to 370 per year.

Based on the additional data,

- a new set of potentiometric head contours for each aquifer (Superficial, Leederville-Parmelia, Yarragadee and Cattamarra-Eneabba-Lesueur) from the year 2010 were generated (Table 6), and

- water-level trends over time for bores with data from 2007, 2010, 2011 and 2015 for the Leederville-Parmelia and Yarragadee aquifers were examined

The same process could not be applied to the salinity data as there was insufficient data generated after 2000 for either trend analysis or contouring.

Table 6 Summary of data from 2010 used to generate new potentiometric head contours

Aquifer	Number of bores		Number of potentiometric head records (calculated)		Direct (field) potentiometric head readings
	WIR database	After GIS analysis	WIR database	After GIS analysis	
Superficial and Base of Superficial formation	22	23	421	422	42
Leederville – Parmelia	28	28	47	47	50
Yarragadee	67	71	1492	1959	161
Cattamarra- Eneabba-Lesueur	18	18	41	41	31

To create the potentiometric head contours for an aquifer, a geo-referenced Surfer grid file is generated using default Kriging interpolation parameters. The Surfer grid files are exported to ArcGIS software and a set of potentiometric head contours generated using the *Contour* tool. The contours were clipped to the aquifer shapefile provided by DoW.

2.3 Results

The additional records obtained through the previous methodology were examined for their usefulness in either supplementing the interpretation provided by DoW; or providing more current information about the aquifers within 5 km of the permit areas. The monitoring results supplied by the consortium members to CSIRO as part of the project as well as the data in the WIR database were considered.

2.3.1 Local vs Regional interpretation

The current state of knowledge of groundwater flow in the northern Perth Basin is by Department of Water, 2016, which presents the regional hydrogeology for Autumn, 2007. One of the objectives of this component was to update the regional interpretation with additional local data from around the consortium members permit areas. However, a review of the monitoring records for new bores identified through the GIS analysis for the 2007 autumn (March -May) monitoring period identified no additional data. There were 15 groundwater-level monitoring records for 2007 in total, three records for February, one record in July, four in November and eight in December. Therefore, there is not sufficient information for 2007 autumn period to modify the existing model as presented in Department of Water, 2016, at the local scale for both potentiometric head and salinity profiles.

2.3.2 Number of monitoring bores and records

Groundwater-level monitoring records for all the bores located within 5km distance from the consortium members permit areas where subdivided into three monitoring periods, 1961 - 1980, 1981 – 2000 and 2001 – 2016 (Table 7). The results show that although the number of monitored bores within the area is declining, the number of water-level records from each bore is significantly increasing. This is due to the installation of data loggers and indicates that although the number of monitoring bores is decreasing, the resolution of the data from those bores that are monitored is increasing. There is a concomitant decline in the number of salinity records, which may be associated with the cost of obtaining and analysing samples (Table 7).

Figure 11 shows the distribution of monitoring bores for the 2000 - 2016 monitoring period. For this period, only 3,331 monitoring records represent the direct (field) water-level readings and the majority of the remaining records were calculated water-level readings obtained through data loggers in the bores. The number of measurements in a specific bore may increase from one or two per year up to 370. Installation of data loggers is relatively inexpensive and downloaded easily and quickly.

Table 7 Potentiometric head and salinity monitoring records for bores located within 5 km distance

Monitoring period	Potentiometric head		Salinity (TDS)	
	Number of records	No of bores monitored	Number of records	No of bores monitored
1961 -1980	7,195	310	934	363
1981-2000	11,632	307	104	37
2001-2016	93,518	212	103	36

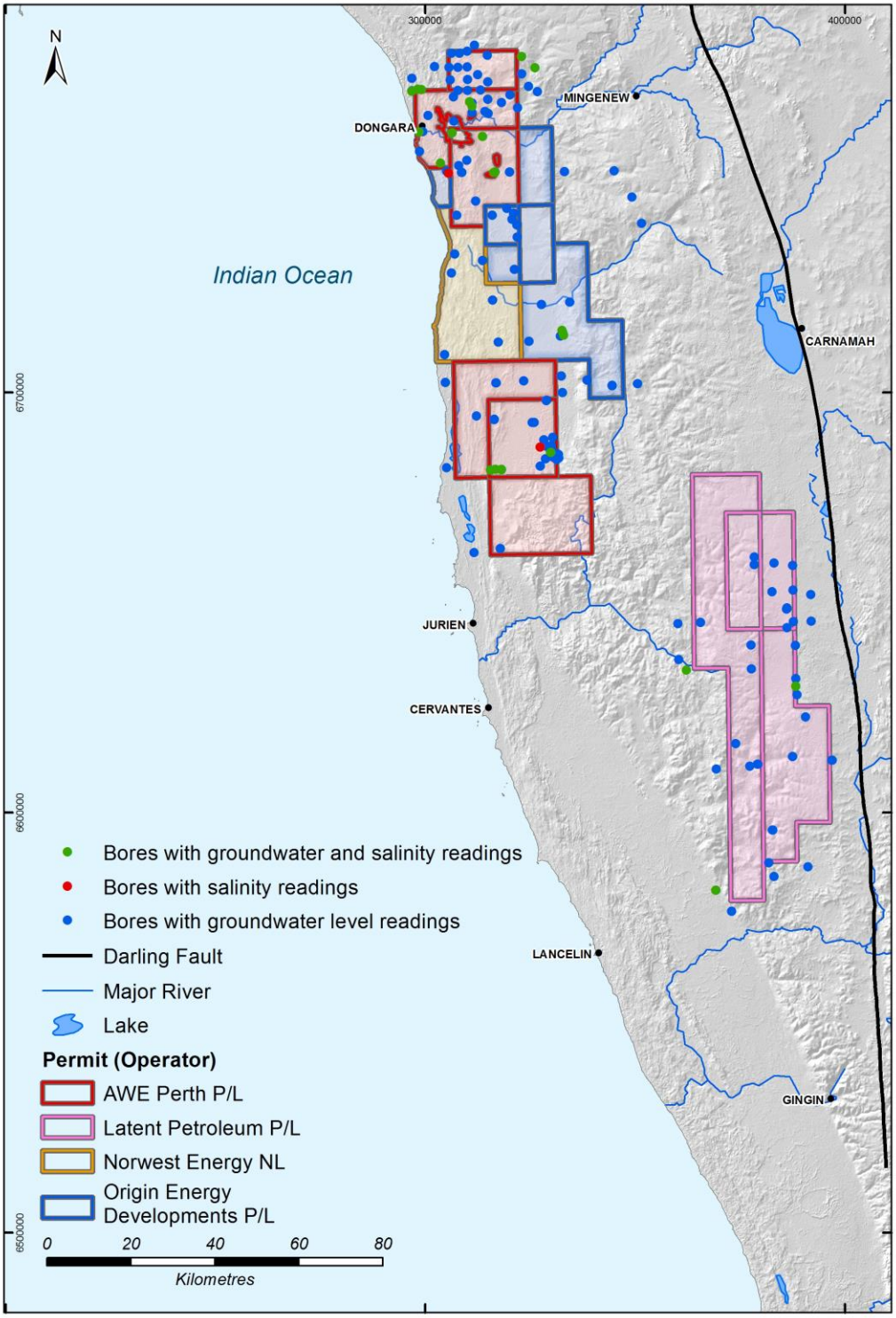


Figure 11 Distribution of monitoring bores for all aquifers for the period 2001 – 2016.

2.3.3 Groundwater Trends between 2007 and 2015

The original potentiometric head and salinity contours developed by DoW and reported in Department of Water, 2016 were created using the entire regional dataset available for 2007 autumn. Due to the scope of this project, potentiometric head contours were created for the Leederville-Parmelia and the Yarragadee aquifers using only bores within 5 km of the permit areas and data from 2010. While this limits the usefulness of the interpretation, a comparison of the data does highlight the importance of a regional perspective when considering local influences. As previously discussed, there was no salinity data available for this period from the publically available records. The only current data available in the permit areas is that being generated by the consortium members themselves.

To highlight local variations at individual bores, water-level trend profiles for 23 Leederville-Parmelia bores located within 5km distance from permit areas for the years 2007, 2010, 2011 and 2015 are considered. Similarly, water-level trend profiles for 73 Yarragadee bores located within 5km distance from permit areas for the years 2007, 2010, 2011 and 2015 are considered.

Leederville-Parmelia Aquifer

Bores considered for trend analysis for the Leederville-Parmelia aquifer are shown in Figure 12. During the 2007 – 2015 monitoring period, water-levels were almost constant with little fluctuations in all monitoring bores except ML3B (Figure 13). A significant decrease in water-level is observed in ML3B during 2007 autumn and 2010 monitoring, however remained at a constant value for both 2011 and 2015 monitoring periods. At the Latent Petroleum permit area, Department of Water (2016) have reported that groundwater flow is south to south-west towards the Lancelin and passes across the transition from the Leederville-Parmelia aquifer to the Leederville aquifer (14). Due to the consistent water-level data, it can be assumed that groundwater flow reported by Department of Water (2016) for 2007 autumn period is still valid for area surrounding these bores. Comparison of the potentiometric head contours for 2007 (Department of Water, 2016) and 2010 (CSIRO, Figure 15) show that both interpretations have almost the same number of bores within the areas and generally, flow is still directed south to south-west. However, the 2010 (CSIRO) contours contain a series of closed highs, which may be an artefact of the contouring method and the limited number of bores outside of the permit areas. Figure 9 shows there are a large number of additional bores located within the permit area which may be assigned to the Leederville-Parmelia aquifer. A survey of current water-levels and installation of water-level loggers across this area may provide a better understanding of the localised flow regime.

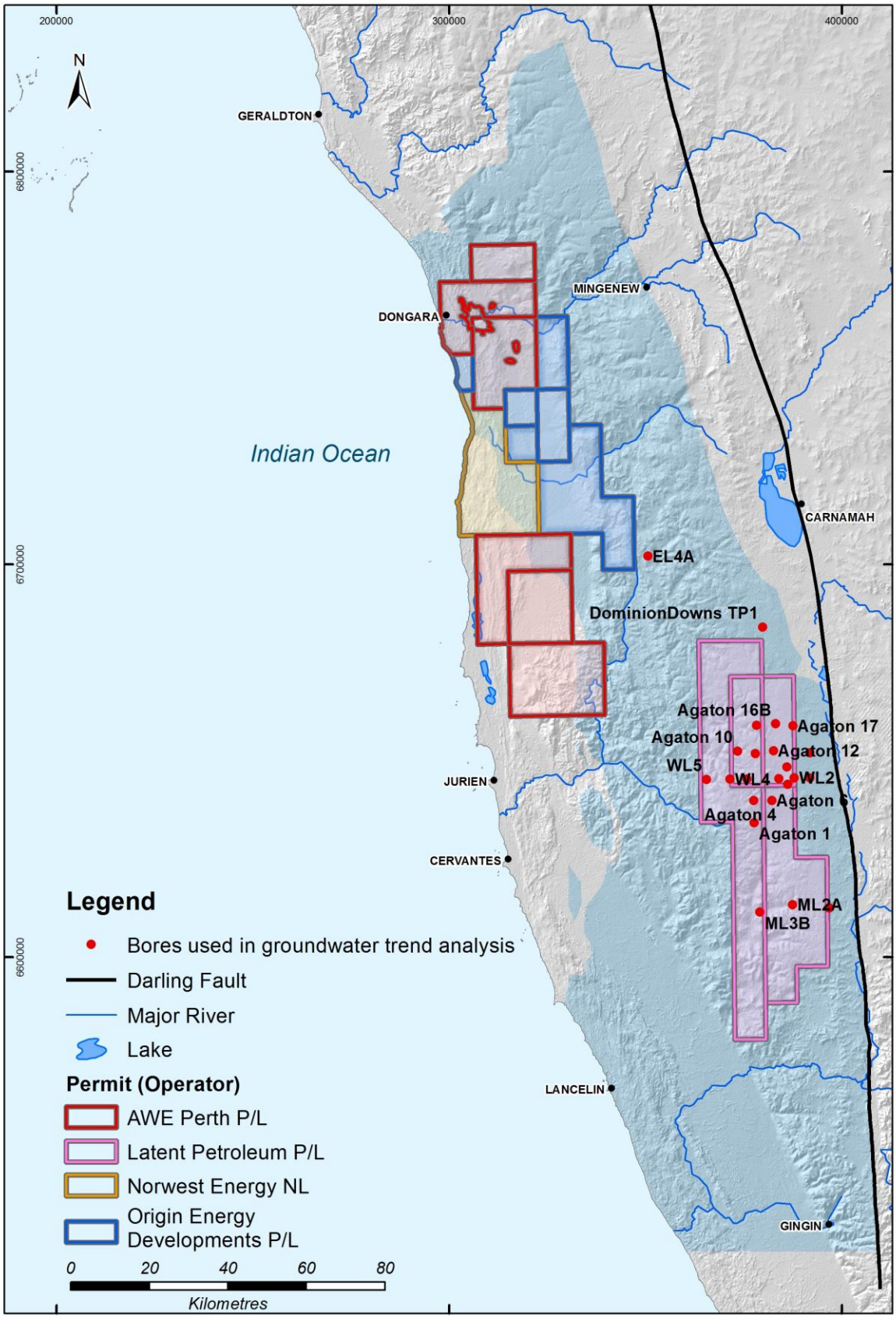


Figure 12 Locations of Leederville-Parmelia aquifer bores used for water-level time series

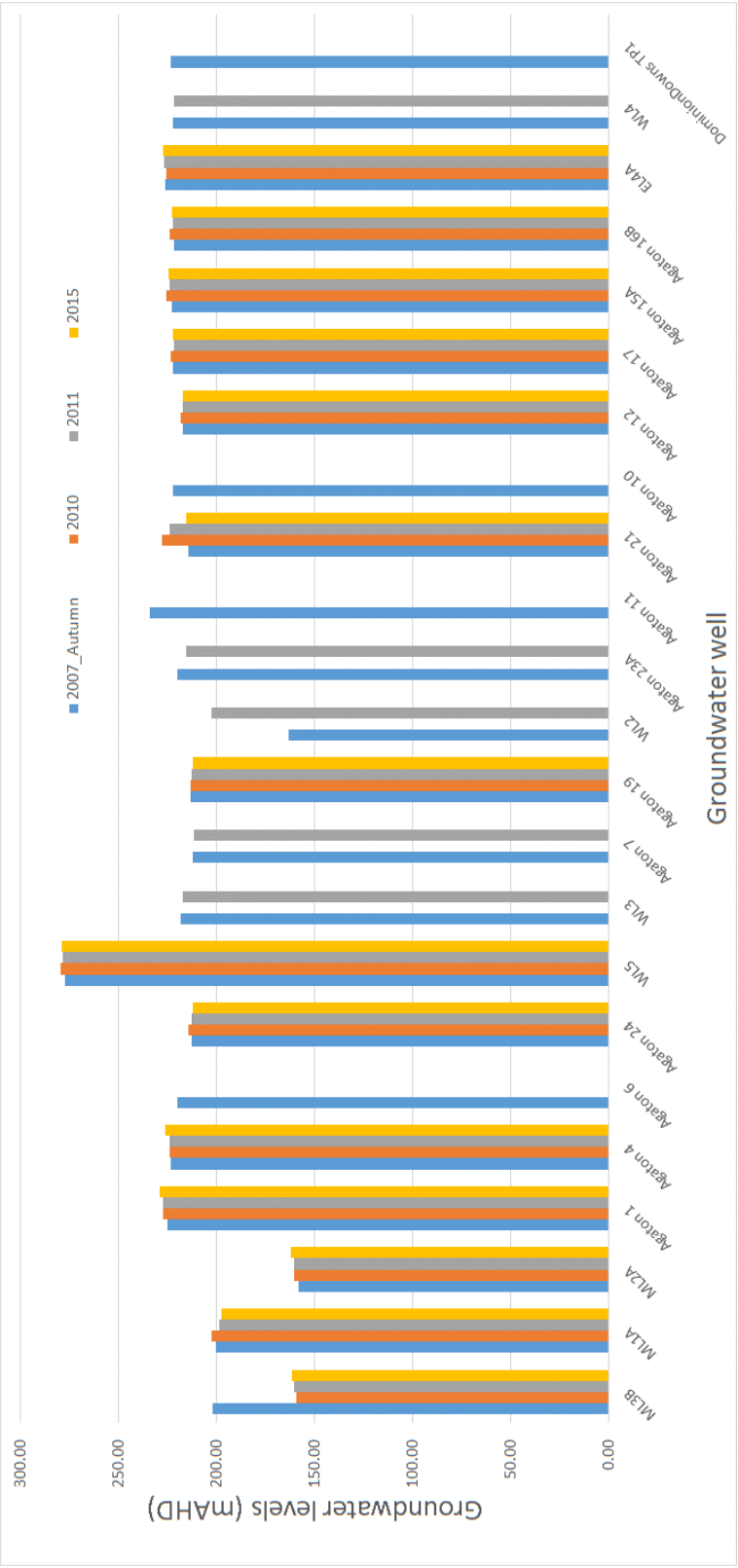


Figure 13 Water-level trends for bores in Leederville-Parmelia aquifer

Note: Water-levels for Agaton 7, WL2, WL3 and WL4 for 2011 were taken from RockWater (2013) report and they represent a single monitoring value.

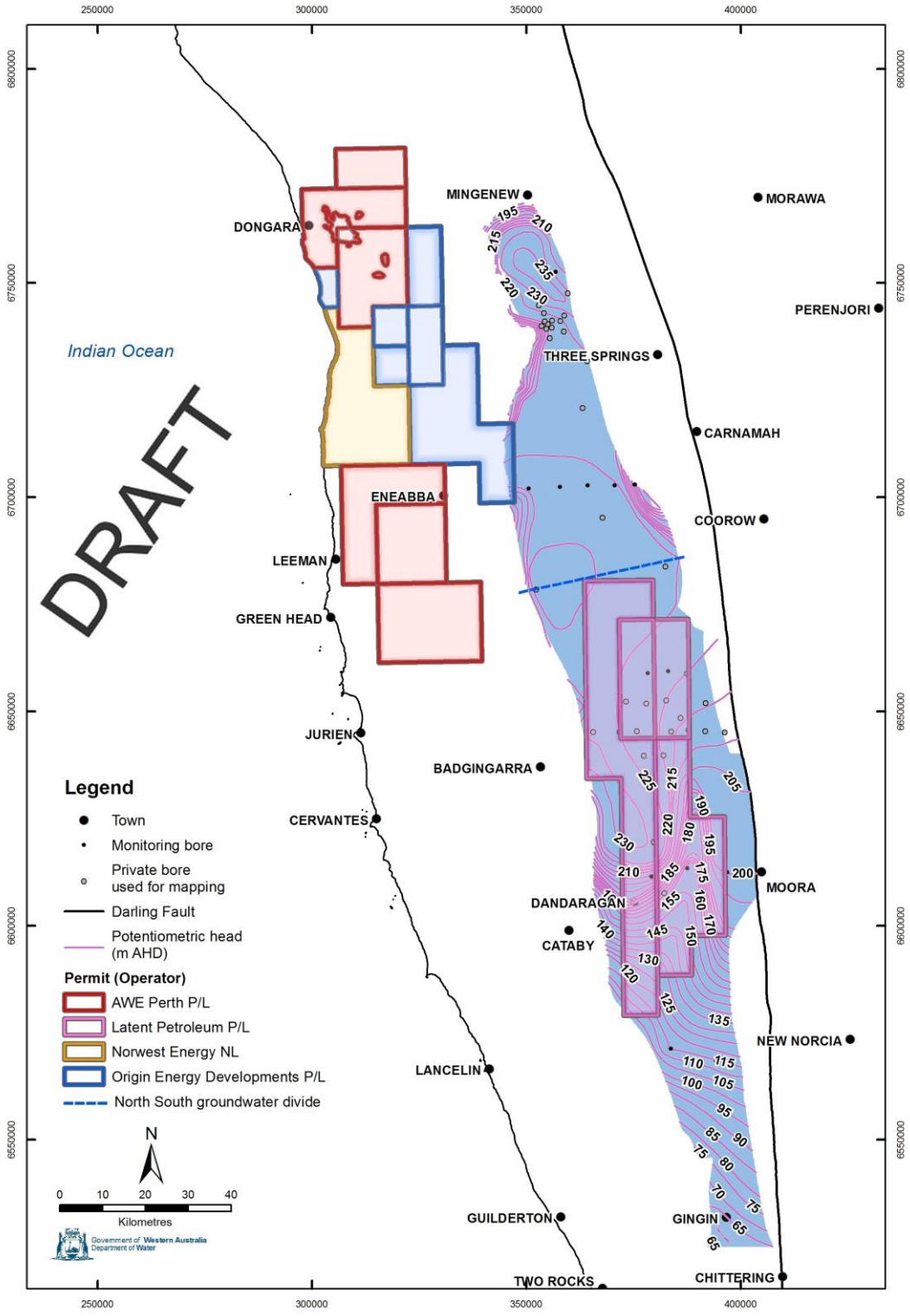


Figure 14 Leederville-Parmelia aquifer potentiometric head for 2007 autumn monitoring period (Source: Department of Water 2016)

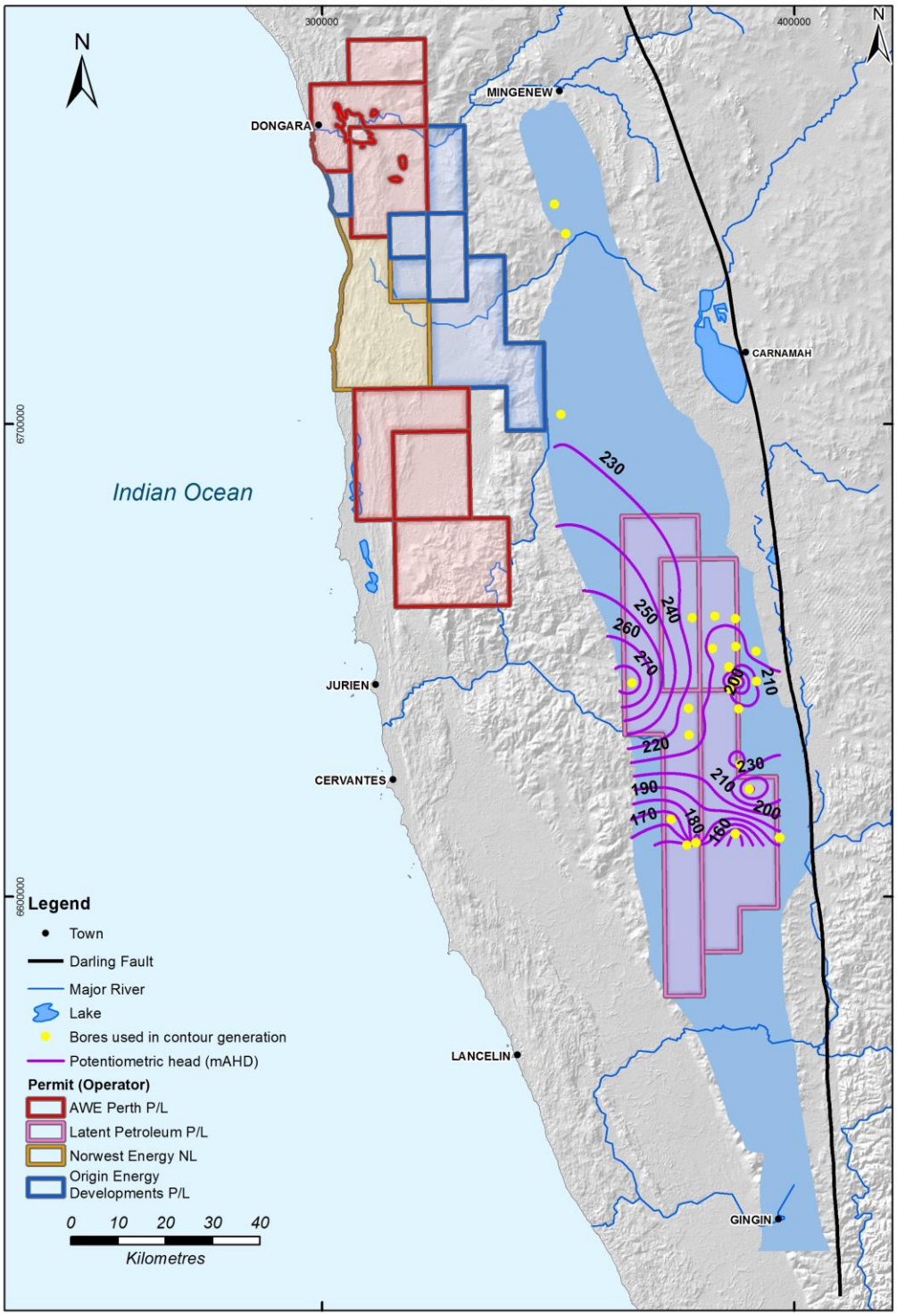


Figure 15 Leederville-Parmelia aquifer potentiometric head for 2010 (CSIRO). Aquifer extent is from Department of Water, 2016.

Yarragadee Aquifer

Bores considered for trend analysis are shown in Figure 16 and water-level trends were compared for four monitoring periods: 2007 autumn, 2010, 2011 and 2015 as shown in Figure 17. Fourteen bores were not monitored during the above monitoring periods. Water-levels of AWE bores for 2010-2015 monitoring periods are also shown in Figure 17.

Similar to Leederville-Parmelia aquifer, during 2007 – 2015, water-levels were almost constant with little fluctuations in all monitoring bores except WL5 (Figure 17). A significant increase in water-level is observed in WL5 during the monitoring periods. At the Latent Petroleum permit area, Department of Water (2016) have reported that groundwater flow is to the west and south-west towards Dongara – Arrowsmith (Figure 18). As with the Leederville-Parmelia aquifer, the consistency in the water-levels indicates the groundwater flow reported by Department of Water (2016) for 2007 autumn period is still valid for area surrounding these bores. The 2010 (CSIRO) contours for the Yarragadee aquifer have a similar number of bores and are broadly consistent with the Department of Water (2016) interpretation. However, there are no monitoring bores in the southern part of the permits areas (Figure 10) for the Yarragadee aquifer. This is due in part to the depth of the aquifer in this area as it is not used for groundwater supply. It is also a gas reservoir and exploration of the gas productivity of the Yarragadee is underway.

The Yarragadee aquifer interval has significant depth and thickness in this area and from petroleum well testing is known to have low permeability and transmissivity. Hence, flow rates are likely to be very low. Nevertheless, consideration needs to be given to the installation of monitoring bores in the Yarragadee aquifer to understand the flow rates and directions. The installation of monitoring bores needs to be evaluated in consideration with the requirement to avoid intersecting a gas zone.

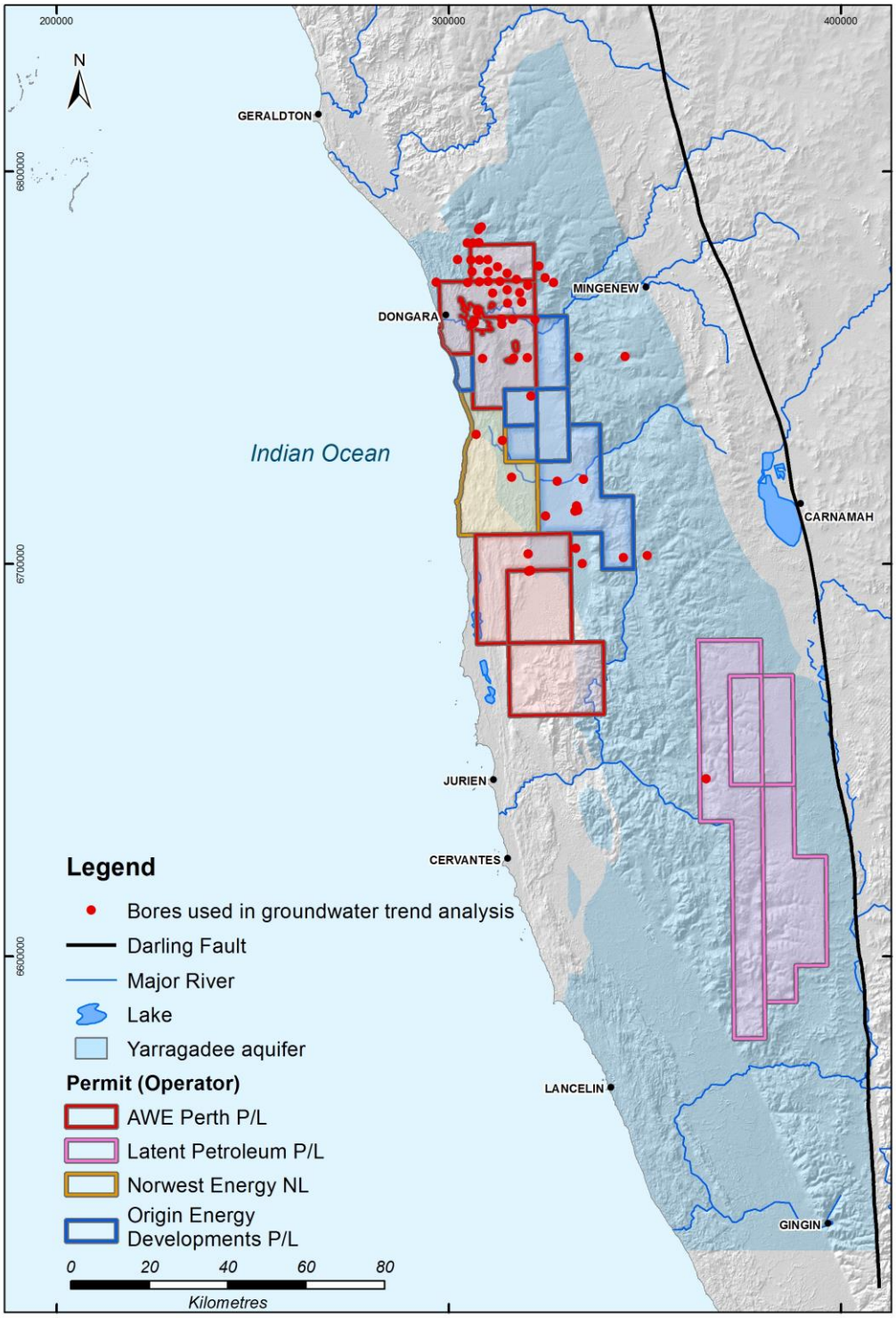


Figure 16 Locations of Yarragadee aquifer bores used for water-level time series

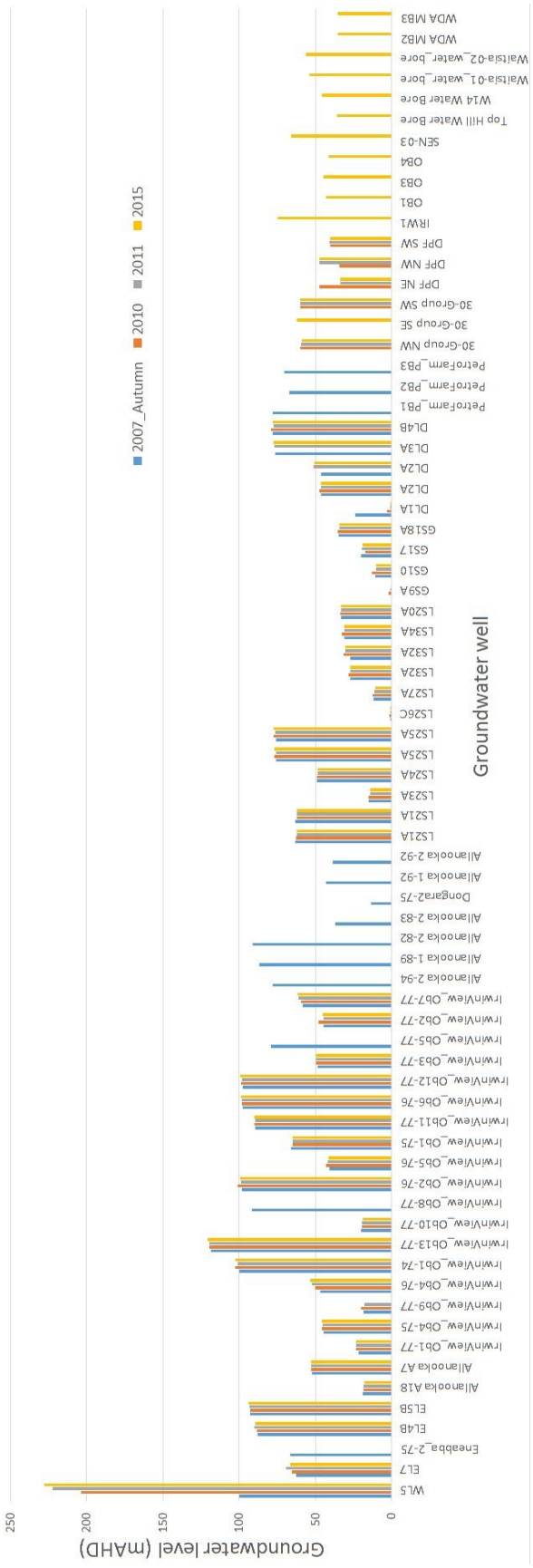


Figure 17 Water-level trends for bores in the Yarragadee aquifer

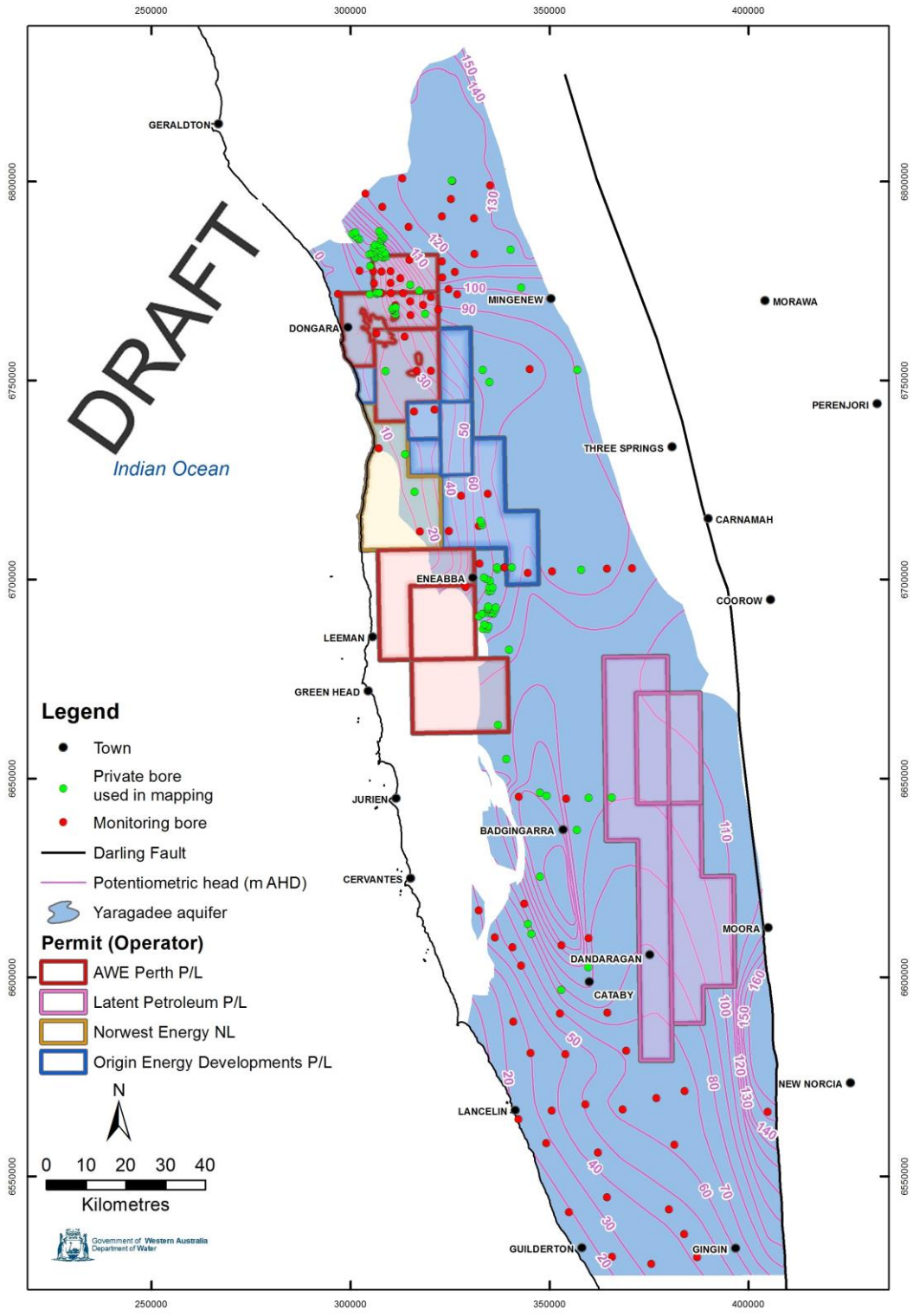


Figure 18 Yarragadee aquifer potentiometric head for 2007 autumn monitoring period (Source: Department of Water 2016)

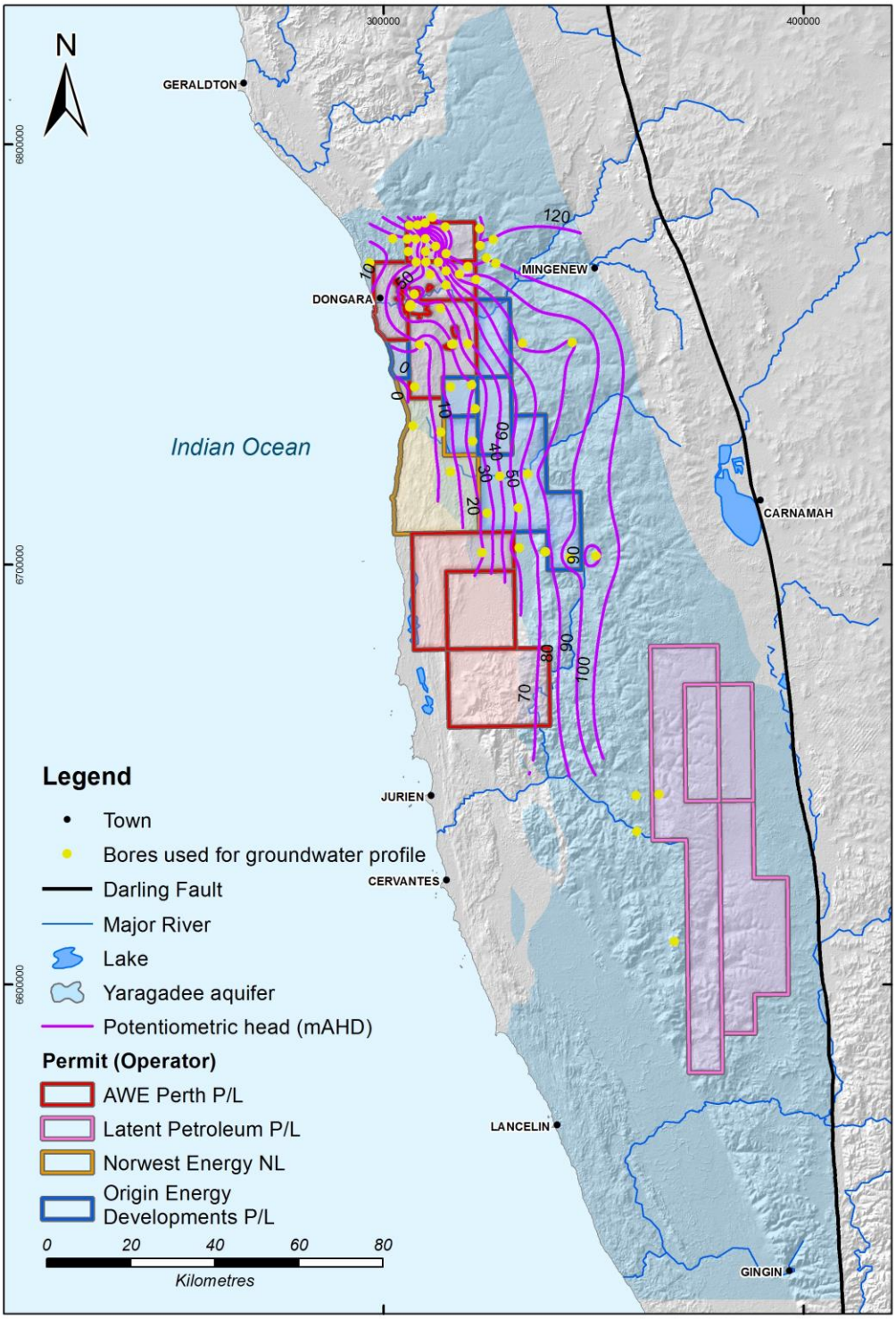


Figure 19 Yarragadee aquifer potentiometric head for 2010. Aquifer extent is from Department of Water, 2016.

2.4 Review of Consortium Member Groundwater Sampling Protocols

Based on CSIRO request for information about the water bores, fluid analyses and chemicals used on their permit areas, consortium members (AWE, Latent Petroleum and Origin Energy) have supplied water-monitoring results for various sampling periods. AWE has also supplied water sampling protocols (developed by contractor Gemec Environmental Consultants), chemical disclosure information and hydrocarbon reservoir data for various well sites. The water data and protocols from each consortium member were compared to current regulations and guidelines referred below, to ensure consistency and best practice.

- Australian and New Zealand Environment and Conservation Council (ANZECC) / Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), October 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality
- Department of Mines and Petroleum, August 2016, Guideline for groundwater monitoring in the onshore petroleum and geothermal industry
- Department of Environment Regulations, December 2014, Assessment and management of contaminated sites, Contaminated Sites Management Series
- Standards Australia, Australian/New Zealand Standard AS/NZS 5667.1:1998, Water Quality – Sampling, Part I: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples
- Standards Australia, Australian/New Zealand Standard AS/NZS 5667.11:1998, Water Quality – Sampling, Part II: Guidance on sampling of water

The field analysis and water quality parameters measured by the consortium members were compared with the list of parameters prescribed in the Table 2 and Table 3 of DMP (2016) groundwater monitoring guidelines for onshore petroleum and geothermal industry. AWE's field and water quality parameters were consistent with the guidelines. The water quality parameters supplied by Latent Petroleum were consistent with the DMP guidelines, however the field analysis parameters were not supplied to CSIRO.

AWE water sampling protocols (developed by Gemec Environmental Consultants) are also consistent with the current guidelines and regulations. In absence of any information on the water sampling protocol followed by the other consortium members, CSIRO could not make any comments.

2.5 Conclusion

The original objective of the groundwater study was to update the regional flow model presented in Department of Water (2016) with local data from the WIR database and the consortium members. Based on the structural and base elevation contours provided by the DoW, a geological model was developed in ArcGIS and, using records from the DoW WIR database, was used to assign aquifers to water bores with monitoring data, but without a designated aquifer in and around the permit areas.

Using these new datasets, water trends for 2007 – 2015 period were developed and a constant water-level was observed in the majority of bores located in both the Leederville-Parmelia and Yarragadee aquifers. It can therefore be generally assumed that water flow directions reported by Department of Water (2016) in the permit areas is still valid and there have been no significant changes in the regional flow patterns since then. Due to lack of sufficient salinity information after 2000 in WIR database, no further salinity analysis has been undertaken.

Groundwater parameters measured by the consortium members (AWE, Latent Petroleum and Origin Energy) were compared with the DMP (2016) guidelines. AWE's field and water quality parameters were consistent with the guidelines. The water quality parameters supplied by Latent Petroleum were consistent with the DMP guidelines, however the field analysis parameters were not supplied to CSIRO. The data being obtained by the consortium members represents an important data source to supplement the data currently existing in the WIR. There is however, a lack of current monitoring data, particularly in the southern part of the permit areas around Latent Petroleum's permits.

In conclusion, the regional modelling undertaken by the DoW represents the best available understanding of regional water flow and trends across the northern Perth Basin. However, it is also clear from the analyses above that there is a lack of current monitoring data available in and around the areas of interest to understand local flow regimes and climactic impacts. It is recommended that a survey of current water-levels and installation of water-level loggers across this southern part of the Leederville-Parmelia aquifer may provide a better understanding of the localised flow regime. In contrast, there are no bores in the Yarragadee aquifer in the southern part of the permit areas. Consideration needs to be given to installing monitoring bores in this area, however, this needs to be undertaken with caution as the aquifer is known to be gas bearing and highly cemented, i.e. to have low to extremely low permeability.

3 Mobile Surveys

3.1 Introduction

CSIRO undertook a series of mobile, vehicle based surveys to assess the ambient concentration of methane across the basin. The methodologies and technologies were based on those published by Day et al., 2015 in the Surat Basin, Queensland. Vehicle based surveys to measure near surface concentrations of CH_4 have been used successfully in many places, including the United States and Australia. The method uses a vehicle fitted with a Picarro methane analyser that has sufficiently fast response time to allow the vehicle to be driven at normal speed along a designated transect. As this technique involves a moving sensor rather than a static sensor, it adds another dimension to identifying the source of any emissions detected, and detection will only occur if the vehicle is downwind of the source at the time of the survey. Mobile terrestrial methods performed by CSIRO, however, were able to detect elevated levels of methane in the Surat Basin, Queensland (Day et al. 2013). The sources detected included grazing cattle, CSG production wells and natural seeps. The Perth Basin, as compared to the Surat Basin, is relatively undeveloped, and background levels of CH_4 and the potential for natural seeps and emissions is largely unknown.

However, it is important to recognise that the concentrations of CH_4 at any point are dependant on the source of the CH_4 and the wind direction at the time of measurement. Stationary sources of CH_4 can be traced and identified, but mobile sources, such as cattle can also be detected and must be considered. The survey undertaken in this project was carried out over five days and as such can only be considered as a “snapshot” of the baseline ambient CH_4 levels across the basin.

3.2 Methodology

The measurement system consisted of a G2201-i cavity ring down spectrometer (CRDS) from Picarro capable of precisely and accurately measuring CO_2 and CH_4 concentration from the gas phase. This particular system can also measure $\delta^{13}C$ values for both CO_2 and CH_4. The Picarro system was selected for its very low measurement drift (3 ppb over 1 month for CH_4, peak-to-peak, 50 minute average) and for meeting MIL-STD 810F test standards for shock and vibration.

All of the equipment was mounted onto two wooden boards (900 mm x 600 mm and 600 mm x 300 mm) to facilitate mobilization into and out of the vehicle. The CRDS was placed onto a 70 mm thick piece of foam to minimize vibration. The Picarro CRDS contains a fully functioning computer running Windows XP. To make the system less cumbersome (and eliminate the need to attach a monitor, keyboard and mouse), a wireless router was hardwired to CRDS through an Ethernet cable allowing wireless access through remote

desktop login to the system from a laptop. This allows the passenger of the vehicle to readily monitor in real-time the CRDS readings.

A Garmin GPS 18x was used to record the longitude and latitude data time stamped to coincide with the CRDS measurements and attached to the outside of the vehicle. ¼" PFA tubing from Swagelok is used for all gas sampling lines both inside and outside the vehicle. The intake point was via tubing secured to the antenna mounted on the front of the vehicle to ensure clean air. With the exception of tubing between the vacuum pump and the CRDS (where Picarro's own tubing is used), Swagelok parts are used to connect tubing to appropriate fittings.

(a) (b)

Figure 20 Vehicle set up for mobile survey showing (a) the intake point attached to the antenna of the vehicle and (b) the sensor mounting prior to loading into vehicle

The first mobile survey was undertaken in March, 2015. This survey was short and designed to test the equipment and the methodology. The data reported here was from the final survey, which was carried out between the 23rd and the 27th of November 2015. During this time there was no rain and the average daily temperature was between 13 and 32 °C. The daily route was influenced by the prevailing wind direction. The vehicle was stopped periodically to measure wind direction and speed. At each stopping point a soil gas flux measurement was taken. The CDRS was calibrated with 1 and 5 ppm CH_4 standards daily and a variation of less than 0.01 ppm was observed.

The vehicle travelled at a normal speed along the road, dependant on the conditions, but assumed to be 100km/hour. The time taken for air to travel along the tubing from the intake point to the measurement point is 28 seconds. Therefore, the maximum lag associated with the measurement was of the order of 785 m.

3.3 Results

The route taken by the mobile survey was designed to cover as much area as possible in and around the permit areas. The survey covered approximately 2300 km's over five days in November, 2015 (Figure 21).

The data collected each day is summarised in Figure 22 as a box and whisker plot showing the median, 25th and 75th percentile. The background levels across the area over the five days clusters around 1.77 ppm, with the median concentration varying between 1.764 and 1.776 ppm (Figure 22). These values are reasonably consistent with the CH_4 values reported from Cape Grim during November, 2015 of 1.796 (http://www.csiro.au/greenhouse-gases/).

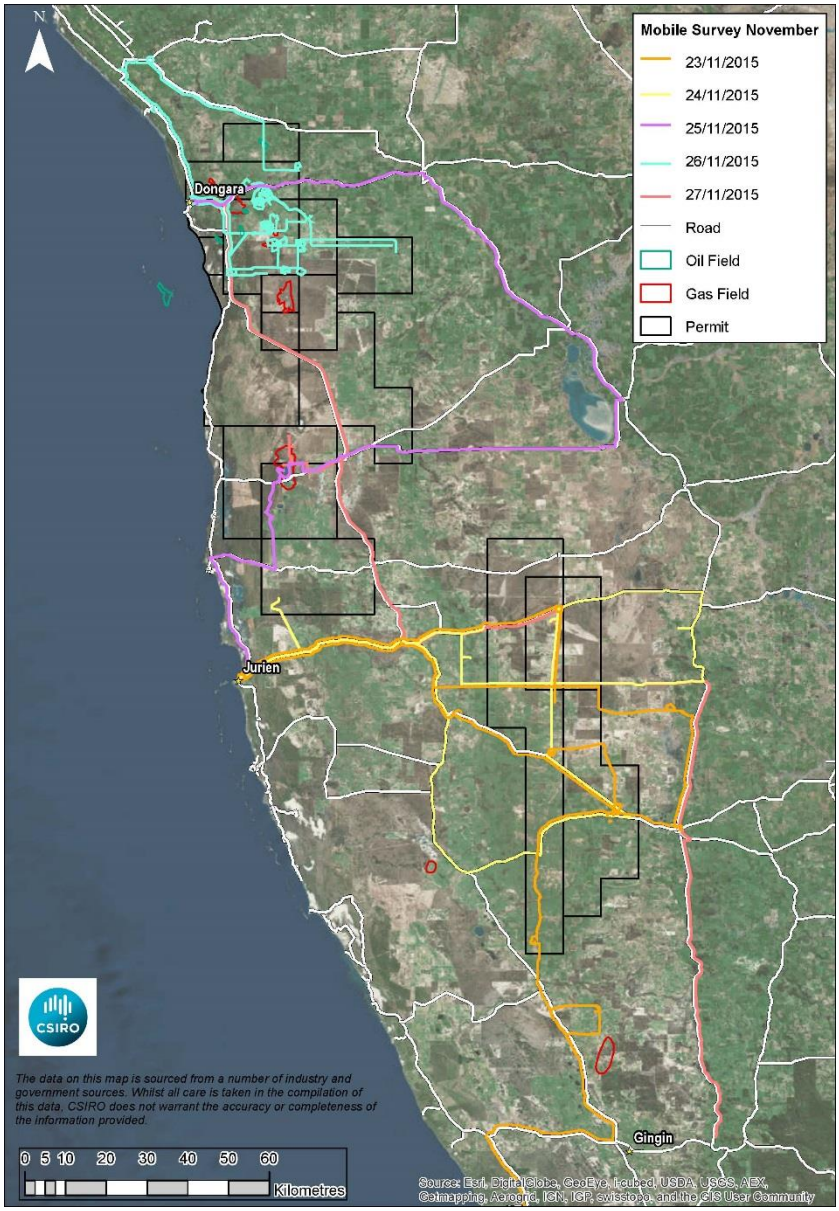


Figure 21 Route taken by mobile survey in November, 2015

The CH_4 concentrations measured along the daily routes are shown in Figure 23 to Figure 27. Although there are numerous small fluctuations, the majority of the data lie close to the mean value of 1.77 ppm. There were several events noted, for example, the higher values measured early on the first day, 23rd November, 2015 (Figure 23) were due to smoke from a bushfire encountered on leaving Perth. The largest concentration measured was on the 27th November, 2015 downwind of the Dongara Production Facility (Figure 27). The

measurements were taken early in the morning, before the wind had risen. The source has not been identified and may be due to higher density CH_4 settling overnight. The measurements were repeated in the afternoon and had returned to background levels. Measurements taken around well sites (roads near the Dongara Production Facility, roads near the Xyris Production Facility, wells at the Woodada Gas Field, Corybas-1, Senecio-2, Senecio-3, Watsia-1, Watsia-2 and Irwin-1) were consistent with background levels.

The original intention was to investigate the usefulness of isotope ratios to understand the source of measured CH_4. Unfortunately the consistently low concentration of CH_4 measured (maximum value was 4.5 ppm) meant that any change was insignificant to isotope ratios after mixing with background atmospheric.

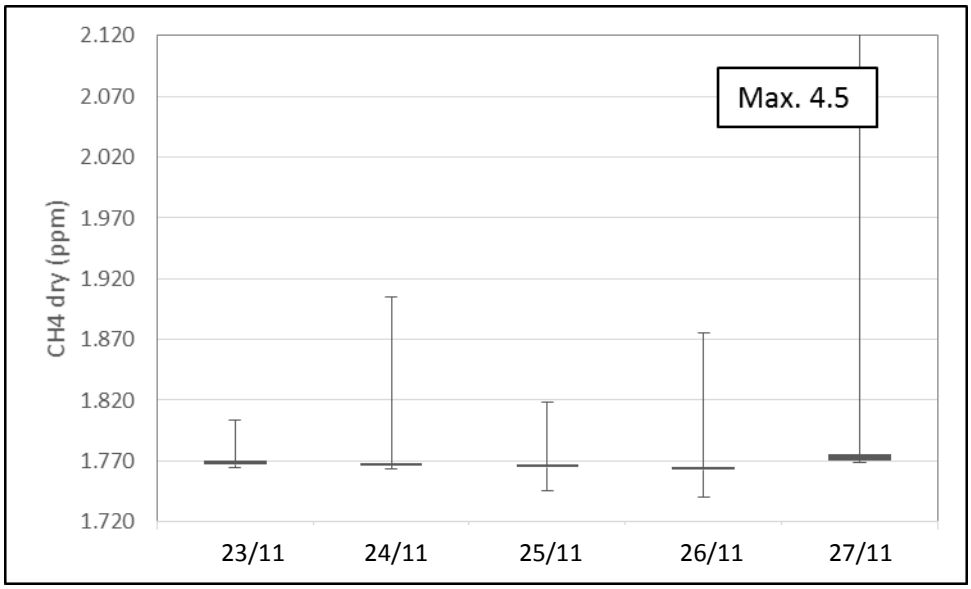


Figure 22 Summary of CH_4 (dry) concentration values measured over the five days of the survey

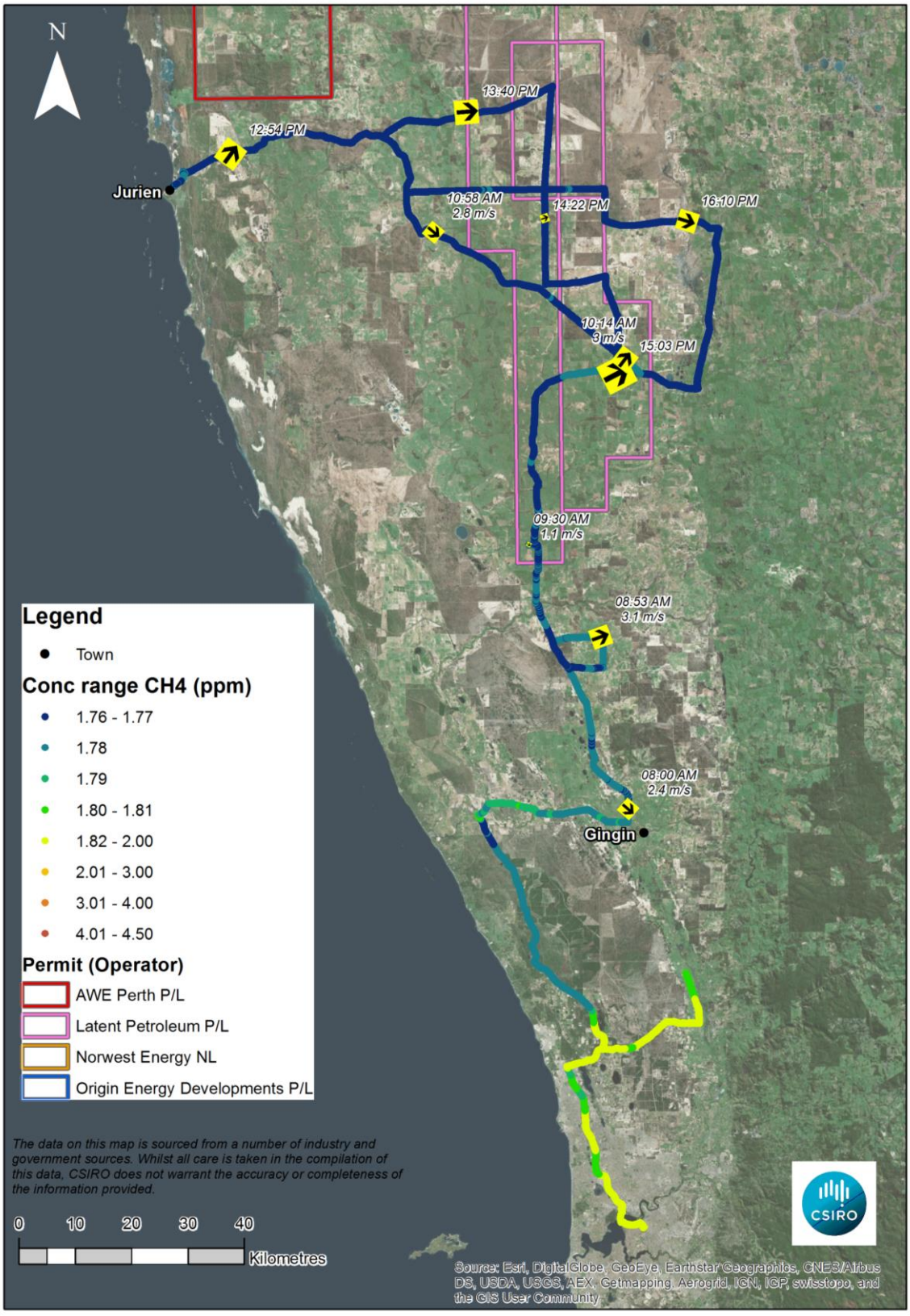


Figure 23 Mobile survey data for the 23/11/2015, showing concentration range and wind direction and speed.

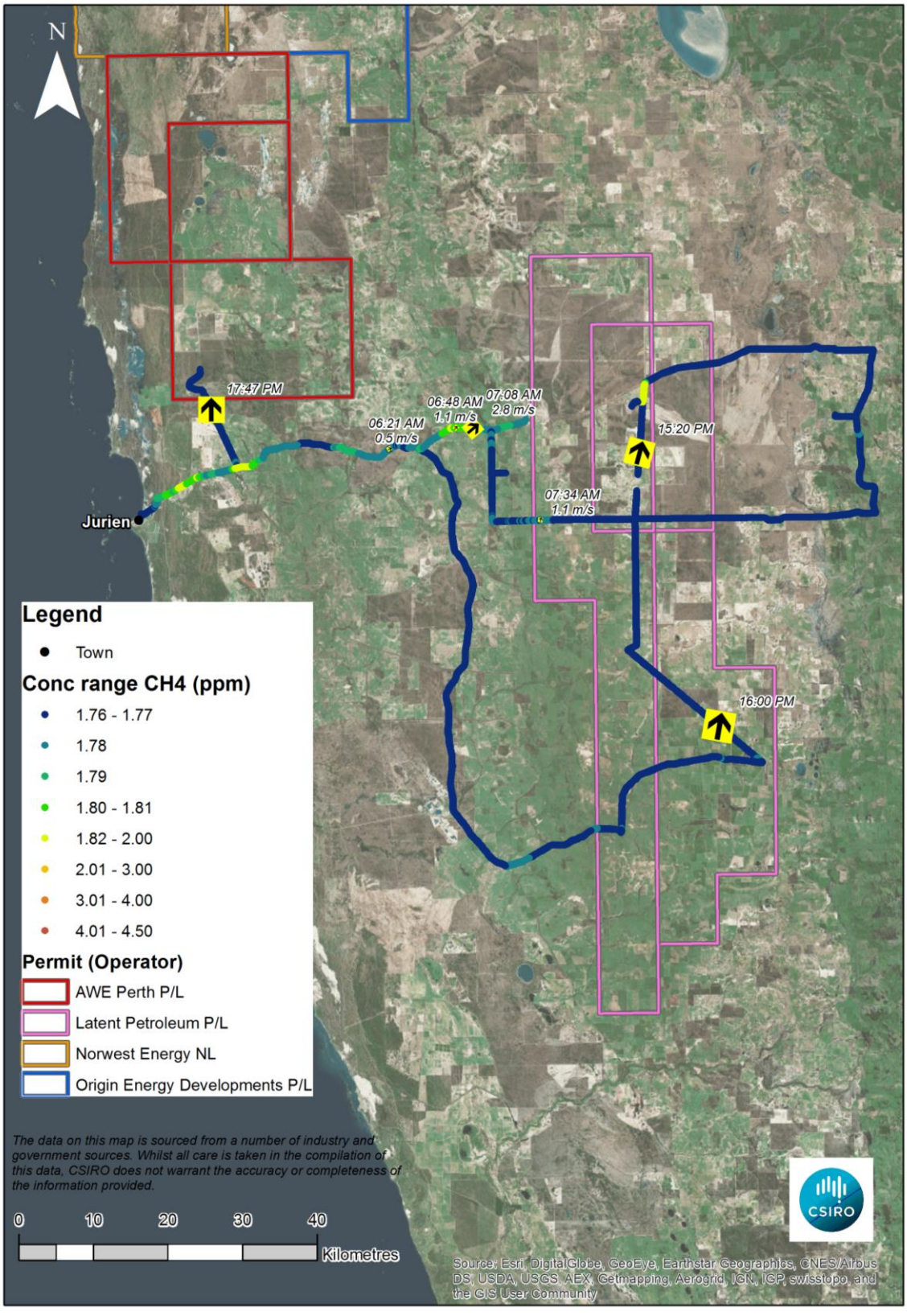


Figure 24 Mobile survey data for the 24/11/2015, showing concentration range and wind direction and speed.

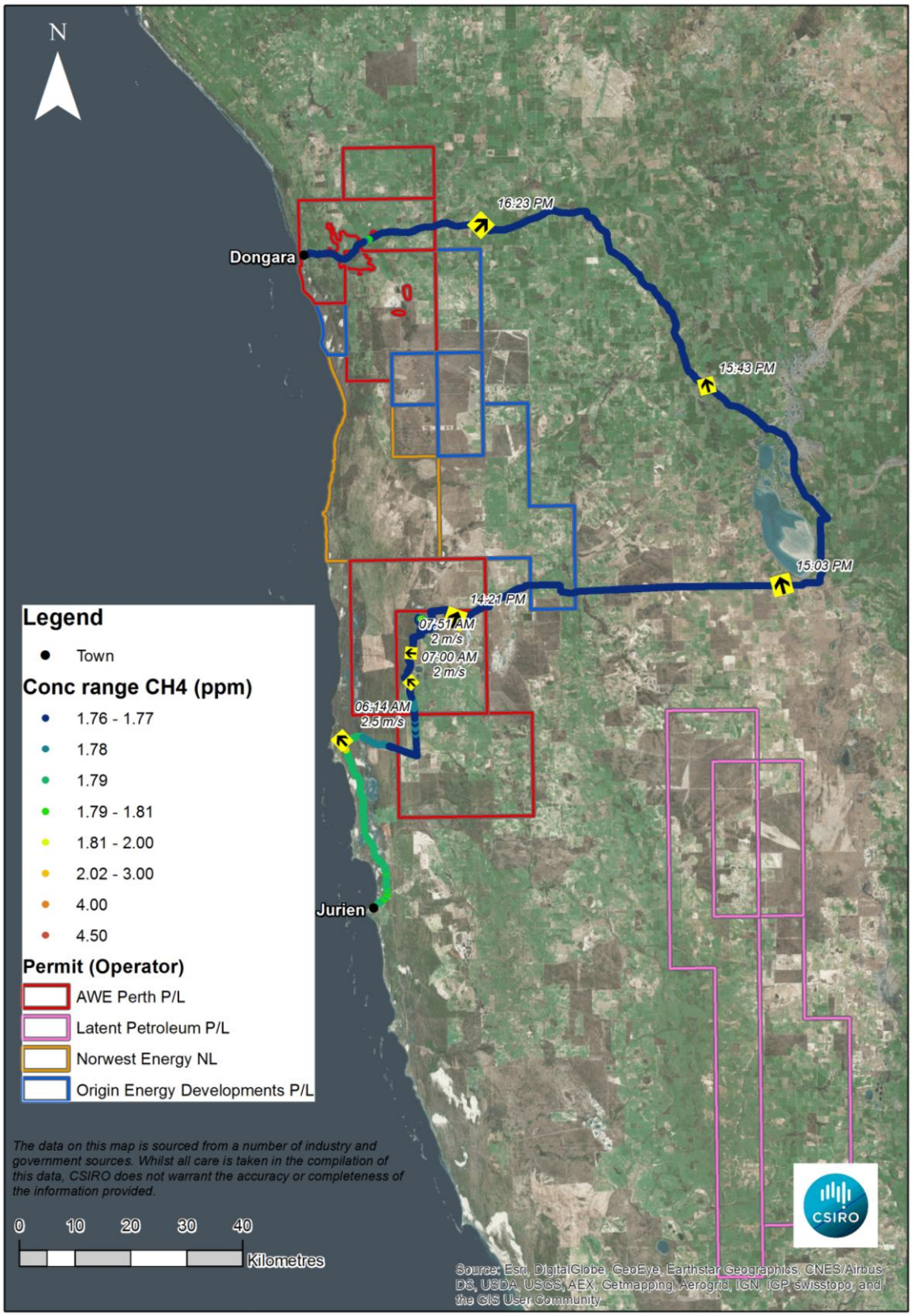


Figure 25 Mobile survey data for the 25/11/2015, showing standard deviation from mean value and wind direction and speed.

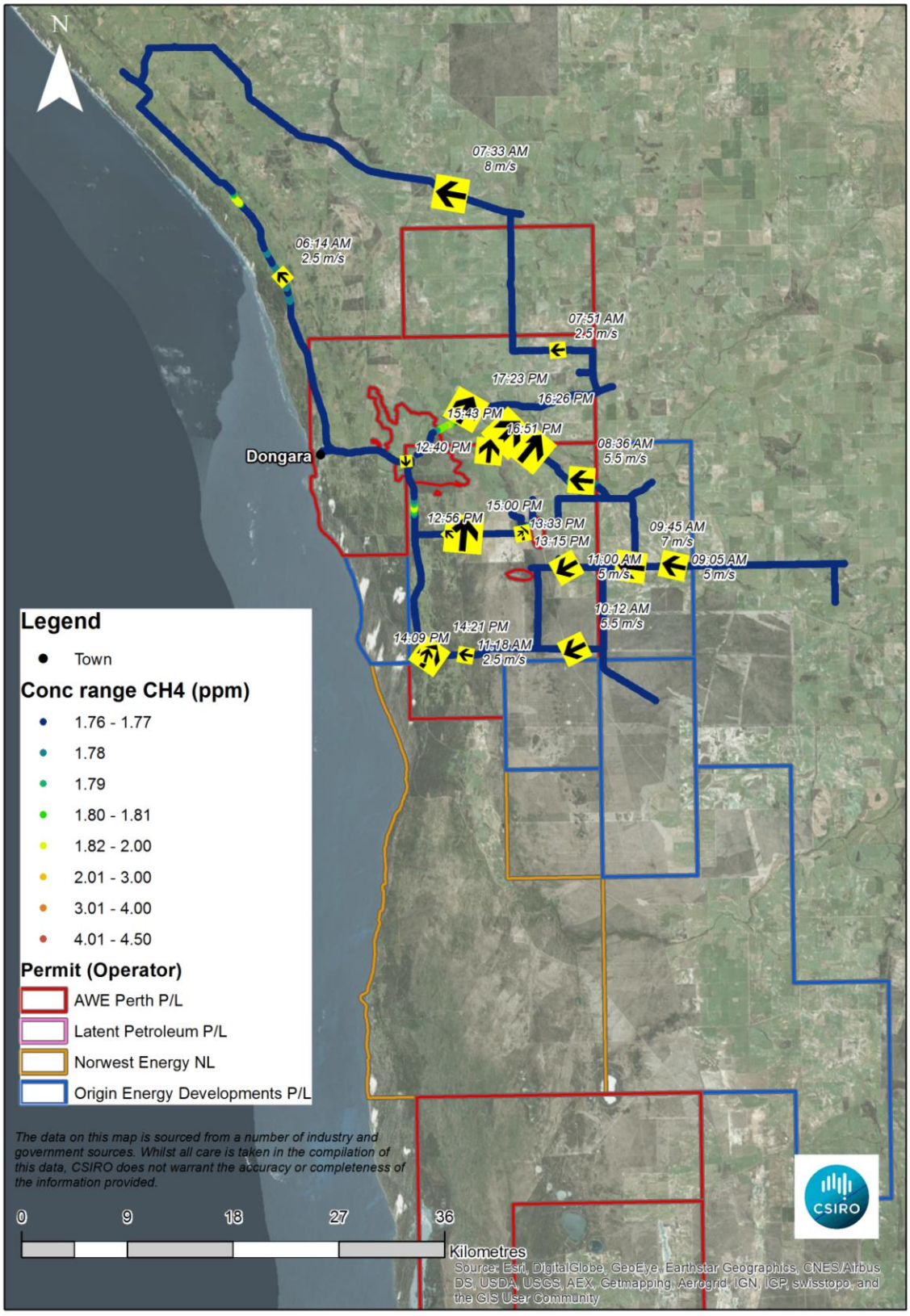


Figure 26 Mobile survey data for the 26/11/2015, showing concentration range and wind direction and speed.

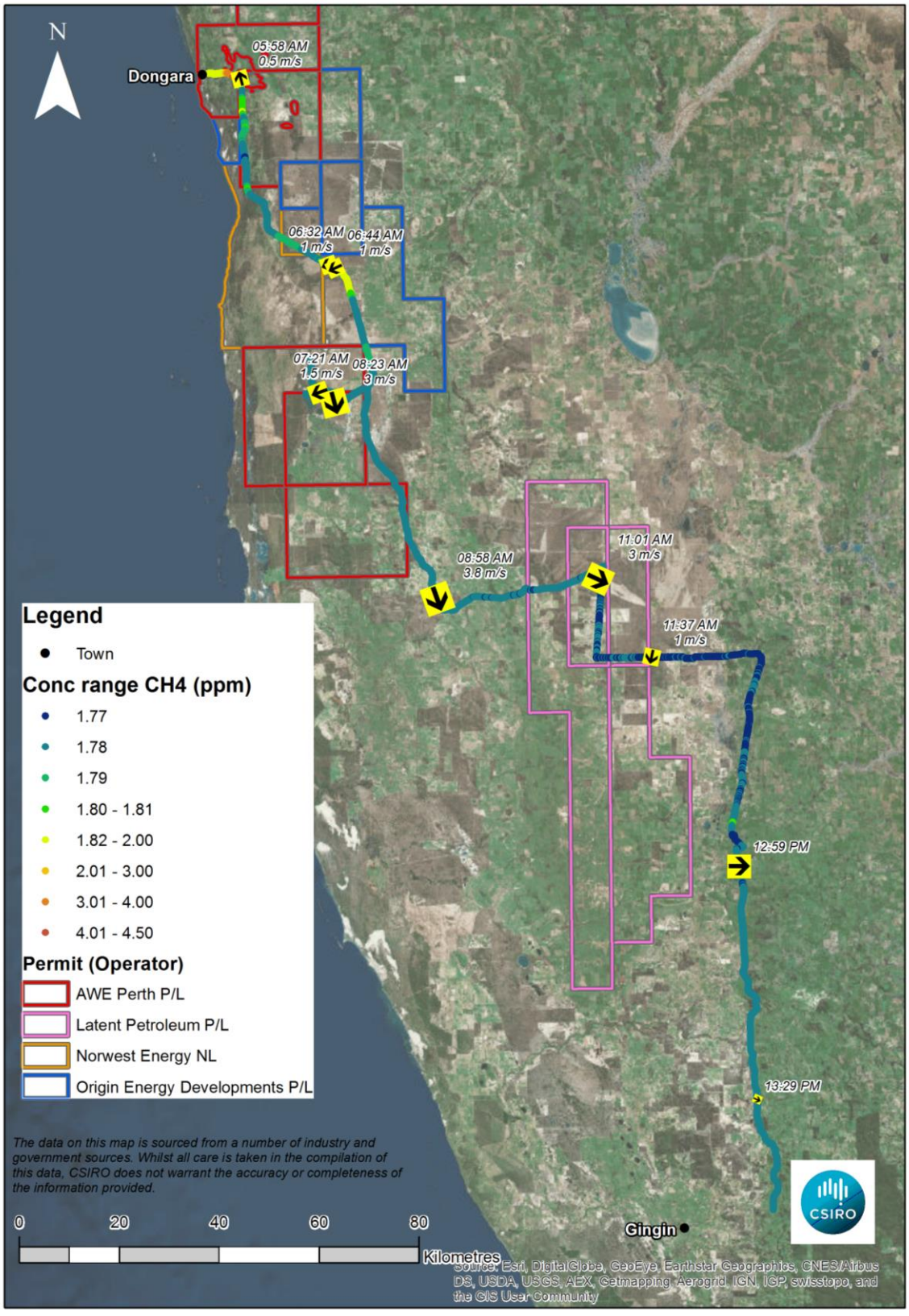


Figure 27 Mobile survey data for the 27/11/2015, showing concentration range and wind direction and speed.

3.4 Conclusion

The results from this initial survey show that the background levels of CH_4 across the area are within the range expected for background atmospheric CH_4. There are numerous small fluctuations which are not always attributable to a source. This method is a simple and effective way to measure methane concentrations across large areas.

The limitation of this method is that it represents a snapshot across the area only at the time of the survey. The Picarro is extremely sensitive, however, the detection of a methane source away from the measurement path is dependant on the methane being carried into the path by the wind.

Future investigations into the application of mobile surveys should be directed at understanding and quantifying the natural variation associated with these measurements. There were several large (up to 4 ppm) events which could easily be tracked to large infrastructure. However, there were a number of other minor events which caused fluctuations in the concentration between 1.76 and 1.79. The significance of these fluctuations and their source should be investigated in future studies.

4 Warro Soil Gas Flux Survey

4.1 Introduction

The project aimed to undertake an assessment of current levels of soil surface CH_4 flux over a spatial scale around the tight/shale gas fields in the Perth Basin prior to any operational activities. The main objective of the CH_4 flux survey was to benchmark the current level of CH_4 flux at specific areas of interested prior to any operation.

Key considerations for selecting the specific areas of interest were:

(i) Identified faults

(ii) Sampling points around existing wells and

(iii) A control site that is not anticipated to undergo any development during the lifetime of the field development.

Sites were located based on available geophysical data and in consultation with rest of the team including the companies involved.

Soil CH_4 gas flux measurement was considered a more robust way to calibrate the processes controlling the ambient concentration of CH_4, compared to transient measurements of gas concentration. However, CH_4 concentrations were also catalogued during the surveys. Along with soil surface CH_4 flux, in order to better constrain the processes controlling CH_4 flux and identify any future anomalous CH_4 response with a higher level of certainly, a suite of relevant soil characteristics were also accounted for. These included: carbon, carbonates, microbial biomass, temperature and moisture (primary abiotic drivers of CH_4 evolution), pH, particle size analysis, bulk density, porosity. This soil physical-chemical-biological monitoring approach was essential for mechanistically understanding the seasonal and spatial variability of soil surface CH_4 flux in order to better identify any future anomalous soil surface CH_4 response.

4.2 Methodology

4.2.1 Soil gas flux survey

The survey points were located based on identified fault and/or anomalous zone, survey points around existing wells and a set of control sites that are not anticipated to undergo any development during the lifetime of the field development. At each location a section of PVC pipe (dimensions: internal diameter 20 cm; height 12 cm; thickness 0.6 cm) serving as a collar for the soil-gas flux chamber was inserted into the surface soil to a depth of about 3-4 cm (Figure 29). This was done 24 hours prior to the commencement of soil-gas flux measurements to allow any soil disturbance effects to settle. The soil gas flux survey was

carried using LICOR survey chamber connected to a LGR ultraportable GHG CH_4/CO_2 analyser. Two campaigns of were conducted during May 2015 and repeated in May 2016. Figure 28 shows the locations of the first survey. Due to time and weather constraints and the difficulty of access, we were not able to get to exactly the same location for several of the sites. In these cases, the second survey point was within approximately 200m of the original.

During these campaigns daytime measurements (morning, afternoon and evening) were taken with the intention of covering a whole daytime cycle. A typical measurement consisted of the chamber being placed over the collar for a period of 3 to 5 minutes and change in CH_4 and CO_2 concentration recorded for calculating the soil CH_4 flux. At each flux measurement point the soil moisture and temperature data is recorded. After the flux measurement is completed, a sample is taken of the top 10 cm of soil within the collar and sealed into a plastic bag for later analysis. Soil samples were refrigerated as soon as possible after collection.

Figure 28 Surface soil survey locations for 2015

Figure 29 Soil gas flux measuring equipment and collar

4.2.2 Soil analysis

Soil carbon and nitrogen content was analysed based on Dumas dry combustion techniques determined by an Elementar analyser (Germany) operating at a combustion temperature of 1000°C resulting in production, purification and measurement when soil C and N is ignited in a stream of O_2. Since the soil samples are quite low in carbonate minerals and charcoal most of the carbon can be assumed as organic carbon.

Soil electrical conductivity was determined based on a 1:5 w/v soil/water extract with air-dry (40°C) by end-over-end mechanically shaking at 25°C for 1 h to dissolve soluble salts then allowed to settle for around 20–30 min and read using a calibrated conductivity cell. While it is realised sparingly soluble salts will contribute to a greater extent at this ratio than at more concentrated ratios, the values of EC are satisfactory for most purposes.

Soil pH was determined using dilute calcium chloride (0.01 M $CaCl_2$) at a 1:5 soil/solution extract with air-dry (40°C) by end-over-end mechanically shaking at 25°C for 1 h to dissolve soluble salts then allowed to settle for around 20–30 min and read by positioning the pH

meter in the unstirred supernatant during measurement. The results obtained using $CaCl_2$ extractant are commonly 0.5 to 1.0 pH unit lower than those obtained in water but pH variability is lower with fluctuation in soil soluble salts, due to seasonal conditions and variation in fertiliser inputs.

Soil particle size analysis was determined using a method involving dispersion and separation of the particles into size groups. This method is a reproducible technique that eliminates factors that may affect field texture such as organic matter content, clay mineralogy, cation composition and the presence of cementing agents. The method comprises two parts: (1) Dispersion and pre-treatment - Pre-treatment of the soil may be needed to remove organic matter and salts such as gypsum. Iron oxides, calcium carbonate and magnesium carbonate should also be removed as they are common cementing agents in Australian soils. Pre-treatment of the soil will allow it to disperse completely. (2) Fractionation: separating each particle size group (sand, silt and clay) from a pre-treated soil and water mixture by allowing the soil particles of different size to settle out of solution at different times (small clay particles take the longest). The fractions are subsequently dried and weighed and the sand, silt and clay must add up to 100%.

Soil microbial biomass consists mostly of bacteria and fungi, which decompose crop residues and organic matter in soil. About half the microbial biomass is located in the surface 10 cm of a soil profile and generally, up to 5% of the total organic carbon and nitrogen in soil is contained in the microbial biomass at any one time. When microorganisms die, these nutrients are released in forms that can be taken up by plants. The microbial biomass was determined based on chloroform ($CHCl_3$) fumigation and extraction method with the rationale that the fumigant lysed the soil microbes and the resulting increase in CO_2 evolution from fumigated soil as compared to unfumigated at 25^oC is directly proportional to the amount of microbial C. The amount of CO_2 released is determined by absorbing in 0.5M K_2SO_4 determined using a total dissolved organic carbon analyser.

4.3 Results

4.3.1 Survey Results for soil surface CH_4 flux

The results of two soil methane surveys conducted during May 2015 and repeated in May 2016 are shown below. For Survey 2 for logistical reasons related to timing and weather, it was not possible to completely duplicate each of the sites measured in Survey 1. Where the original site could not be measured, a new site was chosen as close as practicable to the first, usually within 100-200m. Figure 28 shows the relative locations of Survey sites 1 and 2 and Figure 30 shows the differences between the flux data gathered at each site. In total, there were nine sites where the second survey was not taken and 20 where both surveys were completed. In one case, the second survey could not be completed as the site was now under the cement pad of one of the petroleum exploration holes.

Figure 30 Soil surface CH_4 survey determined during the two surveys and timing details

The soil gas flux values measured at each site are shown in Figure 31. The intensity of the colour reflects the flux, which varies between positive 0.5 to negative 0.05 nmol/sec. The observed fluxes during the two surveys do not show any anomalous flux levels and the current level of background CH_4 is around 1.787 μmol mol^{-1}.

Figure 32 (survey location 28) and Figure 33 (survey location 8) show two examples of the rate of change of CH_4 evolving from the soil for two locations during the flux chamber measurement. At each location, the chamber is closed for a specific length of time (300 seconds in this instance) and the measured data plotted per second. The two scenarios depicted are: 1) when CH_4 rate of change shows a negative flux measurement and the concomitant change in CO_2; 2) when CH_4 rate of change shows a positive flux and the lack of a clear relationship with CO_2, respectively. Figure 36 shows the typical mean soil methane flux observed (0.045 mmols m-2 s-1) across the surveys. The blue line is the 95% confidence level and red line 95% prediction. Overall, it can be seen there is very little variation in the flux across the survey site.

Overall, the daytime soil CH_4 flux measurements have a weak net sink for CH_4 and follow a unimodal pattern, peaking during mid-day and lowest at dawn and dusk. For few observations, especially during early mornings and evening a slight CH_4 source was also observed which was also associated by an absence of strong increase in CO_2.

4.3.2 CH_4 flux at the control sites and well locations

As previously mentioned, the control sites were selected at locations which are not anticipated to undergo any development during the lifetime of the field. The sites were located based on available geophysical data and in consultation with Latent Petroleum. The current levels of CH_4 flux at the control sites is similar to the levels observed at the other survey locations.

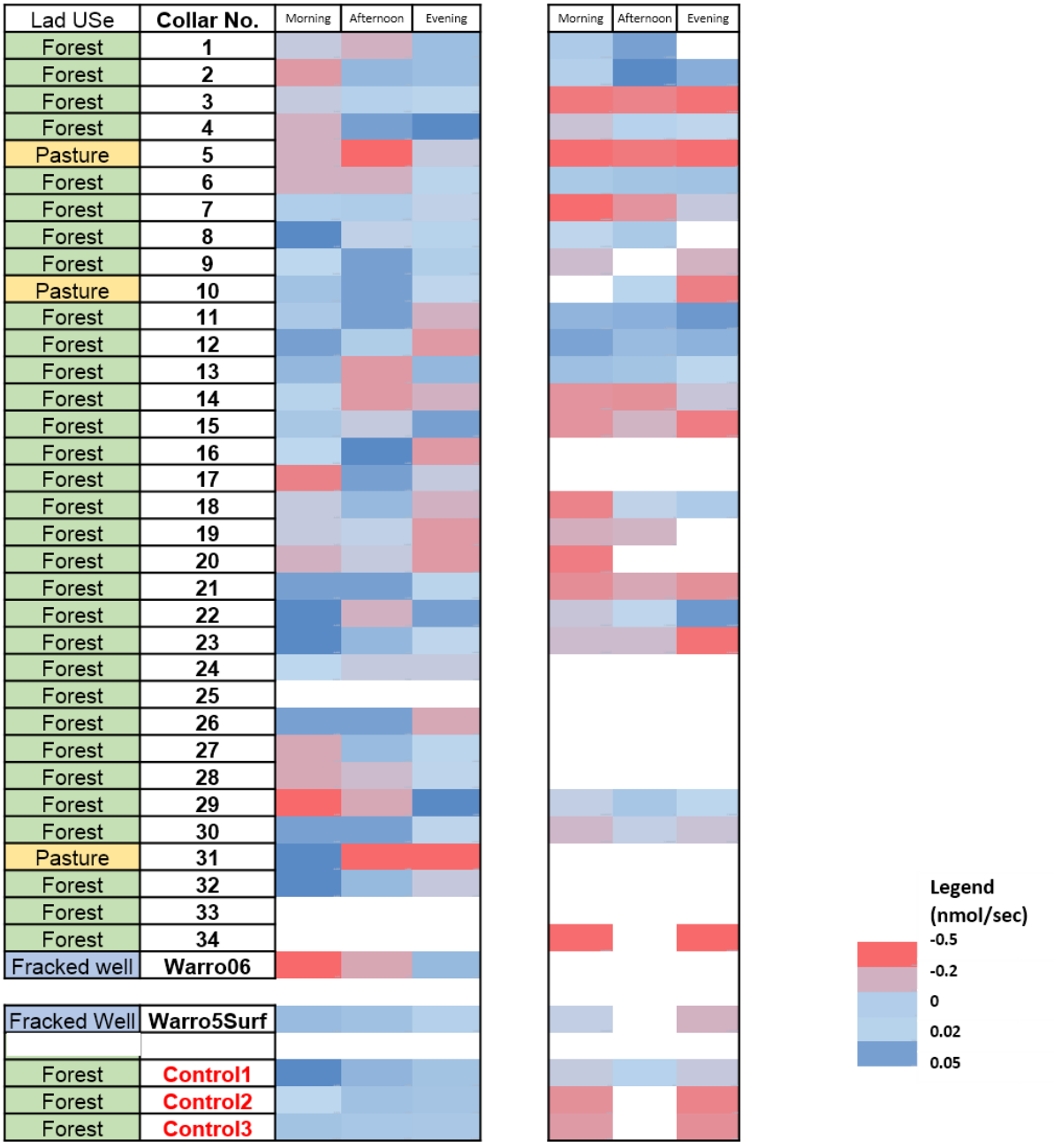


Figure 31 Soil surface CH_4 flux values at each survey location.

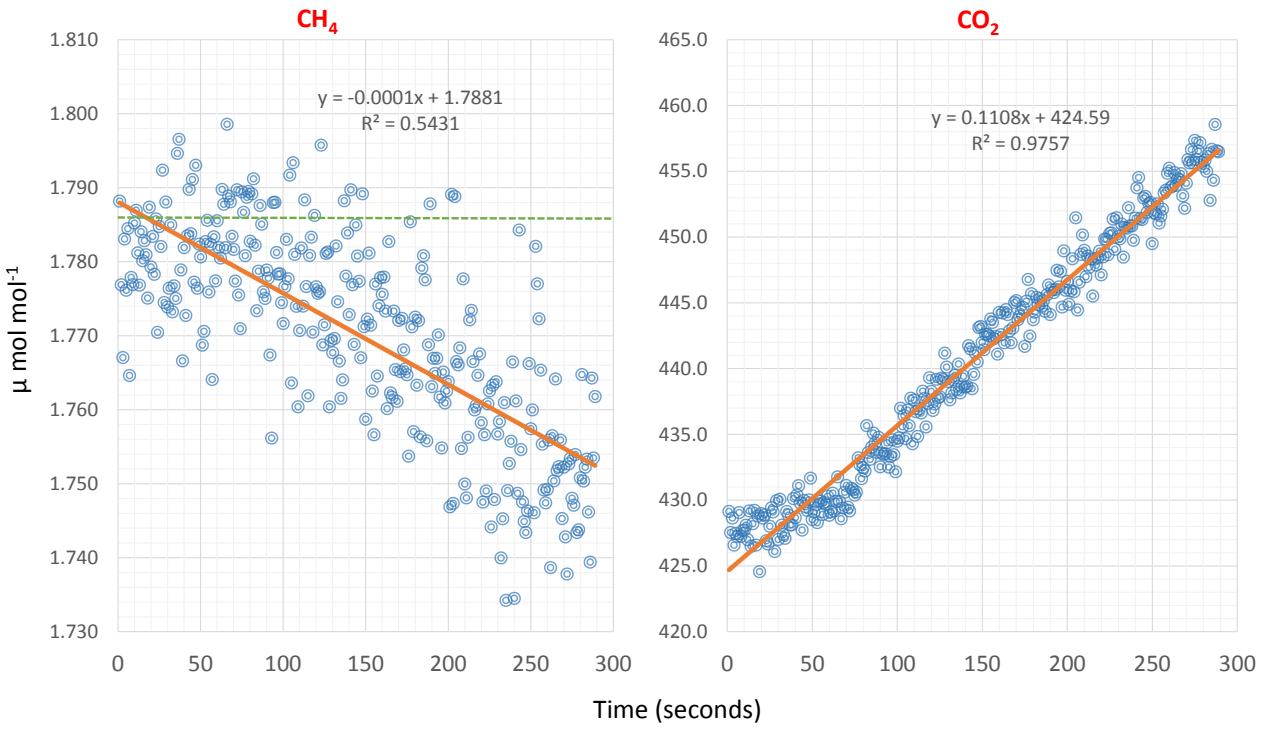


Figure 32 Weak net CH4 sink and associated increase in CO_2 (Survey location: 28). The green dashed line indicates the current level (1.787 µ mol mol^{-1}) of ambient atmospheric CH_4

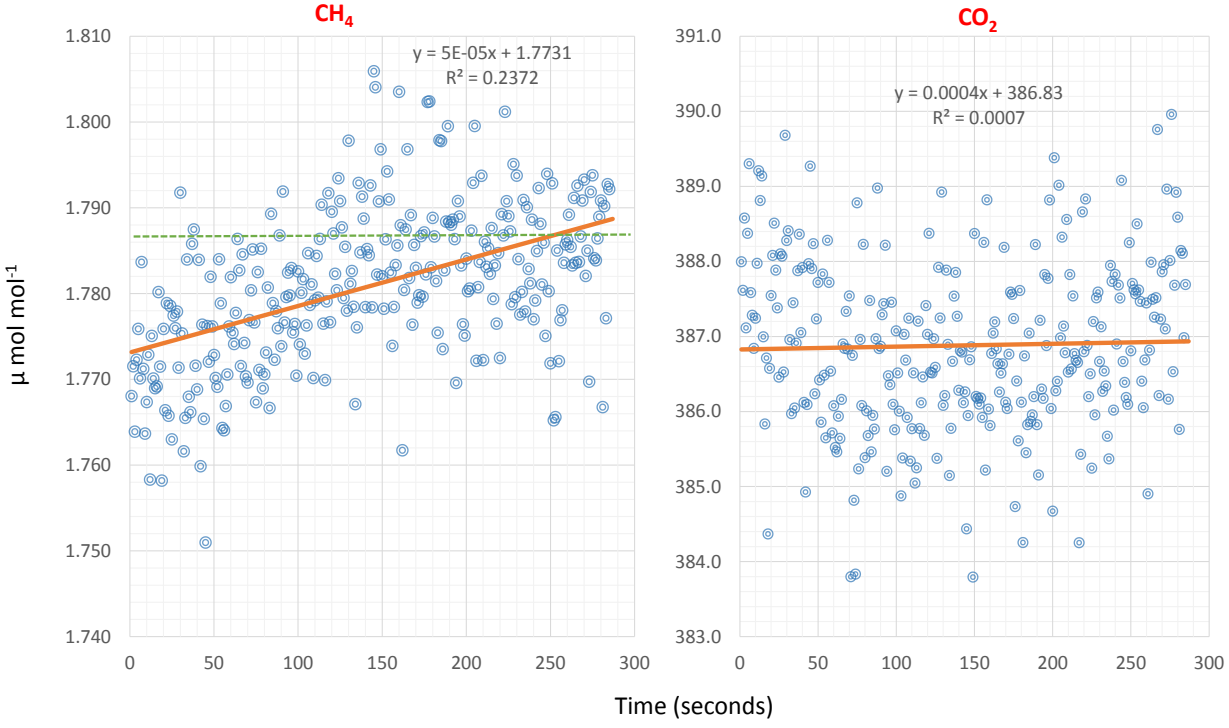


Figure 33 Weak net CH_4 source and absence of strong increase in CO_2 (Survey location: 8). The green dashed line indicates the current level (1.787 µ mol mol^{-1}) of ambient atmospheric CH_4

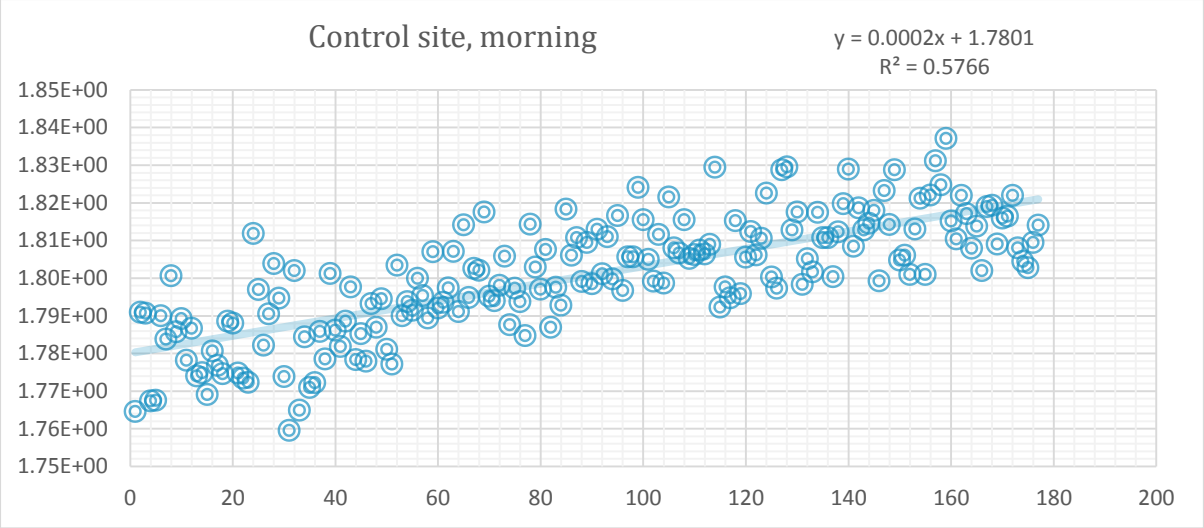


Figure 34 CH_4 flux in the morning, at control site 2

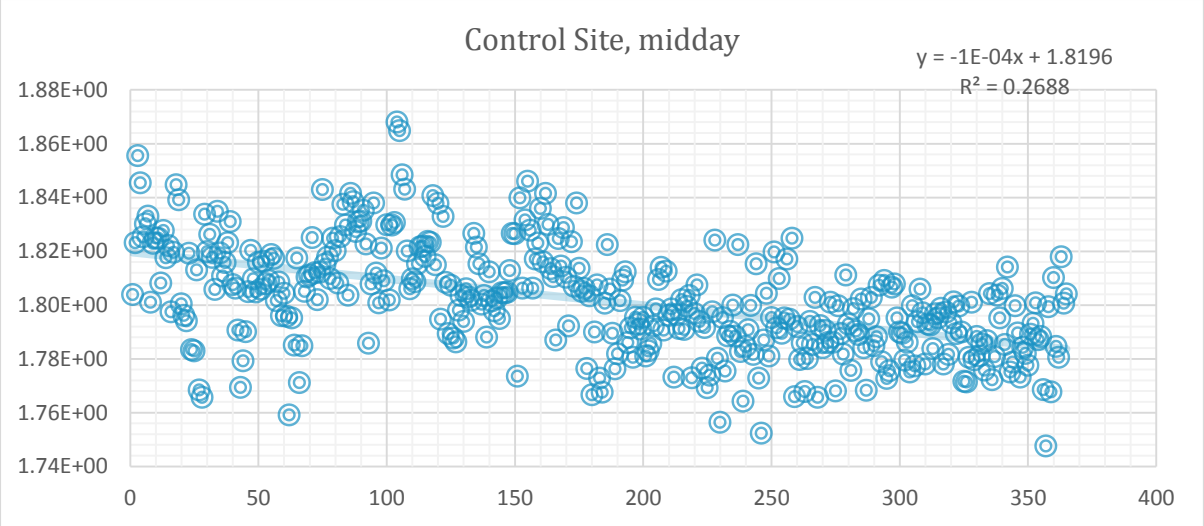


Figure 35 CH_4 flux at midday, at control site 2

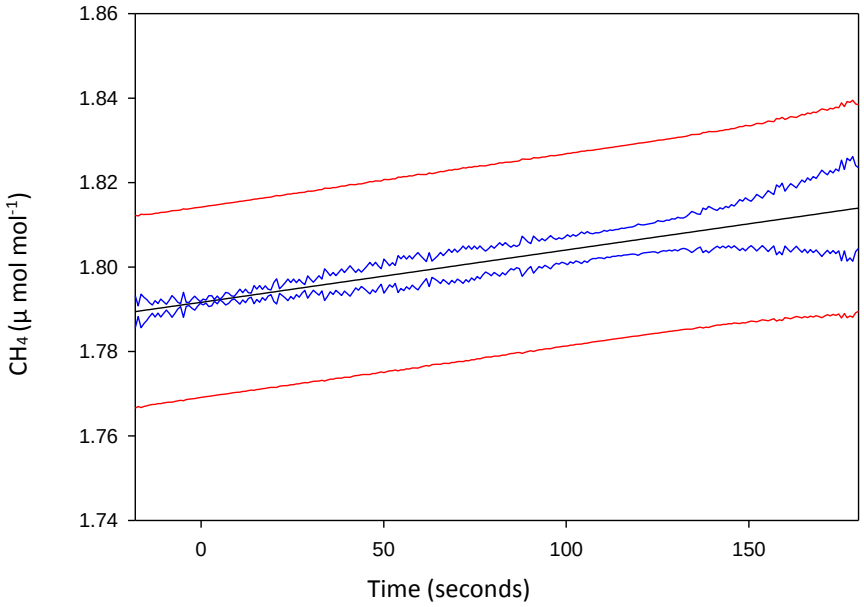
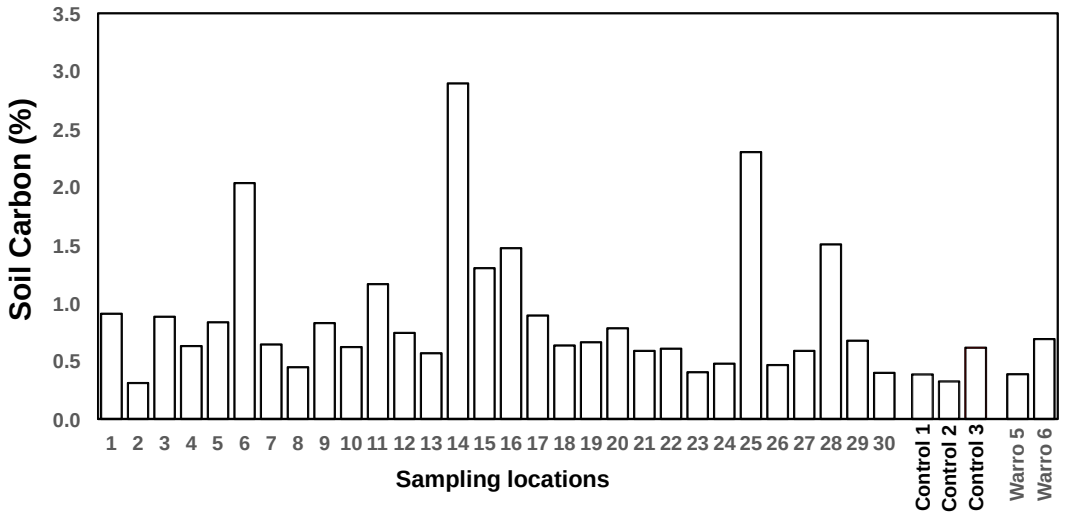


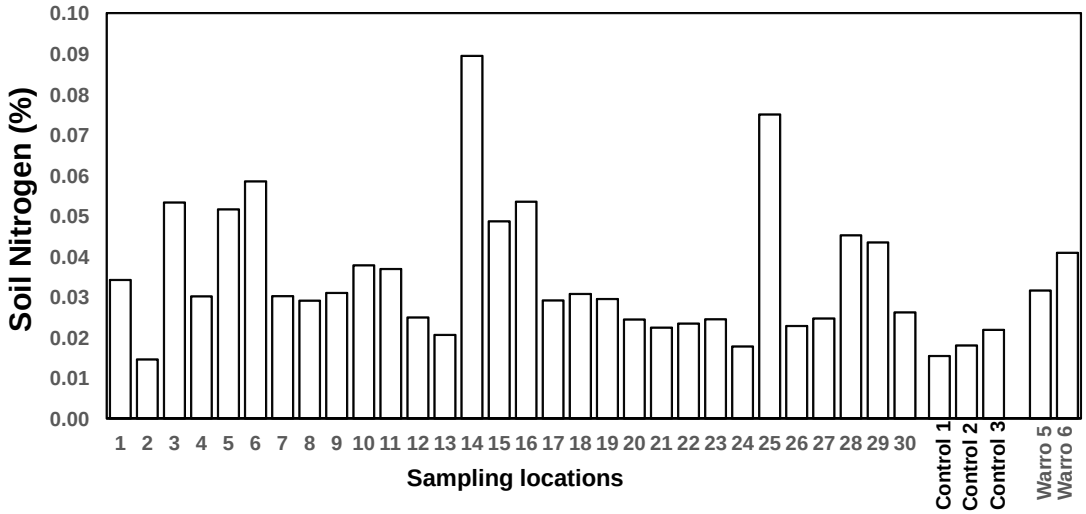
Figure 36 Typical mean soil CH_4 flux observed (0.045 mmols m-2 s-1). The blue line is the 95% confidence level and red line 95% prediction.

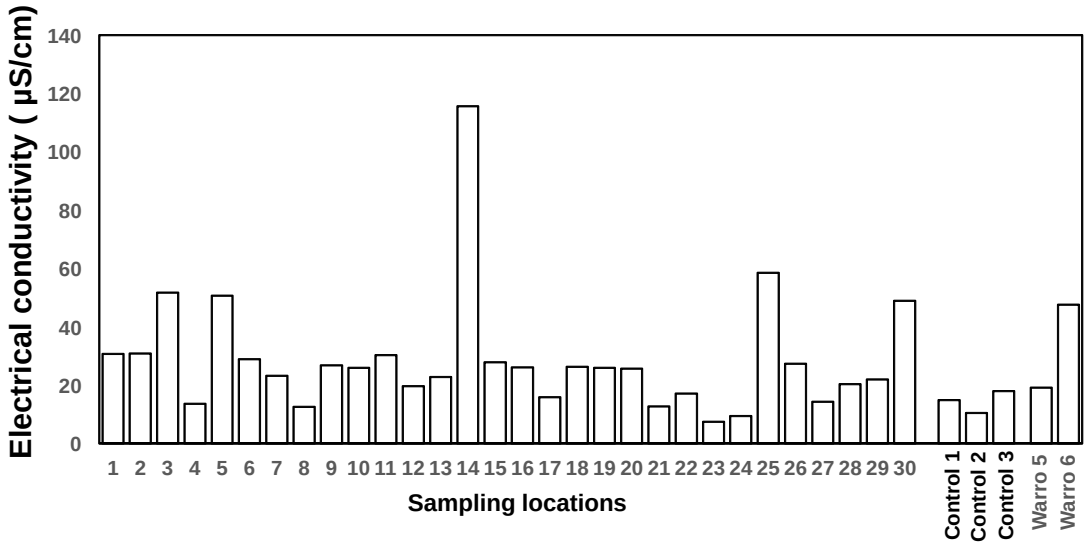
4.3.3 Soil parameters

Even though there is paucity of soil methane flux data from Australia and specifically Western Australia, previous studies have linked soil methane flux to predictor soil properties as potential surrogate soil parameters. A suite of biological and physico-chemical parameters were selected to investigate this relationship: carbon, carbonates, microbial biomass, temperature and moisture (primary abiotic drivers of CH_4 respiration), pH and particle size analysis in order to better constrain the processes controlling CH_4. The results for each parameter analyses are shown below

Average soil carbon 0.84%, standard deviation of ±0.56% and average soil nitrogen values of 0.034 % standard deviation of ±0.016% showed that these values are quite low with little variation at the locations surveyed. Average electrical conductivity values (27.2 µS/cm), $pH_{(CaCl2)}$ (4.2), soil microbial biomass (0.44 µg/g) and dissolved carbon (0.34 µg/g) similarly show a low level of variability for the surveyed locations.


Soil Carbon (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations


Soil Nitrogen (%)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations


Electrical conductivity (µS/cm)
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Control 1
Control 2
Control 3
Warro 5
Warro 6
Sampling locations

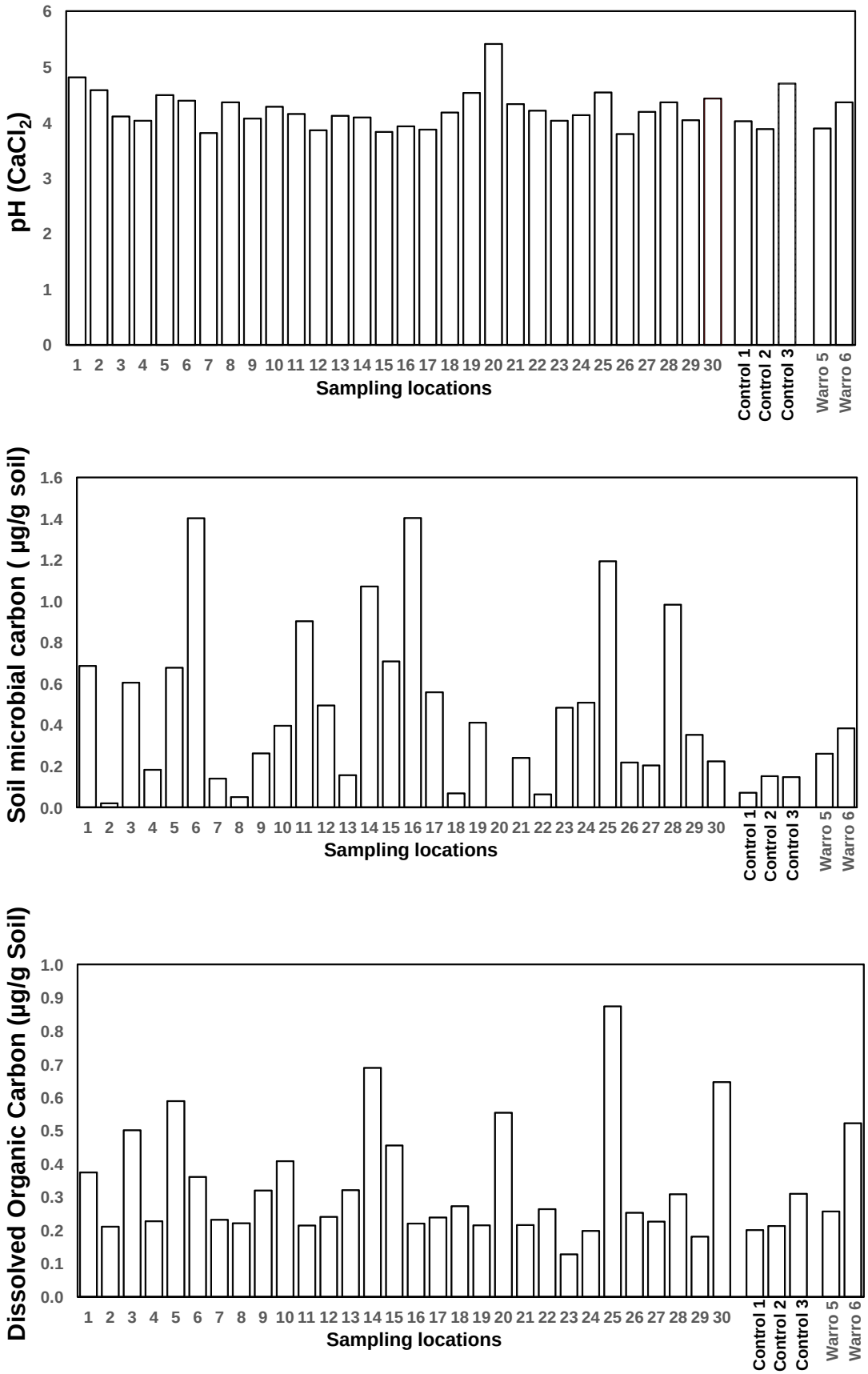


Figure 37 Results for soil sample analysis

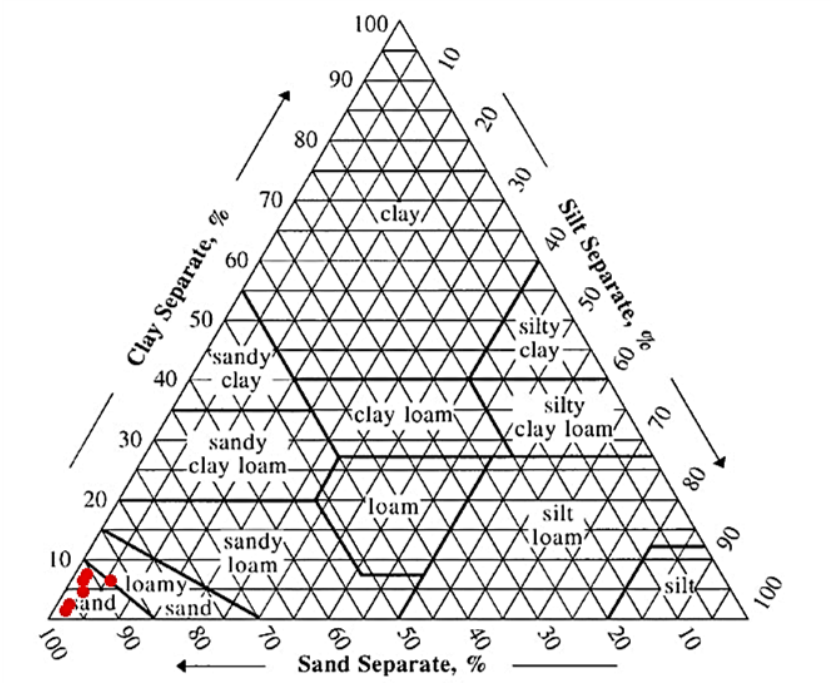


Figure 38 Soil particle size analysis

The soil particle size values showed that the soils are uniformly sandy to sandy loam.

4.3.4 Soil temperature and moisture

Compared to the above mentioned soil parameters, the soil temperature and moisture parameters usually show a higher degree of temporal and spatial variation and thus were recorded at the time of each soil methane flux measurement. Not surprisingly, these values showed variability not only between times of the day but also between the two surveys.

Figure 39 shows the mean soil temperature and moisture values measured at the three periods across the day, morning, midday and late afternoon. On average soil temperature was highest around midday and dropped off again towards afternoon. The soil moisture content was highest in the morning, when the soil was also coolest and dropped off around midday, rising slightly in the afternoon.

Figure 40 shows an increase in CH_4 flux with increasing soil moisture.

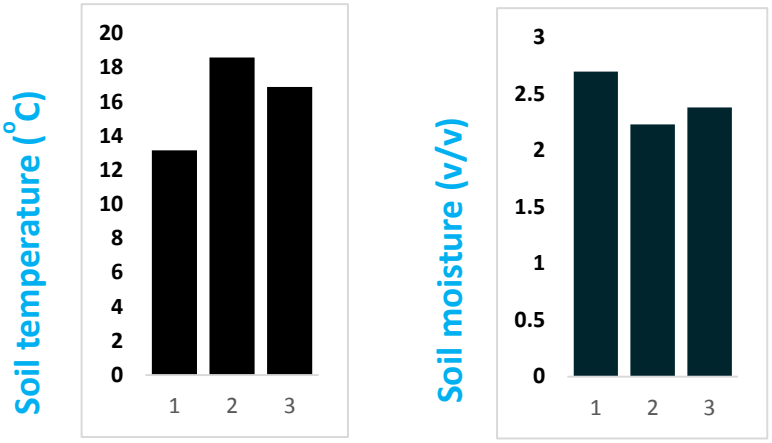


Figure 39 Daytime mean soil temperature and moisture values during the soil surface methane survey (1- morning, 2- mid-day and 3- evening).

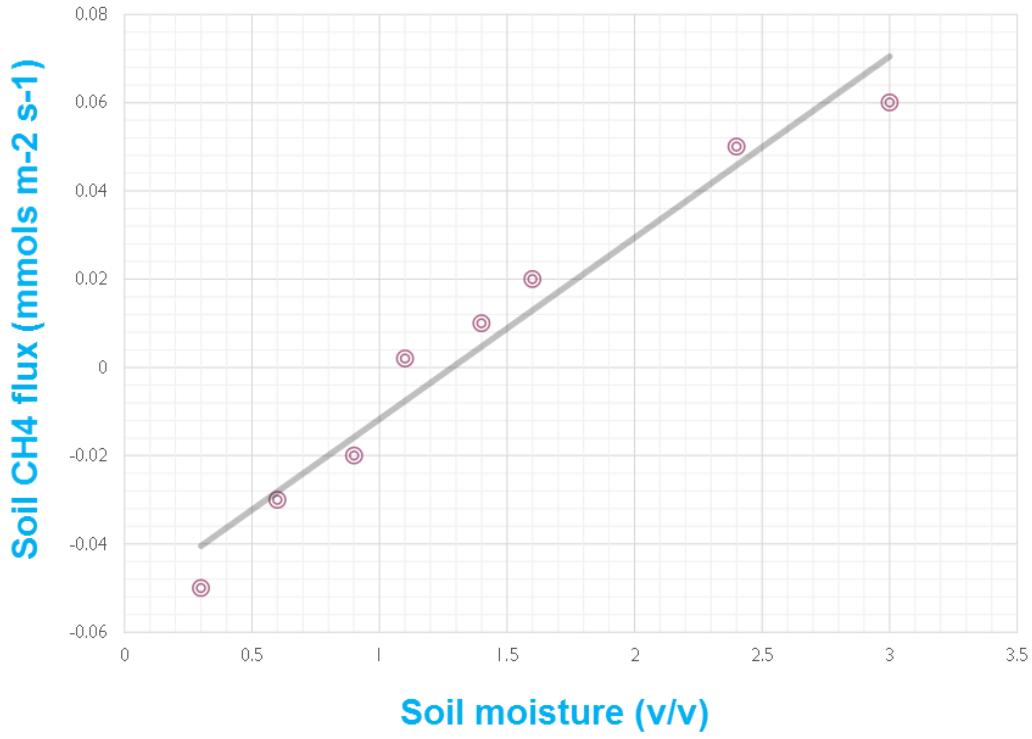


Figure 40 Soil moisture relationship with CH_4 soil flux

4.4 Conclusions

A weak net CH_4 sink was observed probably due to CH_4 oxidation (CH_4+ + $2O_2$ → CO_2 + $2H_2O$) by methanotrophic microbes occurring in aerobic condition which can be observed by a concomitant increase in CO2. For few observations, especially during early mornings and evening a slight CH_4 source was also observed which was also associated by an absence of strong increase in CO_2.

Most of the well-drained soils globally act as sources of the greenhouse gas carbon dioxide, and both sinks and sources of the greenhouse gases nitrous oxide and methane (CH_4), with well-drained aerated soils being one of the most important sinks for atmospheric CH_4. Soil CH_4 uptake is driven by aerobic CH_4 oxidation through methanotrophic bacteria that oxidize CH_4 at atmospheric to sub atmospheric concentrations with soil gas diffusivity being one of the key regulators of soil CH_4 uptake in these systems. Our results show that CH_4 uptake was regulated by soil moisture with uptake rates increasing when soil moisture decreased, which explained the temporal variability in CH_4 at the various sites studied. Soil temperature, soil carbon, soil microbial biomass and soil particle size distribution had a lesser control over this diurnal variation of observed soil surface CH_4.

Based on the two separate surveys, the CH_4 flux measured at the four sites was consistent with expected background levels. In addition, we were not able to detect any anomalous CH_4 concentration values at any of the survey points. The CH_4 concentration measurements taken around the wells were consistent with atmospheric CH_4 levels. CH_4 levels from the more comprehensive survey to determine baseline levels of CH4 within the entire 'anomalous' zone identified on the Warro 3D seismic data at shallow levels and control sites (not anticipated to undergo any development during the lifetime of the field) did not yield any anomalous CH_4.

Additional analyses need to be considered are the stable isotopic signature identification of carbon and soil microbial community studies to confirm the presence and diversity of methanotrophs. Modelling near atmospheric CH_4 on a landscape scale using identified driver variables at selected locations in the Perth Basin is also recommended.

5 Semi-permanent Soil Gas Flux Installation

5.1 Introduction

The soil gas flux survey represents a “snapshot” of the soil gas flux taken at the time of the survey. In order to get an understanding of the seasonal variation in the gas flux in the soil around the Warro field site, we set up a long-term soil gas flux monitoring station. This set-up is unique to the best of our knowledge. There were significant difficulties associated with powering and maintaining the system remotely which required several trips and modifications. Consequently, only a small set of useful data was obtained. However, the system is now considered robust and will be setup locally and undergo further testing before installation at a future site.

5.2 Methodology

The station consisted of a Li-Cor long-term soil gas flux chamber connected to the LGR portable greenhouse gas sensor (described in the previous section). The system was powered by 12 solar panels connected to truck batteries (Figure 41). The Li-Cor was set to measure the soil gas flux every 20 minutes and remained closed for a period of two minutes before opening again (Figure 42). Adjacent to the long term chamber were a soil moisture and a soil temperature probe.

The initial installation did not have telemetry to indicate operational status and required manual restart. During winter there was insufficient sunlight to charge the batteries and solar panels, during summer the system would overheat. In both cases the system would shut down.

These issues have now been addressed through the addition of switches and telemetry to allow us to turn the system on and off remotely, as well as download the data. This modification has had to be made to both sensors, the Li-Cor chamber and the LGR. The LGR system is now on telemetry, however the Li-Cor still needs manual download of the data.

The system as it is now engineered is considerably more stable. The number of solar panels required make it not particularly portable, however, as it is intended to remain at one site for an extended period, that is not necessarily an impediment. The system would be considerably improved by reconfiguring the LGR to enable it to shut down between measurements. Although we had several conversations with the manufacturer who were helpful and enabled us to make some modifications to the system, this particularly modification was not able to be implemented. In future, if the LGR was enabled to shut down between measurements, the power drain on the batteries would be significantly reduced and hence the number of solar panels would also be reduced.

Figure 41 Long term chamber set up, solar panels and telemetry antenna shown

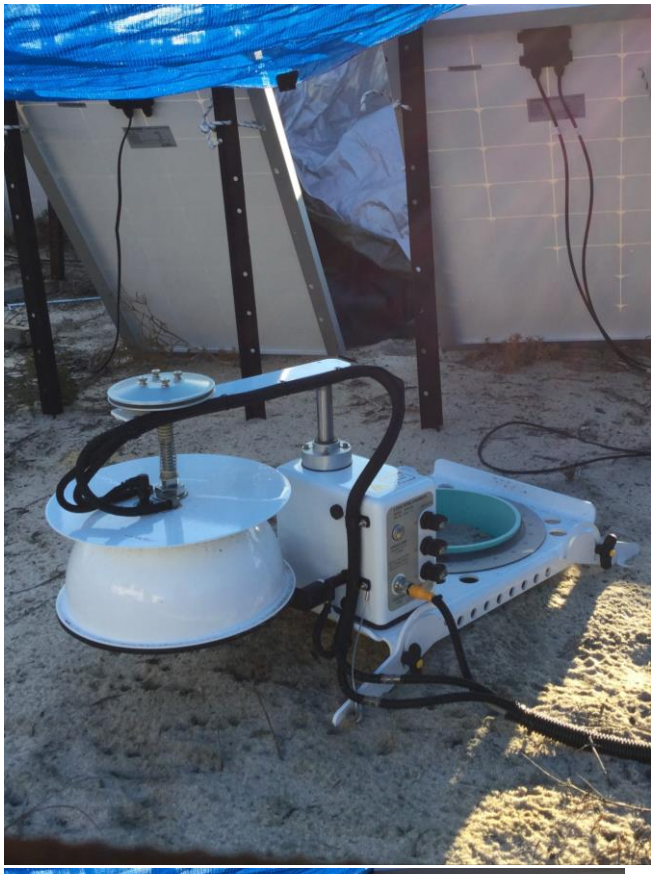


Figure 42 Long term chamber set up (a) open; (b) closed and sampling

5.3 Results

The soil gas concentration data obtained over the period has a number of gaps due to the system instabilities. In total 43 days' worth of data across June, September, October and November were obtained before the sensor failed (Table 8).

Table 8 Dates of useful measurements

Month	Date Range
June	25, 26 and 27
September	23 – 30 (9 days)
October	1 – 31 (31 days)
November	1 and 2

Due to the limited dataset, the gradients were not converted to flux and are presented here as a summary of the rate of change in CH_4 concentration across the sampling period. There was a degree of instantaneous instrument fluctuation during the measurement period which produced anomalous values during the data processing. The resultant gradients for each day have been filtered to show only those between ±0.002 ppm/sec. The gradient data collected daily is summarised Figure 43 as a box and whisker plot showing the median, 25th and 75th percentile for selected days. There were no observable seasonal trends in this preliminary analysis of the data. There are some subtleties in the data obtained, but detailed analysis is outside the scope of this project. No significant anomalies were observed.

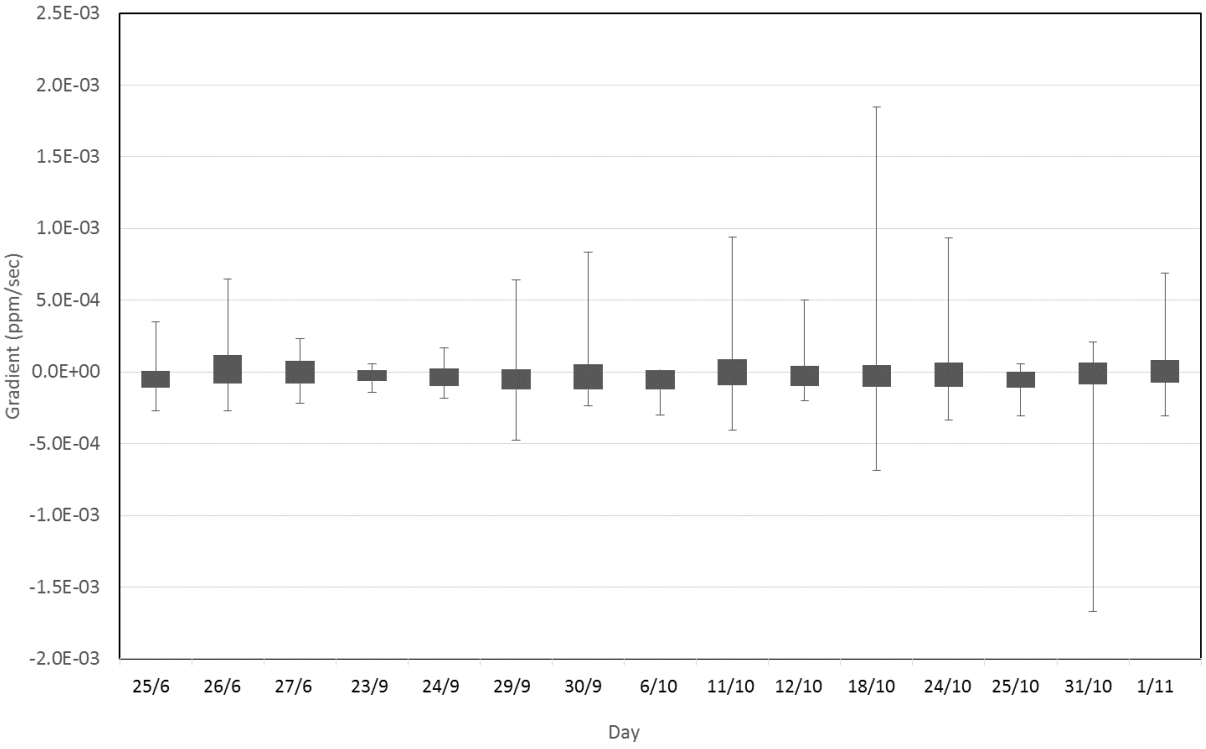


Figure 43 Soil gas gradient from selected days in 2015

5.4 Conclusions

One of the objectives of this component was to set up a long term soil gas flux monitoring station. Although this had a number of unexpected challenges, we were able to engineer a system, using off-the-shelf equipment with a number of modifications. Once the system is stabilised it requires very little maintenance. The sensors do not require regular calibration and are able to accurately measure very low flux values. The system is unique to our knowledge.

The radius of investigation of the soil gas flux surveys is extremely small. The application of a long term monitoring station is potentially useful for two scenarios. It allows the snapshot values of an intensive soil gas flux survey to be put into an annual context, with seasonal variations accounted for. The second potential application is at a point where there is either a known methane flux which needs to be monitored (for example at a near surface fault or leaking well), or at a point of significance where the risk or consequence of an anomalous methane flux is high (for example a well or fault near a water source).

The advantage of this system is that it is relatively self-sufficient, cheap to run, can be set up with telemetry, does not require drilling a well. In addition, it does not require any sampling and therefore any analysis and associated time and costs. We have not yet proven these

advantages, however, we believe we have made significant progress. The system will be setup locally and undergo further testing to be ready for future deployment.

6 Conclusions and Recommendations

There are several conclusions to be drawn from this body of work, the most significant is that this study represents the first attempt to gather ambient concentration values of methane in the near-surface in the northern Perth Basin. In most cases the data gathered in this study represents a “snapshot” of methane distribution across the area at the time of the data gathering.

The project was envisioned as the first step in establishing a Research Program to improve: 1) understanding of suitable methods and protocols for establishing environmental baselines associated with tight and shale gas development, and 2) identification of vulnerable aspects of environmental domains to effectively target monitoring for potential impact. Understanding the controls and variations of the current environmental baseline is necessary to achieve both of these long term objectives.

With respect to understanding and quantifying ambient near-surface CH_4 concentration, this project has concluded that:

1. Although there exists a good interpretation of regional flow in the northern Perth Basin, at this stage there is inadequate monitoring of the key aquifers for establishing baseline conditions.
2. Ambient levels of CH_4 across the basin were found to be consistent with the expected background concentration. It is recommended that the impacts of stationary sources (facilities, towns, lakes and old petroleum wells) and from mobile sources, such as cattle, be investigated in future studies.
3. The concentrated soil gas flux survey found no anomalous readings and the data indicated the flux was being controlled by microbial action. Additional sampling and modelling is recommended.
4. Long-term monitoring of soil gas flux rates to understand seasonal variations are important to place the soil gas flux surveys in context and may provide the basis to allow predictions of changes in methane flux rates related to changing climatic conditions. During this project a system was developed to provide ongoing, continuous (every 20 minutes) measurements of soil gas flux. Due to ongoing system problems very little useful data was obtained, however, the system is now robust and undergoing further testing ready for future deployment.

References

Day S, Ong C, Rodger A, Etheridge D, Hibberd M, van Gorsel Spencer D, Krummel P, Zegelin S, Fry R, Dell'Amico M, Sestak S, Williams D, Loh Z and Barrett D (2015) Characterisation of Regional Fluxes of Methane in the Surat Basin, Queensland: Phase 2: A pilot study of methodology to detect and quantify methane sources. CSIRO Australia.

Department of Water (2016) Geology, hydrogeology and groundwater resources of the Northern Perth Basin, Western Australia, Department of Water, Hydrogeological Bulletin Series, Report No. HB1.

DoW (2016) Water Information Reporting database. Viewed 1 August 2016, <http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx>.

DMP (2016) Guidelines groundwater monitoring in the onshore petroleum and geothermal industry, Department of Mines and Petroleum, Western Australia.

Issa N, Lumley D, Drew J, Hoskin T and Saygin E, (2016) Final Report: Passive seismic monitoring at the Warr field, Prepared for Baseline Characterisation and Monitoring Protocols for Development of Shale and Tight Gas Resources, Perth Basin Project. Centre for Enegy Geoscience, University of Western Australia, 85pp.

Olierook HKH, Timms NE, Wellmann JF, Corbel S and Wilkes PG (2015) 3D structural and straigraphic model of the Perth Basin, western Australia: implications for sub-basin evolution. Australian Journal of Earth Science: An International Geoscience Journal of the Geological Society of Australia. DOI: 10.1080/08120099.2015.1054882

Rockwater (2013) Warro Project Hydrogeological modelling of potential impacts, Report for Latent Petroluem, Report no. 430.0/13/0

Appendix A

A.1 Data Accuracy

A.1.1 Formation Bases

The formation bases have been generated from structural contours with a 200m interval (MGA50 projection) and use AHD (Australian Height Datum) as the vertical datum.

MGA 50 projection parameters

- *GDA_1994_MGA_Zone_50*
- *WKID: 28350 Authority: EPSG*
- *Projection: Transverse_Mercator*
- *False_Easting: 500000.0*
- *False_Northing: 10000000.0*
- *Central_Meridian: 117.0*
- *Scale_Factor: 0.9996*
- *Latitude_Of_Origin: 0.0*
- *Linear Unit: Meter (1.0)*
- *Geographic Coordinate System: GCS_GDA_1994*
- *Angular Unit: Degree (0.0174532925199433)*
- *Prime Meridian: Greenwich (0.0)*
- *Datum: D_GDA_1994*
- *Spheroid: GRS_1980*
- *Semimajor Axis: 6378137.0*
- *Semiminor Axis: 6356752.314140356*
- *Inverse Flattening: 298.257222101*

Bore Depths

Bore depths start from ground level - this is an SRTM 3 arc second (~ 90m) surface. The original SRTM data has the WGS84 datum.

SRTM Metadata

To use C-band and X-band interferometric synthetic aperture radars (IFSARs) to acquire topographic data over 80% of Earth's land mass (between 60degN and 56degS) during an 11-day Shuttle mission. Produce digital topographic map products which meet Interferometric Terrain Height Data (ITHD)-2 specifications (30 m x 30 m spatial sampling with <=16 m absolute vertical height accuracy, <= 10 m relative vertical height accuracy and

<=20 m absolute horizontal circular accuracy). All accuracies are quoted at the 90% level, consistent with National Map Accuracy Standards

The WGS84 datum parameters are:

- *GCS_WGS_1984*
- *WKID: 4326 Authority: EPSG*
- *Angular Unit: Degree (0.0174532925199433)*
- *Prime Meridian: Greenwich (0.0)*
- *Datum: D_WGS_1984*
- *Spheroid: WGS_1984*
- *Semimajor Axis: 6378137.0*
- *Semiminor Axis: 6356752.314245179*
- *Inverse Flattening: 298.257223563*

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