TO:	Clancy Mackaway – Department of Environment Science (DES)
FROM:	Andrew Hall - Arrow Energy (Arrow)
SUBJECT:	Your reference: C-EA-100138470 Hopeland EA Amendment Application – Response to Information Request
DATE:	4 April 2022

Background

- On 8 August 2018, Arrow was granted a site-specific Environmental Authority (EA) to conduct activities in the Hopeland area (EA0001401). This EA authorised six (6) CSG production wells and supported a successful application for the grant of Petroleum Lease (PL) 253.
- On 6 July 2020, Arrow lodged an EA Amendment application to extend the authorised activities by an additional 280 CSG production wells, representing the full Surat Gas Project (SGP) development on PL253.
- After discussions with DES, Arrow withdrew the full development EA Amendment application on 6 October 2021 in favour of a two-staged development application:
    - Stage 1 being 55 wells in the south-eastern corner of PL253 – the EA Amendment application was lodged on 6 October 2021;
    - Stage 2 being the remaining 225 wells – the EA is planned to be lodged Q3 2022.
- The planned activities on PL253 are pivotal to the successful delivery of the SGP. The SGP was approved by the Australian and Queensland governments in 2013 via the approval of Arrow's Environmental Impact Statement (EIS).
- On 20 October 2021, DES notified Arrow that the Stage 1 application was 'properly made' and that the assessment level decision was determined to be a 'major' amendment. The DES provided a further notice advising of the requirement for public notification in a substituted way (i.e. to occur after the information stage).
- On 18 November 2021, DES provided Arrow with an information request in relation to the EA amendment application. An information request is issued by the administering authority (i.e. DES) to obtain further information that will assist with the assessment of an amendment application for a site-specific EA.
- This memorandum describes and responds to the additional information requested by DES.

Response to DES Information Request

The Information Request received from DES on 18 November 2021 is provided in its entirety as Attachment A. The following identifies each of the eleven (11) items of information requested from DES followed by the Arrow response. The numbering below follows that of the DES Information Request.

1) **On page 11 of the application supporting material, Arrow CSG (Australia) Pty Ltd (Arrow) has detailed the proposed changes to General 1 Table 1 of the existing EA. Please confirm the following:**
   a) **Whether additional sediment ponds are required;**
   b) **Whether additional disturbance for raw water pipelines are required; and**
   c) **The disturbance (in hectares) of gathering pipelines being applied for.**

Table 1 – Information Request Item 1

Information Request Reference	Response
1a)	Arrow confirms that no additional sediment ponds are required.
1b)	The raw water pipelines will be installed within a common Right of Way along with the gas pipeline and therefore no additional disturbance is required beyond that already included within the EA Amendment application.
1c)	The maximum disturbance in hectares of gathering pipelines (co-located water and gas gathering) being applied for is 155 ha.

2) Arrow proposes to amend the definition of Essential Petroleum Activities to include communications towers. Please provide an indication of how many communications towers are required, what infrastructure is involved, the maximum size of disturbance/footprint required for each and what impact this may have on environmental values.

Table 2 - Information Request Item 2

Information Request Reference	Response
2	Page 31 states that '*provision within the definitions of this EA is sought to allow for a tower on PL253 as there is one proposed to be located on PL253 on a one hectare pad*.' Each tower will be 55 m in height. At ground level, the tower site will include a communications hut, diesel generator and 1,000 L fuel tank. The tower facility footprint is 30 x 20 metres with additional area required for fire clearance and provision for perimeter roads for light vehicle access and also for crane access during the construction of the tower and for future maintenance activities. These sizes are consistent with the definition of essential petroleum activities in the previously approved Arrow Energy's Dalby Expansion Project (DXP) EA (EPPG00972513). A proposed location has been assessed as part of the EA application however the specific location of the tower is yet to be confirmed because the agreement with the landholder is not finalised. However, the proposed location has been identified based on discussions with the landholder and has been selected due to the elevated position (hill) and because it is adjacent to Ergon power facilities. Nevertheless, Arrow is familiar with the environmental values relevant to the construction of communications towers, and the relevant environmental values that Arrow will seek to avoid and/or minimise impacts to are: • Biological environment; • Air quality; and • Visual amenity.

	Biological environment The proposed tower is located in an area that has been ground verified by Arrow as High Value Regrowth Regional Ecosystem (RE) 11.5.1. This area is also mapped by Government as: • 0.9 ha is mapped as essential habitat for golden-tailed gecko (*Strophurus taenicauda*). As a near-threatened species, essential habitat for golden-tailed gecko does not meet the definition of an Environmentally Sensitive Area under Streamlined Model Conditions for Petroleum Activities, nor is it subject to offset requirements for resources activities under Queensland Government's Environmental Offsets Framework. • Regrowth RE 11.5.1 may provide habitat for the Koala (*Phascolarctos cinereus*). Offsets will be secured under applicable legislation and a fauna spotter catcher will attend sites prior to, during and following construction activities. Site activities will be planned for minimum disturbance and clearing boundaries will be clearly marked in the field to avoid any unplanned clearing of vegetation. The proposed tower is located entirely within land zone 5 (Tertiary-early Quaternary plains with sandy or loamy soils). The dominant soil types in land zone 5 are usually Tenosols and Kandosols, also minor deep sandy surfaced Sodosols and Chromosols. Strict soil handling and reuse practices will be adopted in areas of ground disturbance activities which will then be progressively rehabilitated soon after infrastructure installation. Further, topsoil and subsoil will be stripped according to profile depths and stockpiled separately. Stripping depths for disturbance areas will be subject to further field investigations during stripping activities to ensure the necessary controls are in place to minimise the potential for sediment runoff from the site. Also, the stabilisation and revegetation of long-term stockpiles will be undertaken as soon as practicable to reduce the potential for erosion. The tower site will be designed with careful consideration of the potential impact of overland flow during rainfall and flood conditions. This includes reducing the flow concentration and gully creation by minimising disruption to natural overland flow paths through the re-establishment of natural surface drainage lines where required.

	Air quality Potential impacts to air quality may arise from emissions of particulate matter (i.e. dust) generated during the construction activities. Potential impacts will be managed through implementation of the Construction Environmental Management Plan and include: • Application of water by water trucks on exposed areas including stockpiles; • Visual observation of dust emissions (particularly during dry and windy conditions) and increasing the water application frequency if required; • Vehicle loads that may generate nuisance dust will be covered; • Vehicle speed restrictions will be imposed at the construction site to minimise wheel generated dust. ***Visual amenity*** Visual amenity nuisance caused by the height of the towers will be mitigated by locating the tower in areas with surrounding vegetation and / or with an adequate separation distance from sensitive receptors. This will be discussed with the landholders at the time of siting the towers and Arrow will seek to preferentially locate the towers as per the feedback from the landholder. Including the landholders in the decision-making process for tower locations also reduces the potential for noise nuisance that may otherwise be caused during the construction of the tower. It is noted that there is no audible noise omitted during the operation of the tower.

3) **Arrow proposes to amend the definition for Essential Petroleum Activities to allow disposal of residual drilling material to occur in areas of pre-existing disturbance in the primary protection zones of Category B environmentally sensitive areas that are 'endangered' regional ecosystems and Category C environmentally sensitive areas other than 'nature refuges' or 'koala habitat' areas. Please provide the following:**
   a) **Quality characteristics of the drilling material, including an assessment of whether the material constitutes a regulated waste;**
   b) **Method for undertaking the disposal of drilling material;**
   c) **A risk assessment prepared by a suitably qualified person that identifies the possible impacts due to the proposed activity and all associated risks (including contamination risks) to environmental values. This is to include:**
      i. **An assessment of any additional risk in undertaking disposal of drilling material within primary protection zones of Category B and Category C environmentally sensitive areas;**
      ii. **An assessment of any additional risk associated with shallow groundwater, and potential for any seepage or contamination to occur based on the soil structure and quality within the project area;**
      iii. **Details of additional rehabilitation requirements;**
      iv. **Consideration of the waste and resource management hierarchy in the Waste Reduction and Recycling Act 2011 and describe why all other strategies (avoid, recycle, reuse or recover) would be unsuitable; and**
      v. **Strategies to monitor and mitigate any identified risks to environmental values, including land and groundwater contamination.**

Note: Mix-bury-cover of residual drilling materials may trigger Notifiable Activity 20: Landfill—disposing of waste (excluding inert construction and demolition waste) as listed in Schedule 4 of the Environmental Protection Act 1994.

Table 3 - Information Request Item 3

Information Request Reference	**Response**
Overarching Approach	Arrow undertakes land application of residual drilling material (RDM) in accordance with Arrow's Land Application of Residual Drilling Material Work Method Statement (ORG-ARW-HSM-WOI-00046) (WMS). The WMS, which was prepared by a suitably qualified person, provides the management techniques required for the successful application of RDM to land in a manner that minimises and prevents environmental impacts in the short and long term.

	The suitability of sites for land application of RDM application are assessed using desktop screening methods and onsite assessments. The following constraints are applied unless otherwise approved by a suitably qualified person: • General site and hydrogeological conditions: These are important considerations as they mitigate the potential for runoff and the risk of sediment migration through avoiding slopes greater than 5% and potential for impacts to groundwater by avoiding areas with shallow (<5 mbgl) unconfined groundwater. • Avoid unsuitable soils which are: <30 cm deep; where erosion has exposed subsoils; have noticeable (>50% by volume) coarse particles (>2 mm diameter gravel); and / or rocks, or other large obstructions such as tree stumps or boulders that would impede RDM spreading. • Locate sites at least 100 m from a surface water body to prevent the potential for direct entry into surface water or infiltration and discharge into surface-water. • Locate sites at least 200 m from any natural wetland. • Locate sites at least 100 m from any Environmentally Sensitive Areas (ESAs). A response to each of the points raised in the DES request is provided below.
3a)	Prior to land application, baseline soil sampling for targeted soil quality parameters is undertaken in conjunction with the site selection ecological assessment. Baseline soil data is collected in the proposed application areas and/or an analogue site/s if appropriate to facilitate a testing program. The following occurs: • Validation and/or development of site-specific application rates considering soil salinity and cumulative contaminant loading (CCL) limitations for the proposed application areas; • Provision of data against which post application soil quality data can be compared; • Assessment of soil amendment (e.g. gypsum) and fertiliser requirements (by a suitably qualified person) to facilitate robust rehabilitation and plant growth and management of soil structure. To account for the differences in physical and chemical properties that RDM may exhibit, Arrow characterises the RDM using the Land Application Calculator (which has been developed from historical results

<table>
<tr><td></td><td>including the EHS Support 2016: Theten Land Application Trial) to confirm that the application and potential amendment rates provided in the proposed testing program are appropriate. This occurs prior to the application of the RDM.

Post-application, sampling is also undertaken and compared to the environmental screening levels in the WMS to confirm that no adverse impacts have occurred as a result of the land application.

Guidelines on sampling depths and frequency are including in the WMS. The analytes that are analysed at each stage in the process or shown in the following table.

<table>
<tr><th>Analyte</th><th>Sampling event</th></tr>
<tr><td>pH</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Electrical Conductivity (EC)</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Moisture Content</td><td>Baseline/RDM/Post</td></tr>
<tr><td>SAR, ESP</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Soluble Major Ions (Na, Ca, Mg, K, in mg/l) plus Cl, SO_4, Alkalinity, carbonate, bicarbonate and total</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Exchangeable Major Cations (Na, Ca, Mg, K) plus CEC (meq/100g)</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Particle Size Analysis</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Metals (Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Mo, Ni, Se, Ag, Th, Sn, U, V, Zn)</td><td>Baseline/RDM/Post</td></tr>
<tr><td>Hydrocarbons (TRH/BTEXN-plus F1/PAH) (for RDM samples: Silica gel cleanup)</td><td>Baseline/RDM/Post</td></tr>
</table>
</td></tr>
<tr><td>3b)</td><td>The proposed disposal method is through disposal to land. Land application of RDM will be undertaken as follows, in accordance with the WMS:

• Stockpiled RDM is screened if required to ensure that unsuitable rock is removed prior to land application;

• The moisture content of the RDM is visually assessed to ensure that it is suitable for spreading (e.g. in consideration of avoiding run off, dust generation and clumping)

• Mixing of RDM is undertaken to provide the required homogeneity of material so that it can be applied to land for more consistent incorporation. Trench void walls and floors are excavated to remove</td></tr>
</table>

	RDM as far as practicable without over excavation of potential dispersive subsoils. Amelioration occurs to amend the SAR/ESP levels of RDM during or post application where required.
3c)(i) & 3c)(ii)	Arrow's WMS was developed by a suitably qualified person to comply with legislation and EA conditions regarding land application and the sampling and methodology is based on Arrow's and other CSG proponents' methods for the application of RDM in addition to the experience gained by Arrow in the trial of land application of RDM at the Theten Farm (Land Application Management Plan – Theten Trial Application Site, Arrow 2014 and Theten Land Application Trial Site – Phase 1 Review, EHS 2016). Specific to the risk assessment for RDM proposed in environmentally sensitive areas and their protection zones, the following points extracted from the WMS are of relevance: • Land application of RDM does not occur within 100m of an ESAs (including secondary protections zones and the outer half of the primary protection zones) • Land application of RDM does not occur in areas with shallow (<5 mbgl) unconfined groundwater • Site selection must also include consideration of landholder constraints and applicable EA conditions which may limit types of activities permitted within certain distances of potential sensitive receptors such as ESAs, watercourses and wetlands. • Initial screening of sites will be undertaken based on desktop data to ensure that no ESAs, protected plants or animals or other sensitive receptors are likely to be impacted if land application of RDM is undertaken. Based on the findings from this baseline assessment, adjustments to the location of the proposed land application area (if required) will be undertaken to avoid identified ESAs.
3c)(iii)	Key vegetation and soil criteria in areas associated with the application of RDM will be compared with Arrows rehabilitation criteria, which include vegetation cover and soil condition. Additional soil sampling may be undertaken to identify if: • ESP and EC in shallow soils are not near background levels, or not excessively elevated (as there is likely to be an initial increase following application of RDM) • Corrective actions are identified on a site by site basis and determined by the success or failure of rehabilitation of the area where land spreading has occurred. These actions may include: o Additional testing of soils to determine potential cause of plant stress and lack of growth. On the basis of this

	testing, additional amendments and fertilisers for soils and vegetation can be applied in land application areas Amending the surface soils (post land application of RDM) to mitigate potential impacts on soil structure.
3c)(iv)	Consistent with the *Waste Reduction and Recycling Act 2011* (WRR Act) hierarchy, Arrow has developed an integrated program of drilling fluid reuse, recycling, beneficial use and lastly disposal which avoids, recovers and treats drilling fluids and cuttings and ultimately minimises the volumes requiring disposal to landfill. As per the Arrow Energy (Arrow) Health, Safety and Environment Management System (HSEMS) Procedure – Waste Management (ORG-ARW-HSM-PRO-00066), a Site Waste Management Guide (SWMG) has been prepared to guide the operations of Arrow's Well Delivery team. The guide is intended to achieve the following outcomes: • Minimise waste volumes and disposal costs; • Minimise the risk of causing harm to the environment that may arise due to waste management; • Improve operational efficiency; • Improve environmental performance; and • Meet environmental authority and other legislative requirements. The majority of waste is expected to be generated from the following activities: • Drilling activities; • Workover activities; • Completion activities; and • Plug and abandonment activities. The SWMG identifies: • Types and estimated volumes of waste streams generated • Potential environmental risks associated with waste management • Waste storage and handling requirements for different waste types that reflect the waste hierarchy and risks associated with each • Waste transport and disposal requirements • Assurance requirements • Record keeping and reporting requirements Roles and responsibilities in regard to waste management are included in Arrow's HSEMS Procedure – Waste Management and Guide – Waste classification and tracking. General waste management principles to follow to ensure compliance with EAs include: • All waste must be removed from the site and sent to a facility licensed to accept the waste unless otherwise authorised under the EA to be disposed of or re-used on site or supplied to a third party.

	• All regulated waste must be removed from the site by an authorised transporter, sent to a facility licensed to accept the waste and be accompanied with completed waste tracking certificates. • Waste must not be burned or allowed to be burned on the licensed site unless otherwise authorised under an EA. • Waste fluids and cuttings must be appropriately contained in accordance with applicable standards prior to disposal, remediation or reuse where applicable. • Coal seam gas (CSG) water must be contained and only used for purposes specifically authorised under an EA or other beneficial use approval. Individual EAs may contain additional EA-specific conditions relating to waste, e.g. application of the waste and resource management hierarchy and management principles, management of pipeline wastewater, authorised uses of produced water, supply of CSG water to third parties, sewage treatment, management of residual drilling material, onsite waste disposal and record keeping requirements. EA conditions can differ between ATPs and PLs therefore any persons making decisions regarding waste disposal, management or reuse must ensure that the relevant EA for that tenure is understood, communicated and adhered to. Arrow has also identified a detailed list of waste types anticipated for Well Delivery activities, waste management options and specific management strategies for each within the SWMG. Where more than one waste management option is indicated, the option highest up the waste hierarchy is to be selected where practicable. The order of preference is included within the SWMG. The SWMG contains the following information with respect to drilling fluids and residual drilling material: Drilling fluids are used to maintain primary well control in the well and are pumped down the drill pipe to lubricate and cool the drill bit and flush out the drill cuttings. Arrow uses water-based drilling fluids which contain small amounts of potassium chloride (2 – 3%), clay stabilisers (e.g. potassium chloride), cement additive (e.g. bentonite and calcium sulphate), disinfectant (biocide) and foaming agent (anionic surfactant similar to detergent). Arrow does not use any synthetic polymers in its drilling fluids. Onsite disposal of drill fluids are not permitted in the EA and must be disposed off-site as regulated waste. Residual Drilling Material (RDM) is defined as muds and cuttings or cement returns from well holes and which have been left behind after the drilling fluids are pumped out. Conditions relating to land application or disposal of RDM differ between EAs. Some EAs permit RDM to be disposed of on-site via mix-bury-cover or a land application method where EA conditions can be satisfied.

	A management plan or procedure approved by an environmental representative is required for all activities involving land application as a disposal method for RDM. It is to include how works will be conducted to ensure all EA conditions will be met, including any sampling required to verify that contaminant concentrations in the drill fluid/cuttings do not exceed permitted values. The following documents have been developed, and where necessary certified by a suitably qualified third party. These documents detail the Arrow's regulatory requirements when disposing of residual drilling materials: • Work Method Statement - Application of RDM (ORG-ARW-HSM-WOI-00046) • Work Instruction - Land Application (ORG-ARW-HSM-WOI-00049) • Guide - Residual Drilling Material Sampling (ORG-ARW-HSM-GUI-00114). Arrow will always reuse and recycle materials including drilling fluids and cuttings as long as it is safe and appropriate to do so. It is only once materials become unsuitable for reuse that Arrow will propose the option of disposal to land. Once this has been determined, these materials will only be spread where it has met the parameters explained earlier and were there will be no harm to environment values.
3c)(v)	Soil sampling of the parameters defined in the WMS are undertaken to assess the soil post application. The results of the soil sampling and analysis is compared with baseline soils at relevant soil depths as per the WMS. In the event that monitoring identifies signs of vegetation stress, key soil criteria are compared between the pre and post application (in addition to Arrow's rehabilitation criteria, which include vegetation cover and soil surface erosion) and additional soil sampling may be undertaken to identify if: • ESP and EC in shallow soils are not near background levels, or not excessively elevated (as there is likely to be an initial increase following application of RDM) • Corrective actions are identified on a site-by-site basis and determined by the success or failure of rehabilitation of the area where land spreading has occurred. These actions may include: o Additional testing of soils to determine potential cause of plant stress and lack of growth. On the basis of this testing, additional amendments and fertilisers for soils and vegetation can be applied in land application areas o Amending the surface soils (post land application of RDM) to mitigate potential impacts on soil structure. Should it be identified that land application is unviable (based on sampling and even with treatment of the RDM), Arrow will dispose of

	the RDM to landfill. However, in accordance with the WRR Act hierarchy, this is the least preferred management option.

4) **Section 28 of the Human Rights Act 2019 recognises the cultural rights of Aboriginal and Torres Strait Islander peoples. Section 4.4 of the application supporting material lists the various stakeholders that Arrow has undertaken engagement with, including traditional owner groups. The material mentions native title, but it has not specifically stated whether there is a current native title claim in the proposed disturbance area. Furthermore, the application material does not indicate whether there are other Aboriginal peoples, who may have a connection with the land under Aboriginal tradition, which does not require the establishment of native title. Please provide further information regarding the engagement with all Aboriginal people or groups relevant to this proposal.**

Table 4 - Information Request Item 4

Information Request Reference	**Response**
4	A search of the National Native Title Tribunal (NNTT) shows that there are no current native title claims over PL253. Arrow negotiated an Indigenous Land Use Agreement (ILUA) for an area which includes PL253. The ILUA which was registered by the NNTT on 19 September 2013 was negotiated with 11 Aboriginal groups and is called the Arrow Energy Western Downs Unclaimed Area ILUA and addresses the requirements of the *Native Title Act 1993* for the area of the development. Arrow also negotiated an accompanying Cultural Heritage Protocol with this group. As per the ILUA, Arrow meets with the Group's Committee on a regular basis and engages Western Downs' field crews to undertake pre-clearance surveys in areas of proposed disturbance. Following the SGP EIS, general consultation has continued with the communities of Wandoan, Miles, Chinchilla, Dalby and Cecil Plains. Smaller indigenous groups that belong to these communities have been included in these engagements and will continue to be engaged through these community events.

5) Provide further information to justify an amendment to condition Water 13(f) from "at least biannually" to "at least annually". This includes an impact assessment of risks to environmental values, especially groundwater.

Table 5 - Information Request Item 5

Information Request Reference	Response
5	A risk assessment was undertaken in 2020 to assess all dams across Arrow's Surat Basin tenures. The assessment examined the construction and operation of each dam along with the groundwater characteristics including sensitive receptors such as groundwater dependant ecosystems (GDEs) and landholder bores. The risk assessment demonstrated that there was a low risk of seepage to groundwater from any dams located across these tenures. Key factors for the low-risk rating included the following: • Background water quality in the vicinity of the dams is poor due to high salinity levels, and is generally unsuitable for potable, irrigation or stock watering uses. Although a release from the dams could potentially result in localised changes in groundwater salinity, it is unlikely to impair groundwater for any of these purposes. o Few sensitive groundwater receptors occur in the vicinity of the dams. Therefore, potential impacts to groundwater receptors are unlikely. The possible exceptions to this are the Derived Terrestrial GDEs in the vicinity of the Daandine and Tipton dams. However, if a loss of containment were to occur and reach a receptor, it is not likely that the impacts to a potential receptor would be any greater than that of the background groundwater, which is of poor quality in these areas. o Notwithstanding the above, estimated linear groundwater flow velocities for shallow groundwater is slow, and does not present an immediate risk to potential groundwater sensitive receptors. In most cases, assuming a significant release from a dam, the predicted groundwater travel times from dam to potential groundwater receptor are over 100 to 1,000 years. It is not expected that seepage would impact a potential groundwater receptor over the life of the dam. • Based on the risk assessment and the construction techniques applied to Arrow dams, it is considered that annual monitoring is

	sufficient to ensure the integrity of each of Arrow's SGP South dams and the surrounding groundwater. While the seepage monitoring program covers all containment facilities, regulated dams are considered to present the greatest risk to groundwater resources, due to the large volumes that they typically contain. Seepage from other containment facilities (e.g., scour pits, drill pits, cellars), can be assumed to present less of a risk to groundwater resources, due to them containing much smaller volumes, with many only used intermittently, during drilling operations at individual wells. As such, the risk assessment undertaken on Arrow's containment dams would represent the worst-case.

6) **Deviated Wells**
   a) **Provide further information regarding whether proposed deviated wells will go off tenure (subsurface).**
   b) **Provide further information on whether proposed deviated wells will result in an increased rate of dewatering/depressurisation and how this may impact the structural integrity of the formations. Consideration should also be given as to whether there will be an increased potential for fracturing to occur.**

Table 6 - Information Request Item 6

Information Request Reference	Response
6a)	Arrow confirms that no subsurface deviated well paths will leave PL253.
6b)	There is no difference in depressurization rates between vertical and deviated wells. The limit imposed on the depressurization is by the water pump off rate which is limited by the Artificial lift sizing (maximum water rate) and not by the well type. Both the vertical and deviated wells are limited by well head skid water design flow rate of 1500-1600 bbl/day. Hence the structural integrity of the formations is not impacted by deviated wells. The coal seam gas water extraction is an isothermal process. Arrow will not be conducting any stimulation (fracturing for example) on its deviated or vertical wells. It is unlikely that any fracturing will occur as a result of water and gas extraction from Walloon Coal measures. Thermal fracking of a formation might occur in high temperature operations which are a result of the underground coal gasification process. In the case of Arrow's development, the depressurisation will not change the temperature of coal seams and the likelihood of any fracturing due to temperature changes is negligible.

7) **Biodiversity:**
   a) **Appendix C of the Amendment Application Report contains a Terrestrial Ecology Report (Ecosmart Ecology, June 2017) for the entire Surat Gas Project (SGP) area. This appears to be a summary only. Please provide further details of the ecological assessment relevant to PL253 that includes, but is not limited to:**

      i. **Methodology of ecological surveys undertaken including details and justification where survey methodology has deviated from methods detailed within current Queensland Guidelines; including but not limited to the following Guidelines:**

         a. **'Methodology for surveying and mapping regional ecosystems and vegetation communities in Queensland (V5.0)' (Neldner et al. 2019);**
         b. **'Flora Survey Guidelines – Protected Plants (V2.01)' (DES 2019b);**
         c. **'Management of endangered plants' (Cropper 1993);**
         d. **'Terrestrial Vertebrate Fauna Survey Guidelines for Queensland (V3.0)' (Eyre et al. 2018); and the**
         e. **'Queensland Targeted species survey guidelines' available: https://www.qld.gov.au/environment/plants-animals/biodiversity/vertebrate-survey#download**

      ii. **Details of how the ground-truthed biodiversity values differ from Queensland government mapping e.g., locations, amount (hectares), composition, habitat features;**

      iii. **Detailed assessment results**

      iv. **A thorough, evidence-based, justification for any presence/absence determinations for matters of State environmental significance (MSES), particularly where that deviates from the Queensland government records;**

      v. **Details regarding the level of survey effort undertaken for flora and fauna values within the proposed disturbance area for the amendment as the provided Terrestrial Ecology Report (Ecosmart Ecology, June 2017) mapping indicates that no fauna surveys and limited flora surveys were undertaken within the area of PL253 that is proposed to be disturbed. If no additional survey effort has been undertaken, provide justification for the suitability of the Terrestrial Ecology Report (Ecosmart Ecology, June 2017);**

      vi. **The Terrestrial Ecology Report (Ecosmart Ecology, June 2017) is dated 2017, the database searches that were undertaken as part of the ecological assessment are from this time period, please provide updated database searches for all ecological values, in particular updated**

mapping showing MSES and Matters of National Environmental Significance (MNES) fauna and flora species records; and

vii. The Terrestrial Ecology Report (Ecosmart Ecology, June 2017) is four years old with surveys occurring over five years ago. Provide justification of the suitability for this assessment given the time lapsed.

b) Table 6-3 of the Amendment Application Report (page 76) lists the proposed significant residual impacts to prescribed environmental matters. To determine the appropriateness of these values, the department requests the following:

i. A GIS layer of proposed disturbance;
ii. Detailed justification of the significant residual impact (SRI) assessment on prescribed environmental matters, including connectivity areas;
iii. The scale and extent of the activity planned for those areas that would result in a SRI on prescribed environmental matters; and
iv. The status of the Offset Strategy under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) that may be relevant to the application.
v. Further detail is sought regarding the proposed significant residual impacts to prescribed environmental matters; please provide guidance if the assessment is limited to the additional impact approval or if the assessment has considered the cumulative impact of the proposed disturbance and the SGP on all prescribed environmental matters associated with the SGP area.

c) The Amendment Application Report (page 49) identified that MSES also listed as MNES under the EPBC Act will be dealt with at a Federal Level. Provide further detail regarding the following:

i. The EPBC Referral Decision in place for the Project, including the date of the original EPBC Referral Application;

ii. How the Offset Strategy under the EPBC Act provides for MNES species that were not listed under the EPBC Act at the time of the decision but are also considered MSES for the SGP. In particular, how the strategies/measures described within the Offset Strategy will ensure that MSES species will be appropriately offset.

d) It is identified that terrestrial groundwater dependent ecosystems (GDEs) in the form of riparian vegetation may be present along significant reaches of some watercourses and their tributaries. It is indicated that a groundwater drawdown within PL253 would be less than 0.2m. Provide further detail regarding:

i. The tree species associated with the terrestrial GDEs;

ii. **The current depth of the groundwater in relation to these terrestrial GDEs;**

iii. **How the drop of 0.2m in groundwater would not result in the current groundwater levels exceeding the tree species root uptake zones;**

iv. **Whether the proposed activities have the potential to lower the current groundwater quality, and whether any change in groundwater quality may affect the identified terrestrial GDES;**

v. **The potential of GDEs occurring outside of the tenure being affected by changes to groundwater depth and quality as a result of the proposed activities.**

e) In relation to offsets for PL253, provide further information as follows:

I. **Details of whether suitable offsets exist for the proposed impacts to prescribed environmental matters, including the endangered *Hemiaspis damelii* (Grey Snake);**

II. **If already determined, the proposed offset delivery mechanism, i.e., land-based, financial payment or a combination of both. Where financial payment is proposed, the values to which the financial payment relates and the quantity (as determined by the offset financial calculator). Where land-based offsets are proposed, provide an assessment of 'habitat quality' of the impact area and offset area; and**

III. **Details of whether the proposed impacts / offsets will be undertaken in full prior to the impacts occurring, or whether they will be staged over the life of the project. If staged impacts / offsets are proposed, identify what those stages are, which impacts are proposed for each stage and the anticipated timeframe for each stage.**

Table 7 - Information Request Item 7

Information Request Reference	Response
7a)	The Terrestrial Ecological Report (*Ecosmart Ecology, June 2017*) forms part of a broader process of assessment adopted by Arrow to identify, avoid where possible and minimise impacts to prescribed environmental matters to determine significant residual impacts. The assessments were first described in the Queensland and Australian governments' approved Surat Gas Project Environmental Impact Statement (EIS) and Supplementary Report to the EIS (approved October 2013 and 19 December 2013 respectively). Subsequently, the process has been refined and detailed in the Australian Government approved SGP Species Impact

	Management Plan (approved 14 December 2018) and in each of the three main Environmental Authority applications approved by the Department of Environment Science (DES) for the SGP (being the EA North – approved 7 August 2018; EA South – approved 16 January 2019; EA Kogan East – approved 8 August 2019). The Terrestrial Ecological Report contributes to the assessment process in the following ways: • Desktop and geospatial analyses of relevant Government mapping • Ground verification of vegetation communities across the entirety of PL253 by third party, suitably qualified ecologists • Identifying the presence of prescribed environmental matters within the proposed project area • Updating of Arrow geospatial database layers to capture the ground-verified information and to ensure the accuracy and currency of Arrow data; • Overlay of the proposed field development layout on top of the Government layers and ground verified layers to understand potential impacts on prescribed environmental matters • Iterative and detailed constraints analyses of Arrow's proposed field layouts against the ecological values. Further detailed assessments of biodiversity values are undertaken during pre-construction clearance surveys (yet to be undertaken for the 55 wells in PL253) that deliver site specific mapping at a scale suitable for site-specific planning. These surveys will facilitate: • Optimisation of the infrastructure footprint and minimise vegetation clearing; • Confirmation of habitats and listed species; • Confirmation of site-specific sensitive areas and appropriate buffers; • Relocating infrastructure and optimising field layouts to reduce impacts to matters such as MSES as much as practicable; • GIS analysis to determine the proposed areas of impact when the datasets are overlain.
7a)(i)	The Terrestrial Ecology Report (Ecosmart Ecology, 2017) outlines the methods and results of a detailed, seasonal flora and fauna survey covering 202,915 ha, including the PL253 tenement. The methods applied across the entire survey area are the same and resulted in detailed,

	ground-verified mapping incorporating survey sites, vegetation communities and threatened species and their core habitat. The methods are outlined in detail in Section 3 of Ecosmart Ecology (2017) and cover desktop analyses, field survey methods, survey techniques and survey effort. **Flora Survey Methods** The flora field survey was consistent with Queensland Herbarium standards (Neldner *et al*., 2012) and included secondary, tertiary and quaternary sites to confirm vegetation communities present on site. In total 218 secondary, 17 tertiary and 2,223 quaternary flora survey sites have been sampled throughout the Surat Gas Project study area. The location of these sites was selected using aerial photograph analysis, or opportunistically during traverse, to ensure that the field survey targeted a representative range of habitats. Six flora ecologists completed two 12-day surveys, one during the wet season and one during the dry season, totalling over 1,440 person hours in the field. As shown in Figure 4.2 of the Terrestrial Ecology Report (Ecosmart Ecology, 2017), there were no protected plant trigger areas within PL253 at the time of the survey. **Fauna Survey Methods** The terrestrial fauna surveys used a variety of recognised survey methods consistent with relevant federal and state survey guidelines. These included trapping (Elliot, pitfall, funnel and Harp), observation (spotlighting, bird survey, and active search), remote sensing (Anabat ultrasonic bat detection and camera trapping), and targeted methods (i.e. Koala [SAT], Glossy Black Cockatoo searches, microbat trip-line over water bodies and reptile artificial shelter). Eight fauna ecologists completed two 12-day surveys, one during the wet season and one during the dry season, totalling over 2,304 person hours in the field. In addition to the above, the two lead ecologists (David Stanton and Mark Sanders) conducted a five-day 'pilot study' to visually inspect the SGP study area, identify survey constraints, and locate possible detailed fauna trap sites; and, a three-day 'follow-up' survey to sample fragmented habitats (including habitats for Squatter Pigeon, Painted Honeyeater and Yakka Skink), habitats not subject to effort during the detailed surveys (e.g. wetlands), or areas which may not have been otherwise inspected. The north-western extent of **Figure 1** (extracted from Figure 3.3B of Ecosmart Ecology, June 2017)) below includes PL253. As shown, a variety of fauna survey methods were undertaken across the site within all colour coded vegetation types.

	An assessment of the fauna survey effort across the whole SGP Project, including within PL253, against the EPBC survey guidelines is provided below.

Scientific Name Common Name	Guideline Requirements							Adjusted for Habitat Extent			ESE Effort
	Survey Period	Techniques	Value	Effort	Min Duration	Area unit	Notes	Possible BVG's	Extent (ha)	Required effort (approx)	
Delma torquata Collared Delma	Late spring/ summer	Primarily hand searches.	primary	No documented species-specific survey effort. Large survey areas (> 50ha) must include sampling of distinct vegetation types and provide good spatial coverage. Documentation must include justification of survey effort.				10,12, 13,16, 25	32,771	N/A	122.75 hrs
		Pitfall traps	supp								1276 trap nights
Anomalopus mackayi	Late spring/ summer	Active search (when possible)	primary					30	0	N/A	125.25 hrs
		Pitfall traps	primary								1,276 trap nights
		Artificial shelter	primary								Nine shelters
Tympanocryptis condamiensis Condamine Earless Dragon	Late spring/ summer	Pitfall traps	primary					30	0	N/A	1,276 trap nights
Furina dunmalli Dunmall's Snake	Late spring/ summer	Active search	primary					10,12, 13,16, 17,18, 25,30, 34	76,351	N/A	122.75 hrs
	Late spring/ summer	Pitfall traps	primary								1276 trap nights
	Late spring/ summer	Road driving	supp								48 hrs
Anthochaera phrygia Regent Honeyeater	Breeding season	Area search	primary	20hrs	10 days	< 50ha		13,16, 17,18, 34	15,239	6,095hrs	106 hrs bird survey + 1038 hrs site traverse
	Peak flowering	Targeted searches	primary	20hrs	10 days	-				6,095hrs	NIL
Grantiella picta Painted Honeyeater	No survey guidelines							25	176	N/A	106 hrs bird survey + 1038 hrs site traverse
Rostrulata australis Australian Painted Snipe	-	Transect/ area search	primary	10 hrs	3 days	< 50ha		34	1,233	147hrs	106 hrs bird survey + 1038 hrs site traverse (NIL in suitable habitat)

Scientific Name Common Name	Guideline Requirements							Adjusted for Habitat Extent			ESE Effort
	Survey Period	Techniques	Value	Effort	Min Duration	Area unit	Notes	Possible BVG's	Extent (ha)	Required effort (approx)	
	-	Targeted stationary watches	suppl	10 hrs	5 days	< 50ha				147hrs	NIL
Geophaps scripta scripta Squatter Pigeon	-	Transect/ area search	primary	15hrs	3 days	< 50ha		10,12, 13,16, 17,18, 25,29, 30,34	35,660	1,548hrs	106 hrs bird survey
	-	Flush survey	primary	10hrs	3 days	< 50ha				7,132hrs	1038 hrs site traverse
Petauroides volans Greater Glider	No survey guidelines							13,16, 17,18, 34	52,239	N/A	139.75 hrs foot-based + 27.08 hrs vehicle-based spotlight
Phascolarctos cinereus Koala	-	Indirect signs (scratch/ scat).	primary	No specific survey effort documented. Surveys must undertaken to 'maximise the chance of detection'				13,16, 17,18, 34	52,239	N/A	122.75 hrs active search + 111 SAT searches
	Aug-Jan	direct observation (search/ spotlight)	supp								139.75 hrs foot-based + 27.08 hrs vehicle-based spotlight
Nyctophilus corbeni South-eastern Long-eared Bat	Not cold nights	Harp nets	primary	20 nights	>=5 nights	< 50ha	Mutually exclusive (i.e., don't need both harp *and* mist nets)	10,12, 13,16, 17,18, 25	75,118	30,047 trap nights	164 trap nights
	Not cold nights	Mist nest	primary	20 nights	>=5 nights	< 50ha					NIL
Chalinolobus dwyeri Large Pied Bat	Not cold nights	Unattended Anabat	primary	16 nights	4 nights	< 50ha		10,12, 13,16, 17,18, 25	75,118	24,038 nights	69 Anabat nights
	Not cold nights	Attended Anabat	primary	6 hrs	3 nights	< 50ha				9,014hrs	NIL
	Not cold nights	harp	supplementary	16 nights	4 nights	< 50ha	Useful near possible roosts			24,038 trap nights	164 trap nights
Dasyurus maculata Spotted-tailed Quoll	-	Active searches	primary	2hrs	1 day	5ha	Recommendation for	10,12, 13,20	28,674	11,469hrs	122.75 hrs active search

7a)(ii)

Queensland Government data was found to be inaccurate in several locations. Much of the area consists of government mapped mixed RE polygons which have been assessed in the field and broken into single-RE areas for improved accuracy. The table below shows the polygons in the area where on the ground biodiversity values differ significantly from Queensland Government mapping:

Government Mapped RE Codes	**Ground-verified Mapping (VMA Class)**	**Area (ha)**	**Composition and Location**
11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.3.4/11.5.1; 11.5.20/11.5.1a/11.5.1	RE 11.3.14 (LC)	19.9	Open forest dominated by *Angophora floribunda* and *Eucalyptus tereticornis* in the Kogan Condamine Rd reserve and Kogan Creek tributary banks
Non-Remnant	RE 11.3.14 (LC)	0.9	Open forest dominated by *Angophora floribunda* and *Eucalyptus tereticornis* in the Kogan Condamine Rd reserve and Kogan Creek tributary banks
11.3.4/11.5.1	RE 11.3.18 (LC)	0.4	Open forest dominated by *Eucalyptus populnea* and *Callitris glaucophylla* in the Wambo Creek tributary banks
(11.3.2/11.3.18/11.3.4; 11.3.4/11.5.1)	RE 11.3.25 (LC)	44.9	Woodland dominated by *Eucalyptus tereticornis* or *Eucalytptus*

				camaldulensis in the Kogan Creek and Wambo Creek tributary banks
	Non-remnant	RE 11.3.25 (LC)	6.2	Woodland dominated by *Eucalyptus tereticornis* or *Eucalytptus camaldulensis* in the Kogan Creek and Wambo Creek tributary banks
	11.3.2/11.3.18/11.3.4; 11.3.4/11.5.1; 11.5.20/11.5.1a/11.5.1	RE 11.3.27f (LC)	6.7	Sparsely vegetated wetland with ground cover dominated by *Cyperus* and *Juncus* species in the Kogan Creek and Wambo Creek tributary banks
	Non-remnant	RE 11.3.27f (LC)	1.9	Sparsely vegetated wetland with ground cover dominated by *Cyperus* and *Juncus* species in the Kogan Creek and Wambo Creek tributary banks
	11.3.2/11.3.17; 11.5.20/11.5.1a/11.5.1	RE 11.3.4 (OC)	4.7	*Eucalyptus tereticornis* dominated woodland in the alluvial floodplains surrounding Kogan Creek tributary banks
	Non-remnant	RE 11.3.4 (OC)	2.5	*Eucalyptus tereticornis* dominated woodland in the alluvial floodplains

				surrounding Kogan Creek tributary banks
	11.3.4/11.5.1; 11.5.1a	RE 11.4.3 (E)	36.7	Mid-dense woodland dominated by *Acacia harpophylla* and *Casuarina cristata* in lot/plan 8/DY86 and the Kogan Condamine Rd reserve
	Non-remnant	11.4.3 (E)	2.3	Mid-dense woodland dominated by *Acacia harpophylla* and *Casuarina cristata* in lot/plan 8/DY86 and the Kogan Condamine Rd reserve
	11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.7.4/11.7.7/11.7.5; 11.7.7; 11.9.7/11.5.20	11.5.1 (LC)	71.5	Woodland dominated by *Eucalyptus crebra* and *Angophora leiocarpa* throughout batch boundary
	Non-remnant	11.5.1 (LC)	75.2	Woodland dominated by *Eucalyptus crebra* and *Angophora leiocarpa* throughout batch boundary
	11.5.1a/11.5.1; 11.7.4/11.7.7/11.7.5	11.5.20 (LC)	104.6	Woodland dominated by *Eucalyptus woollsiana* in lot/plans 56/DY71 and 25/DY249
	Non-remnant	11.7.4 (LC)	16.7	Open woodland dominated by *Eucalyptus exserta* on lot/plans 56/DY71 and 2/SP207408

	11.7.7	11.7.5 (LC)	3.1	Sparse shrublands in lot/plans 52/DY249 and 55/DY71
	Non-remnant	11.7.5 (LC)	15.1	Sparse shrublands in lot/plans 52/DY249 and 55/DY71
	11.7.4/11.7.7/11.7.5	11.7.6 (LC)	1.7	Woodland dominated by *Corymbia citriodora* in lot/plan 55/DY71
	11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.5.1a	11.7.7 (LC)	67.9	Woodland dominated by *Eucalyptus fibrosa* and/or *Eucalyptus crebra* in lot/plans 55/DY71, 8/RP166603, 2/SP207408, 11/RP166603 and 7/RP166603
	Non-remnant	11.7.7 (LC)	52.1	Woodland dominated by *Eucalyptus fibrosa* and/or *Eucalyptus crebra* in lot/plans 52/DY249, 55/DY71, 8/RP166603, 2/SP207408, 7/RP166603, 6/RP16603
	11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.5.1a; 11.5.20/11.5.1a/11.5.1; 11.7.7	Disturbed RE 11.3.4	66.4	Sparsely vegetated floodplains with *Eucalyptus tereticornis* or *E. camaldulensis* present in T1 surrounding a Kogan Creek tributary
	Non-remnant	Disturbed RE 11.3.4	24.5	Sparsely vegetated floodplains with *Eucalyptus tereticornis* or *E. camaldulensis*

				present in T1 surrounding a Kogan Creek tributary
	11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.5.20/11.5.1a/11.5.1; 11.7.4/11.7.7/11.7.5; 11.7.7	Disturbed RE 11.5.1	30.2	Sparsely vegetated woodlands with *Eucalyptus crebra* present in the T1 in lot/plans 11/RP176344 and 52/DY249
	Non-remnant	Disturbed RE 11.5.1	64.9	Sparsely vegetated woodlands with *Eucalyptus crebra* present in the T1 in lot/plans 11/RP176344 and 52/DY249
	11.3.2/11.3.18/11.3.4; 11.3.4/11.5.1; 11.5.1; 11.5.1/11.5.20; 11.5.1a; 11.5.1a/11.5.1/11.5.20; 11.9.7/11.5.20	High Value Regrowth RE 11.5.1	1466.6	Casuarina dominated vegetation throughout the batch boundary
	Non-remnant	High Value Regrowth RE 11.5.1	494	Casuarina dominated vegetation throughout the batch boundary
	11.3.2/11.3.17; 11.3.2/11.3.18/11.3.4; 11.3.4/11.5.1; 11.5.1; 11.5.1a; 11.5.1a/11.5.1/11.5.20; 11.5.20/11.5.1a/11.5.1; 11.7.4/11.7.7/11.7.5; 11.7.7	Non-remnant	217.1	Various locations throughout the batch boundary (predominately cleared road and pipeline corridors)
7a)(iii)	Detailed surveys undertaken by Arrow Energy ecologists in August 2021 found that the 3D Ecosmart ground-verified mapping was largely accurate throughout the infrastructure footprint. After a thorough survey of the area on foot, there were only three alterations made to the ground-verified mapping: • Approximately 7.5 Ha of mapped non-remnant vegetation was upgraded to High Value Regrowth brigalow (RE 11.4.3) of a			

	medium quality. The area is now dominated by brigalow over 15 years of age. • Approximately 0.7 Ha of mapped remnant least concern RE 11.5.1 was changed to remnant least concern RE 11.3.25 because it was located on alluvium fringing a watercourse and the T1 layer was dominated by Eucalyptus camaldulensis approximately 20 m in height. • Approximately 167.9 ha of regrowth RE 11.5.1 has been cleared by the landholders on 64DY78 and is now a non-remnant pasture paddock with shrubby regrowth to a maximum height of 2 m. Arrow Energy has taken these alterations to the ground-verified mapping into consideration when drafting the Prescribed Environmental Matters table within the EA.
7a)(iv)	**Appendix C** of the Terrestrial Ecology Report (Ecosmart Ecology, June 2017) identifies flora and fauna species that are either known from within 50 km of the SGP, have been identified in the EPBC online Protected Matters search or have habitat identified within the Project Area. The Likelihood assessment has been based on the Project having a Life of Operation of approximately 25 years. Mobile fauna species which could occur within the Project Area over this timeframe, but are unlikely to represent a permanent population or a population relying on the Project Area for their long-term viability (vagrants), are assessed as 'Transient'.
7a)(v)	**Figure 1** of the RFI Response indicates the types of fauna surveys undertaken within PL253 including Elliot traps, pitfall, harp traps and general fauna surveys. Additionally, between 2013 and 2017 a total of 2,458 locations across 5 surveys have been subject to flora surveys within the broader SGP. The distribution of these survey points in relation to survey events is shown in Figure 3.1 of the Terrestrial Ecology Report (Ecosmart Ecology, June 2017). This figure indicates that a suitable density of studies has been undertaken within the PL253 geographical area.
7a)(vi)	Updated desktop assessment results using state and federal databases are provided as Attachment B.
7a)(vii)	When combined, the data gathered across years of survey and 5 survey efforts is considered to provide a statistically robust account of what vegetation and fauna is likely to occur across PL253, accounting for seasonal variability and natural fluctuations in population densities. Additionally, pre-clearance surveys will also be undertaken prior to disturbance.
7b)(i)	A map of PL253 showing the proposed significant residual impacts to prescribed environmental matters is presented at Figure 2. Shape files

	have also been provided along with this response to the information request.
7b)(ii)	The following documents have been used to assess whether the project will have a SRI on PEMs: • *Environmental Offset Act 2014* (EO Act). • *Environmental Offset Regulation 2014* (EO Regulation). • Queensland Environmental Offsets Policy (Version 1.10) (DES, 2021). • Queensland Environmental Offsets Policy Significant Residual Impact Guideline (DEHP, 2014). • Method for mapping Matters of state environmental significance (DEHP, 2017). The Queensland Government's Landscape Fragmentation Connectivity Tool was used to determine impacts to connectivity communities. The Tool determined that Arrow's proposed development on PL253 will not result in significant residual impacts to connectivity areas. Arrow's assessment and monitoring of SRIs is a live process, and planning and management of surface activities and ground disturbance is undertaken utilising a set of hierarchical management principles used to avoid, minimise, and mitigate impacts to ecological values. These principles are: • **Avoid:** Arrow's first preference is to avoid environmental values such as ESAs, Prescribed Environmental Matters (PEMs) and areas of high ecological significance including those protected under the Nature Conservation Act 1992 and EPBC Act • **Minimise:** where other competing constraints or the scale / location of ESAs and PEMs dictate that avoidance is not possible (e.g., where there are long linear strips of Brigalow that need to be crossed or large areas of suitable habitat for wide ranging fauna species), Arrow will preferentially locate infrastructure in a manner that minimises the impact to these values (e.g., cross the Brigalow at the narrowest or most degraded part or where practicable on the edge of suitable habitat for listed species so as not to bisect good quality habitat) • **Mitigate:** implement mitigation measures to further minimise the direct and indirect impacts on ecological values • **Remediate and rehabilitate:** actively remediate and rehabilitate impacted areas to promote and maintain long term recovery • **Offset:** Arrow will offset unavoidable significant residual impacts to PEMs as per the EA conditions and the Queensland Environmental Offsets Policy.

	The following steps are already embedded in Arrow's process and will be undertaken to implement the above-mentioned management hierarchy for the activities the subject of this EA amendment application. **1. Pre-clearance surveys** Arrow has already completed ecological surveys within the areas of proposed activities. However, additional pre-clearance surveys will be undertaken when the SGP activities proceed through the detailed design and planning phase. At this point in time, a field inspection of the specified disturbance footprint will be undertaken by a suitably qualified ecologist. The pre-clearance survey will confirm the presence, absence and extent of environmental values and these will be mapped in the field via GIS. The results of this step will be recorded within Geocortex (Arrow's GIS based mapping system) and the Arrow Access and Approvals System (Arrow's data compilation software used by the Access and Approvals Team). **2. Final Layout Approval** Following the pre-clearance surveys, a Final Layout Approval (FLA) meeting will be held with the project engineers, planners, ecologists, land liaison officer and an archaeologist. At this meeting the ecologist will be reiterate Arrow's management hierarchy for ESAs/PEMs and aiming to avoid and minimise impacts to these values. **3. On-site management and reporting** Where impacts are unavoidable and will result in SRIs, the actual impact will be monitored throughout the project to monitor impacts against the approved PEM maximum disturbance limits provided within the Hopeland EA conditions. **4. Annual reporting** Reporting on monitoring associated with SRIs will be incorporated into annual reporting.
7b)(iii)	Currently, the total footprint for the proposed development is 360 ha and is located in the south-eastern corner of PL253 as per Figure 4-2 of the amendment application report (6 October 2021). The actual area of construction within PL253 tenure has been selected to have minimal environmental impact where possible. There have been no changes to the scale or extent of the proposed significant residual impacts to prescribed environmental matters that were presented in the amendment application report (as per Figure 4-2 and Table 6-3 from that report) except for impacts to Koala habitat. Arrow propose to add 220 ha of Koala habitat to the PEMs table (Table 6-3 of the amendment report) given this species was not listed under the

	EPBC Act at the time of Arrow's approval under this Act and the requirement for Arrow to offset in accordance with State offset processes. It is noted that SRIs will be developed in recognition of the EPBC approval for the SGP EIS (EPBC 2010/5344) and Tables 1 and 2 of that approval whereby maximum disturbance areas for Matters of National Environmental Significance MNES) have been prescribed and will be offset via the approved EPBC Offset Strategy.
7b)(iv)	The Projects Offsets have been approved to be undertaken using a staged approach. The approval notice specifies that a Stage 1 Offset Strategy be submitted for approval of the Minister prior to project commencement and updated for approval prior to the commencement of each subsequent stage. The approval decision defines the stages as: • Stage 1: means year 1 to 3 (inclusive) of the action, starting at the date of commencement • Stage 2: means year 4 to 11 (inclusive) of the action • Stage 3: means year 12 to 20 (inclusive) of the action • Stage 4: means years 21 to decommissioning (inclusive) of the action. The Stage 1 Offset Strategy was approved on 7 July 2019 and addresses each of the information requirements stated in the 'Offsets' section of the approval (i.e. Conditions 8A and 8D).
7b)(v)	The proposed significant residual impacts to prescribed environmental matters are limited to the additional impacts proposed across PL253 and subject to this amendment application. Arrow has never previously had the authority to clear MSES on PL253.
7c)(i)	On 19 December 2013 Arrow Energy Pty Ltd (Arrow) received approval from the Australian Government to proceed with the Surat Gas Project (SGP) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC 2010/5344). There have been three variations to the original approval related to biodiversity (dated 29 March 2017, 29 May 2018 and 31 October 2018) to: • Split the Stage 1 SIMOP into two separate documents: a Species Impact Management Plan (SIMP) and a Stage 1 Offset Strategy; • Include the requirement for a more detailed Offset Area Management Plan (OAMP) to be submitted within 12 months of project commencement; • Increase the Stage 1 maximum disturbance to core habitat areas in Table 2 for the two listed threatened species that have very broad

	core habitat mapping requirements (South-eastern Long-eared Bat and Dunmall's Snake); • Removed the need to provide details on minimum Stage 1 offset areas from the Stage 1 Offset Strategy because this detail is now to be provided in the OAMP.
7c)(ii)	The approved Offset Strategy was developed to address the residual significant impacts to MNES predicted for Stage 1 of the SGP. Arrow will submit a revised and current offset strategy for each subsequent development stage which will address the MNES PEMs associated with that stage. The Stage 2 Offset Strategy and associated management strategies will be required to be approved prior to the commencement of these activities. The MNES species (Koala, Greater Glider and Painted Honeyeater) that were not listed under the EPBC Act at the time of the original decision in 2013 were included in the approved Stage 1 Offset Strategy with the intention of offsetting impacts via this approval. However, Arrow have received recent advice from both the Federal and State Government that these species will need to be offset under each relevant EA. As such, Arrow propose to include these species as State values in the PEMs table and offset in accordance with State offset processes.
7d)(i)	Eucalyptus populnea, Callitris glaucophylla, Allocasuarina luehmannii, Eucalyptus crebra and/or E. populnea, Eucalyptus tereticornis or E. camaldulensis, Angophora leiocarpa.
7d)(ii)	Regional mapping, derived from assessment of vegetation types and geology, indicates that the alluvial deposits associated with creek systems and the sandy plains of the Cenozoic sediments overlying the Westbourne Formation may support terrestrial GDEs. This is assumed to be due to the Westbourne Formation acting as a shallow aquitard. As there is limited groundwater in these areas, there are no groundwater supply bores installed into this formation and there are no indications of water strikes within this formation in drill logs within the GWDB. Arrow has installed a groundwater monitoring bore (Hopeland 16) to a depth of approximately 49.6 m as a background monitoring bore to the seepage detection network for the Hopeland Pilot Dam. Groundwater in the areas associated with the Westbourne formation is sub-artesian with average depth to groundwater of 18.5 to 18.8 mbgl since commencement of monitoring in 2013.
7d)(iii)	As discussed in the Amendment Application, the terrestrial GDEs occur on unconfined aquifers above a Westbourne Formation aquitard, the details of which are discussed above. The 2019 Surat CMA UWIR determined that drawdown within the supporting aquifer would be less than 0.2 m. This

	was considered insignificant at the time of assessment by a suitably qualified organisation and therefore did not assign a risk rating to these terrestrial GDEs. Additionally, studies of GDEs across the SGP as a part of the Updated CSG Water Monitoring and Management Plan identified that the depth to the regional aquifer (which could be subject to CSG depressurisation) at each site is considerably deeper than: • The deepest observed rooting depth; • The inferred likely zone of predominant soil moisture uptake by trees; and • With the possible exception of Burunga Lane (which is in a separate tenure to PL253), the likely maximum tree rooting depth for deeper rooted potential GDE species (such as River Red Gums).
7d)(iv)	Arrow has completed groundwater monitoring in accordance with the groundwater monitoring program (GMP) for the Hopeland Pilot and the Hopeland Groundwater Characteristics Monitoring Program (GCMP). Modelling of the predicted impact of Arrow's proposed development on the groundwater regime and contaminants associated with the former Linc Energy Underground Coal Gasification (UCG) operations at Lot 40 DY85 on PL253 has also been completed and is provided in Appendix E of the EA Amendment document. Generally, the groundwater quality data available for the aquifer associated with the GDEs (Westbourne Formation), indicates that it is slightly acidic, saline and of a sodium-chloride type water with minor calcium and magnesium components. This poor quality of the groundwater is consistent with the fine grained and low permeability nature of the formation, resulting in water-rock geochemical interaction over a long residence time. Activities associated with the project are unlikely to reduce the quality of water quality further as groundwater is drawn toward the deep coal seams during CSG production. Potential for groundwater contamination of shallow formations from surface activities will be mitigated by engineering controls and other methods to manage storage of potential contaminants in containment systems.
7d)(v)	The 2019 UWIR included an assessment of TGDE which was further revised in OGIA's 2019 UWIR Approval Condition 3 Response released on 16 December 2020. This document identified potential TGDEs and applied a risk assessment to evaluate potential impacts to TGDEs from industry wide cumulative groundwater drawdown. Through this process, a site to the east of PL253 located on PL493 associated with the Condamine River was identified as a potential TGDE at risk of impact from groundwater drawdown in the Walloon Coal Measures

	(WCM). Further evaluation of the site identified that given the available lithology and groundwater level data indicate the water table aquifer is hosted within the Condamine Alluvium in the vicinity of the site, potential TGDE in the site are not expected to be impacted from groundwater drawdown in the WCM: • Parts of the site were previously assessed in Arrow's SGP Updated Water Monitoring and Management Plan (WMMP) (2019) for potential TGDE potentially impacted from predicted groundwater drawdown in the WCM. The assessment concluded that, based on the lithology and groundwater level monitoring data collected from Arrow monitoring bore Wyalla-16, the water table aquifer is hosted within the Condamine Alluvium. As a result, no potential impacts to potential TGDEs as a result of predicted groundwater drawdown in the WCM was expected. • Lithology information collected from Arrow holes flanking either side of the site support the above conclusion and show that sufficient Condamine Alluvium is present within the site north of Wyalla-4 to host the water table aquifer: o Wyalla-17 and 18 (same pad as Wyalla-16) recorded 21.27 m and 20.87 m of alluvium from surface; o Wyalla-1 recorded 16 m of alluvium from surface; o Wyalla-5 recorded 22.15 m of alluvium from surface; o Wyalla-4 recorded 34 m of alluvium from surface; and o Wyalla-3 has 9.86 m of alluvium from surface. • South of Wyalla-4, DRDMW bore cards show there is also likely sufficient thickness of Condamine Alluvium and presence of groundwater to host the water table aquifer: o RN16136 has a total depth of 14.33 m within the Condamine Alluvium. The water level measured in the bore at the time of drilling (1964) was 12.8 mbgl; o RN16137 has a total depth of 14.6 m within the Condamine Alluvium. The water level measured in the bore at the time of drilling (1965) was 12.8 mbgl; o RN42230194 has a total constructed depth of 11.3 m within the Condamine Alluvium. Long-term groundwater level monitoring has been undertaken in this bore and the latest water level measurement was 5.88 mbgl in 2016; and o RN42230198 has a total constructed depth of 14.6 m within the Condamine Alluvium. Long-term groundwater level monitoring has been undertaken in this bore and the latest water level measurement was 10.6 mbgl.
7e)(i)	Arrow undertakes a process to assess SRIs for each component of the proposed development. Where an MSES, such as the grey snake (*Hemiaspis damelii*), is identified as being significantly impacted, these

	impacts are offset. Offsets are either provided as direct, land-based offsets, or as financial payments in accordance with the offsets calculator and the offset options available to a Proponent.
7e)(ii)	The offsets delivery method has not been determined as yet. Appropriate offsets will be delivered in accordance with the Qld Offsets Policy 2020 (V1.9) and EA prior to the commencement of the activity as required, and will either be provided as direct, land-based offsets, or as financial payments in accordance with the offsets calculator and the offset options available to a Proponent.
7e)(iii)	In line with the EPBC Act approval for the SGP (EPBC 2010/5344), offset stages will generally align with: • Stage 1: means year 1 to 3 (inclusive) of the action, starting at the date of commencement • Stage 2: means year 4 to 11 (inclusive) of the action • Stage 3: means year 12 to 20 (inclusive) of the action • Stage 4: means years 21 to decommissioning (inclusive) of the action. Activities for each stage will not commence until an offset strategy has been developed and approved for each stage.

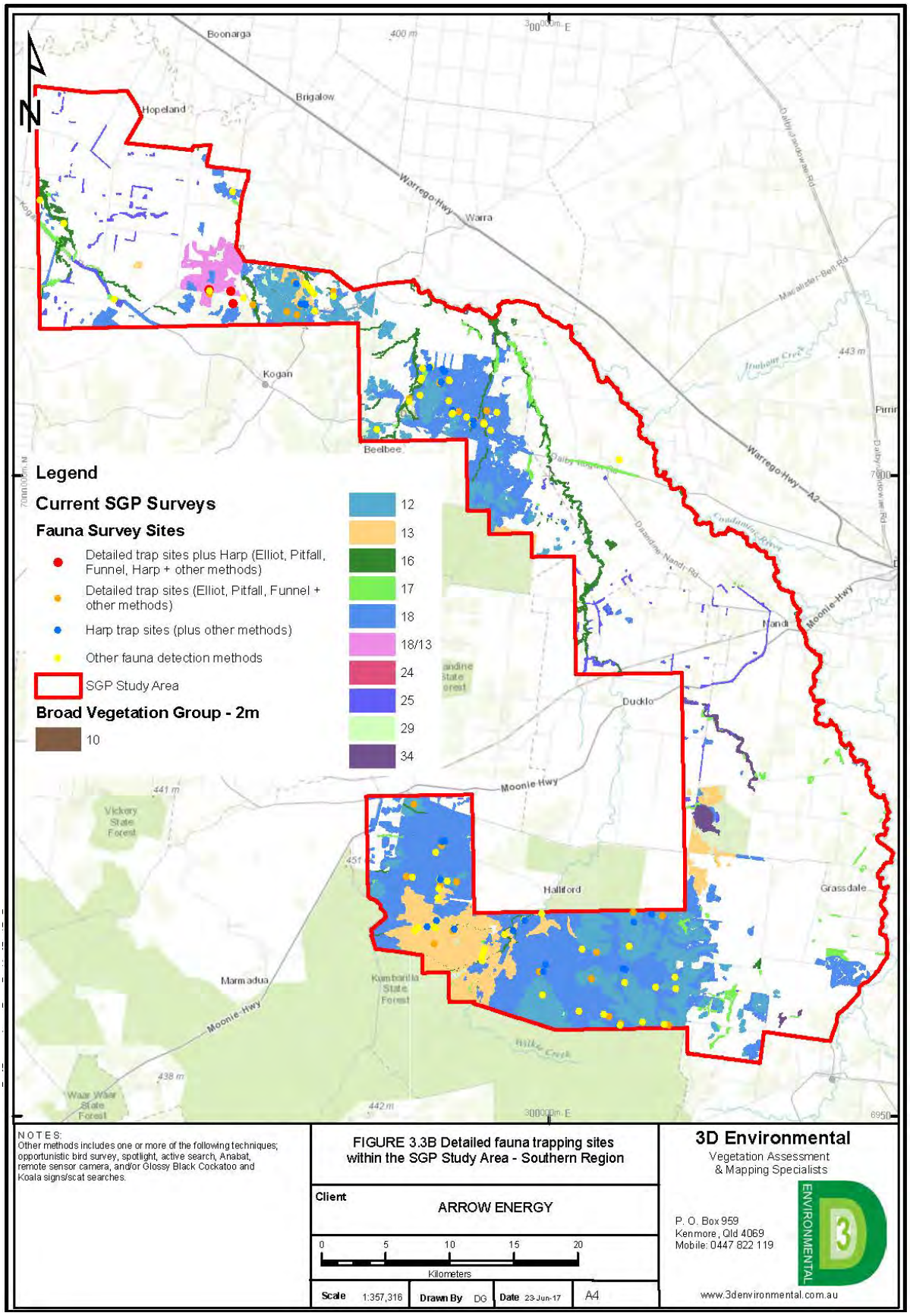


Figure 1 - Fauna Survey Effort (Ecosmart Ecology, June 2017)

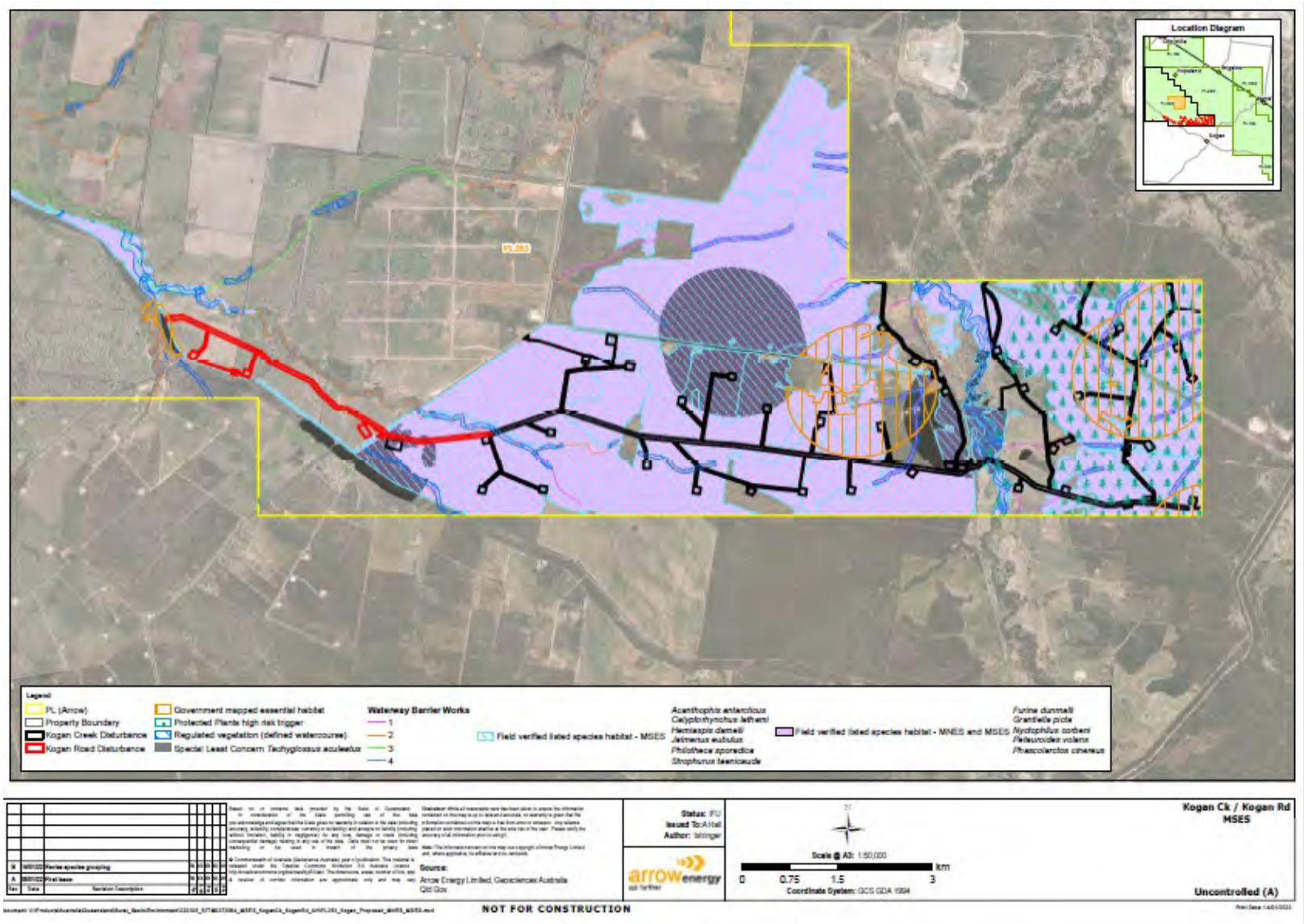


Figure 2 - Proposed significant residual impacts to prescribed environmental matters

8) **Subsidence has been cited as an indirect impact of coal seam gas activities.**

   a. **Provide further information regarding the potential impacts to land and its use that may occur as a result of the activities. This should include mitigation measures to manage the impacts to land and details of any current or planned subsidence monitoring.**

   b. **Provide further information regarding the potential impacts to surface drainage and overland flow as a result of the activities. Consideration should be given to the potential changes to the direction and rate of surface flow and impacts to environmental values that these changes may have.**

Table 8 - Information Request Item 8

Information Request Reference	Response
Overarching Approach	Coal seam gas occurs within coal formations through adsorption to the surface of the coal under hydrostatic pressure. Depressurisation of the coal seams below a threshold (by groundwater extraction) reduces hydrostatic pressure and liberates the gas from the formation. At any point below the ground surface, the weight of overlying strata is supported partly by water pressure and partly by the fabric of the rock mass. A reduction in water pressure therefore results in an increased proportion of the load being carried by the rock mass, leading to compression of the rock. The combined compression over the thickness of rock strata affected by reduced water pressure results in subsidence at the ground surface. Therefore, any CSG induced subsidence will be markedly different to coal mining or UCG induced subsidence where a void is generated that can result in collapse of the overlying roof strata. CSG induced subsidence occurs as a broad downward warping of strata rather than acute subsidence due to physical collapse of structures. A conservative assessment of potential subsidence from Arrow activities indicates predicted subsidence of less than 100 mm within PL253, with the modelling indicating that trigger thresholds are unlikely to be exceeded (see below for discussion of trigger thresholds). The discussions occurring with landholders with regards to subsidence are related to the potential impacts on land use and farming practices predominantly in areas of Intensively Farmed Land (IFL) where laser-levelled paddocks are more common. This is not the case in the area relevant to the FID1 wells on PL253 to which this EA Amendment refers. Irrespective, Arrow's position is that the predicted subsidence, being a gradient change of 0.0002% reflecting 65 mm over a distance of 35 km or

	a surface elevation change of 5 mm over a 1 km long paddock, is considered to represent either no or a minor impact to land use practices.
8a)	Regional subsidence arising from CSG-related groundwater extraction is managed through the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act to ensure potentially affected areas, including any outside of our tenure, are protected. Arrow's Surat Gas Project must be conducted, amongst other things, in accordance with conditions of approval issued by the Commonwealth Minister for the Environment under the EPBC Act. These conditions required Arrow to prepare a WMMP. The WMMP (Arrow, 2019) is the key mechanism which governs how Arrow will manage subsidence. Arrow's subsidence management framework in the WMMP has been reviewed by a Ministerially-approved water resources expert and approved by the Federal Government. It includes: • a program to monitor subsidence impacts, • trigger thresholds, and • reporting of monitoring results annually. Arrow (2018) and OGIA (2021) have undertaken an assessment of the potential for impacts from subsidence and have derived similar results. OGIA (2021) modelling of subsidence predicts that most of the cropping area around the Condamine Alluvium is likely to experience less than 100 mm of subsidence, with a maximum change in slope for most areas of less than 0.001% (10 mm per km) and up to 0.004% (40 mm per km) for some areas. Observations from satellite data indicate that up to about 90 mm of CSG-induced subsidence has occurred since 2015 around the CSG fields near the Condamine Alluvium. Natural movement of up to 25 mm/year is also observed away from CSG fields. OGIA (2021) state that observed and predicted subsidence is very small and unlikely to materially change surface flows to watercourses. Arrow acquires Light Detection and Ranging (LiDAR) surveys over tenure, which provide information on elevation and ground slopes. An assessment of slopes in PL253 from 2020 LiDAR data (Figure) shows that slopes are greater than 0.06% (600 mm per km) for greater than 97% of the tenure area. This indicates that the predicted change in slope of 0.001% to 0.004% is much less than natural slopes and therefore would not form a material impact.

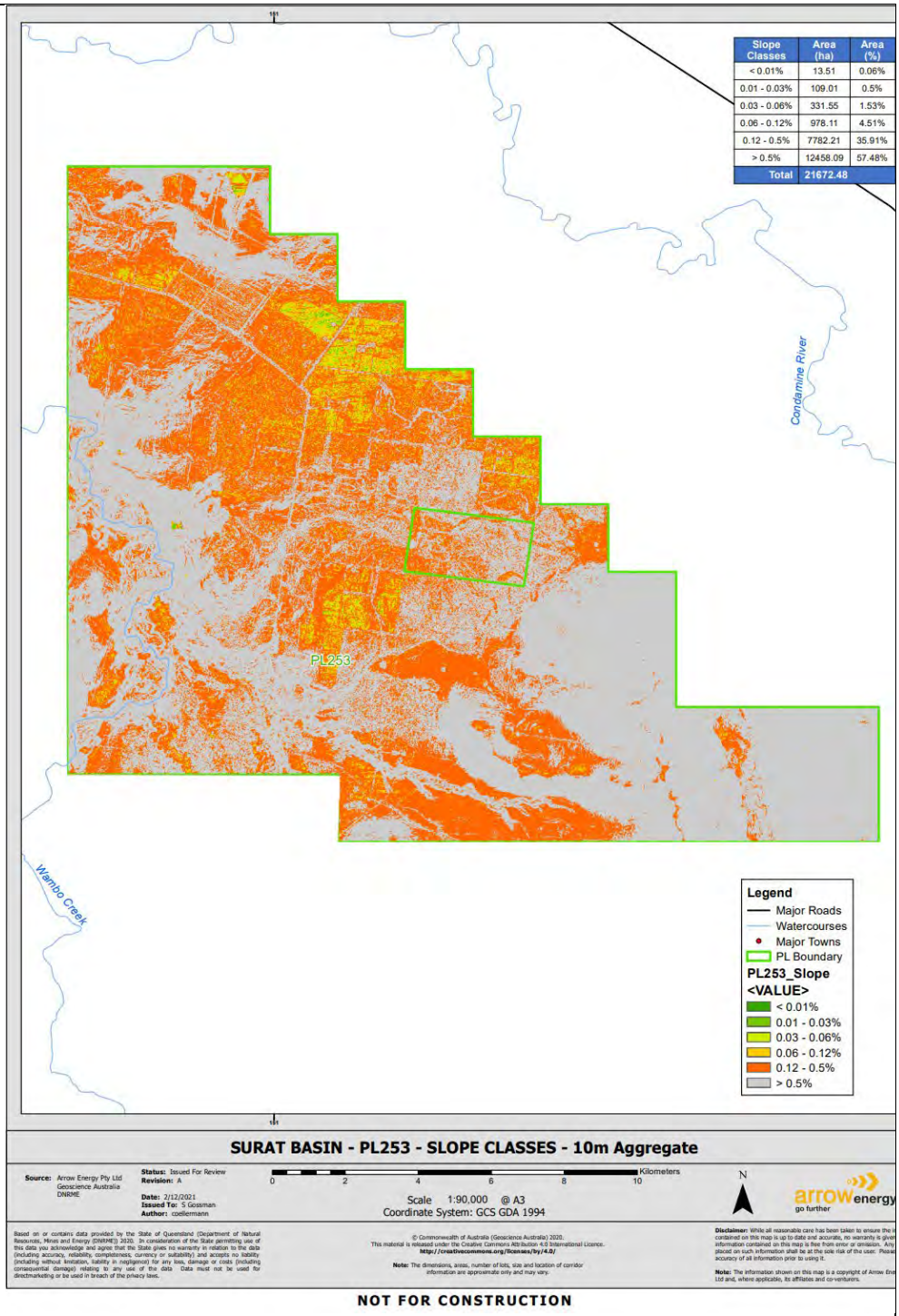


Figure 3 - Slope Classes on PL253

Arrow (2018) has prepared an assessment and monitoring plan for subsidence as part of its EPBC approval conditions.

Subsidence monitoring is carried out using satellite borne Interferometric Synthetic Aperture Radar technology (InSAR). This provides a baseline from which future data can be assessed to determine changes in vertical ground elevation, and also provides a snapshot of current vertical ground

	movement. Separate geodetic measurement of ground movement will be taken to provide a ground-truthing check and control on the InSAR results. Locations for geodetic ground movement monitoring are proposed to be co-located with groundwater monitoring bores, to provide coverage of the full ground profile potentially influenced by the SGP. One of these geodetic ground movement monitoring points has been installed at the Hopeland Pilot site in the southwest of PL253. These sites provide daily monitoring of ground movement. Periodic LiDAR surveys that Arrow acquires are also compared for changes in ground slope. The WMMP includes a three-tier subsidence management framework: • Tier one is screening – involves comparison of InSAR data at a 1km x 1km grid. • Tier two is investigation – involves comparison of changes in the slope of the ground. • Tier three is trigger threshold – a site specific in-depth look at changes to drainage and impacts to farming, to determine if there is a material impact. If there is determined to be an adverse impact, Arrow must develop and implement an Action Plan to mitigate impact. The subsidence assessment and monitoring plan from the Arrow Energy Surat Gas Project WMMP can be accessed at the following location: https://www.arrowenergy.com.au/environment/groundwater/water-monitoring-management-plans.
8b)	The potential impact to surface drainage has been assessed in the OGIA Draft UWIR 2021 which can be accessed at the following location: https://www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/surat-cma/uwir. OGIA (2021) state that observed and predicted subsidence is very small and unlikely to materially change surface flows to watercourses.

9) Noise:

a. **Arrow propose to increase the night time noise limit for drilling activities. Table 6.12 in section 6.5 lists 30dBA as the proposed night time outdoors limit. In other components of section 6.5, a night time outdoors limit of 33 dBA is mentioned. Confirm what outdoors night time drilling noise limit that Arrow is applying for.**

b. **Arrow has not provided details of what separation distance between the drill rig and receptor is required for noise increases from 28dB(A) so that sensitive receptors are not impacted. It is unclear whether Arrow considers implementing separation distances a feasible management measure and how it aligns with the management hierarchy for noise in the Environmental Protection (Noise) Policy 2019.**

c. **Arrow has not demonstrated what avoidance measures other than entering into alternative arrangements have been considered in the first instance in accordance with the management hierarchy for noise in the Environmental Protection (Noise) Policy 2019. Provide further information regarding what avoidance measures are used prior to considering alternative arrangements.**

d. **Arrow's assessment focuses on noise impacts to sleep, however the environmental values to be enhanced or protected by the Environmental Protection (Noise) Policy 2019 are also the ability of individuals to study or learn, and be involved in recreation, including relaxation and conversation, as well as protecting the amenity of the community. It should be noted that while the Environmental Protection (Noise) Policy 2019 acoustic quality objectives to be enhanced or protected has health and wellbeing in relation to the ability to sleep as an environmental value for night time, this does not mean other environmental values do not apply during this time, for example the amenity of the community. Provide further information to address other impacts to environmental values.**

e. **The application has not addressed how the proposal will not result in background creep in areas where petroleum activities will occur. This also involves Arrow demonstrating how the consideration of façade reduction will not result in background creep in an area.**

Table 9 - Information Request Item 9

Information Request Reference	Response
9a)	Arrow is applying for an outdoor night-time noise limit of 33 dBA LAeq, adj, 15 mins. This is considered equivalent to an internal noise limit of 28 dBA LAeq, adj, 15 mins assuming a conservative 5 dBA façade reduction for a bedroom with wide open windows as consistent with DES's Planning for Noise Control Guideline. The alternative night-time noise criterion for drilling: • Takes into account credible literature and recommended values for the protection of sleep disturbance; and • Considers the WHO's recommendation that slightly lower noise criteria may be appropriate in areas with low background levels, and • Is consistent with the requirements of both the Queensland EP Act and the EPP Noise, including the General Environmental Duty. Further detail on the analysis of noise limits and potential for impact is provided in the report, Coal Seam Gas Activities: Noise Criteria Review – Review of Alternate Noise Criterion for Night-Time Drilling. This report has been submitted to DES associated with a number of EA submissions. The comprehensive analysis has been reviewed and discussed with DES on a several occasions. The EA conditions were considered acceptable for EA applications: • EA0001613 – SGP South • EA0001399 – SGP North • EA0001498 – SGP Kogan East • EPPG00972513 – Dalby Expansion Project
9b)	The night-time noise limit of 28 dBA LAeq, 15 mins was designed to protect against the impacts of background noise creep as discussed in Coal Seam Gas Activities: Noise Criteria Review – Review of Alternate Noise Criterion for Night-Time Drilling and is based on the threshold background level of 25 dBA (as discussed in DES's Planning for Noise Control Guideline). As drill rigs are mobile temporary equipment and variable noise sources, the potential for drill rigs and associated equipment to impact long term noise creep is minimal. Due to the temporary nature of drill rigs and infrequent occurrence of noise events for any given sensitive receptor, the more appropriate worst-

	case noise impact aspect to provide protection against nuisance and human health is sleep disturbance. Review of literature indicates that the night-time threshold to protect against noise impacts to sleep disturbance is 33 dBA (LAeq, 15 mins). This is discussed in more detail in the attached report (Attachment C), Coal Seam Gas Activities: Noise Criteria Review – Review of Alternate Noise Criterion for Night-Time Drilling. For instance, for the majority of the time at a receptor, the noise from the rig and associated equipment will not be present - only present during initial construction and present once every three years for a scheduled workover (per well). Assuming that the rig is present for 10 days during initial construction and 3 days per workover every three years, and when the rig is present causes 33 dBA at a sensitive receptor for the entire time that the rig is operating, the average background night time noise level (LA90) would be 25 dBA which is the same as the deemed background night time noise level. That indicates there is no change to the night-time background noise level even if the temporarily rig activities are permitted a 33 dBA (LAeq, 15 mins) noise limit. It is noted that this assessment is highly conservative as well, as background noise would be impacted by weather and other noise sources and the rig would not result in a constant 33 dBA noise level at a sensitive receptor whenever it was present. The separation distance of an attenuated rig1 (or associated equipment) to achieve 28 dBA (LAeq, 15 mins) under worst case weather conditions is 1,420 m and as discussed above is conservative beyond that of the EPP Noise and WHO. A change to 33 dBA (LAeq, 15 mins) for temporary mobile drilling activities will reduce that separation distance to 1,000 m and this distance is included in our project planning tools and aligns with our Noise Management Plan so as to be protective of all relevant environmental values. Arrow uses the framework illustrated in Figure to manage noise emissions on Arrow tenures. This framework has been developed based on the noise management principles and hierarchy of the EPP noise: • Avoid – plan the activity and engage with affected stakeholders to minimise noise impacts; • Minimise – implement noise mitigation measures; and

[1] An attenuated rig can achieve < 33 dBA at 1,000 metres

- Manage – conduct monitoring and ensure compliance with Arrow's HSEMS.

A more detailed step-wise implementation of the strategy to manage noise emissions is outlined in Figure 5.

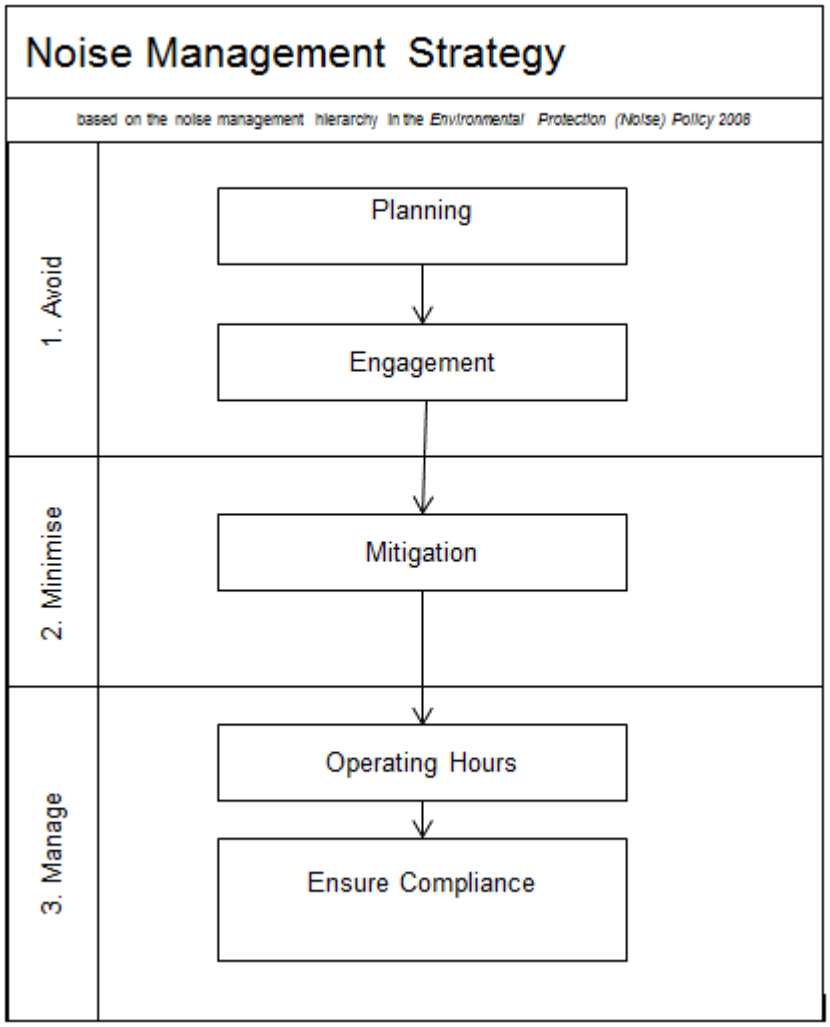


Figure 4: Strategy to manage noise emissions

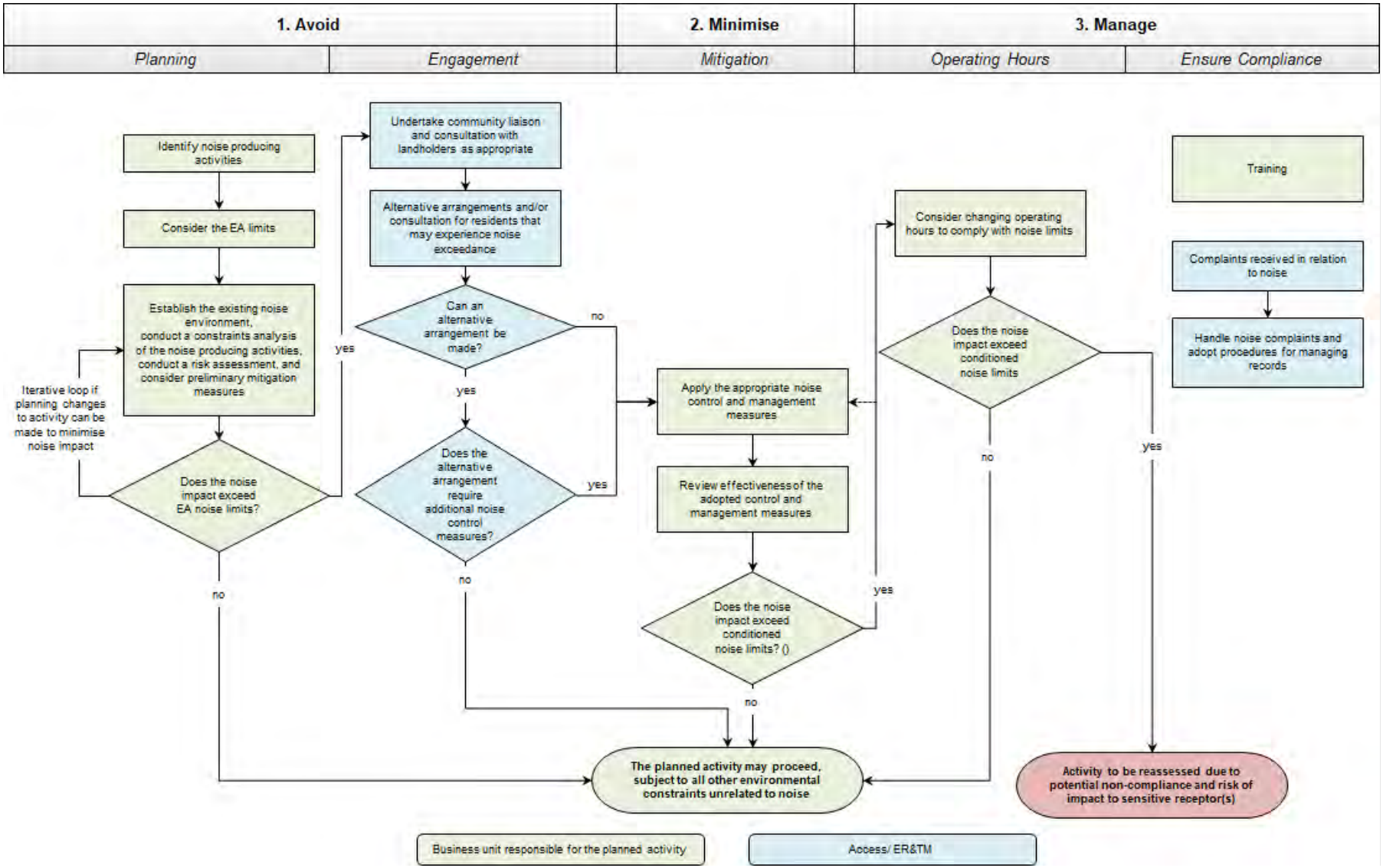


Figure 5: Process to Manage Noise Emissions

9b) continued	During field development planning, Arrow optimises the distances between well skids and sensitive receptors to reduce impacts (i.e. the distance between planned well pads and sensitive receptors is maximised within existing constraints). This is completed for more reasons than just noise management. Increasing the separation distance between infrastructure and sensitive receptors is a key management approach to reducing environmental impact. In terms of noise management, this assists Arrow to avoid noise impacts. Arrow also requires all contractors involved in drilling, well completion intervention and other ancillary activities to meet noise performance specifications specified in contracts. Arrow's noise performance specifications require contractors to meet a noise limit of 33 dBA (LAeq, 15 mins) at 1,000 metres under adverse weather conditions for noise propagation. This is the night-time noise limit on all of Arrow's current Environmental Authorities in the Surat Basin for drilling and associated activity. This ensures that sleep disturbance is not expected to occur beyond 1,000 metres of a drill rig or associated activity even under the worst-case weather conditions for noise propagation. Arrow's contract conditions require contractors to demonstrate compliance with Arrow's performance specification through a standardised measurement and modelling approach. The noise performance contract conditions have resulted in significant improvement in noise performance from rig activities in the Surat Basin. Modifications to rigs and associated equipment through Arrow's performance specifications have included (but are not limited to): • Pipe racks with rubber installed to reduce impact noise • Catwalk racks and indexes lined with rubber • Sound curtains installed on light plant and mud pumps • Acoustic lagging of exhausts • White noise reversing beepers on mobile plant • Acoustic enclosures for cementing units These types of measures have reduced the overall sound power levels (SWL) of rig activities by approximately 6 – 7 dBA and from cementing activities by approximately 15 dBA. By incorporating noise performance standards in contract conditions, Arrow has ensured that potential noise impacts are avoided through planning and mitigated through engineering controls as noise performance is a key consideration when designing equipment to operate in the Surat Basin on Arrow tenure.

	Furthermore, where possible and where sensitive receptors have been identified near to the rig activity, noisy rig activities (e.g. drilling, cementing, air cleanouts) are scheduled to occur in the daytime period only to avoid noise impacts. Only after the noise impacts have potentially been avoided through field development planning, rig design measures, planning of rig activities are alternative arrangements considered as a noise management tool.  **Figure 6: Examples of noise attenuation measures included in rig activities contracted to operate on Arrow Energy gas fields.**
9c)	Please refer to the response provided to previous query for avoidance measures utilised in accordance with the Environmental Protection (Noise) Policy 2019 to avoid potential noise impacts from rig activities.
9d)	Arrow's application focuses on a slight relaxation for temporary rig activities for night-time noise impacts in order to protect impacts to sleep disturbance. This is because the noise limit to protect against impacts to night-time sleep disturbance is lower than potential impacts to other related noise environmental values. The proposed night-time noise limit for rig activities is 33 dBA (external) or 28 dBA (internal).

	For context, a whisper has a noise level of approximately 30 dBA and a normal conversation has a noise level of approximately 60 dBA. Arrow's proposed night-time noise limit of 33 dBA (external) and 28 dBA (internal) would be inaudible during a normal conversation, so is protective against impacts to the ability to hold normal conversation. The EPP Noise lists a number of noise levels for the protection of other environmental values such as health and wellbeing, community amenity for recreation and ability to converse. All noise objectives for the protection of other environmental values related to noise impacts are much greater than the night-time noise limit for the protection of sleep disturbance. This is the reason Arrow's EA application focuses on the noise limit for the protection of impacts to sleep disturbance. Protection against impacts to the sleep disturbance environmental value also ensures protection against impacts to other environmental values related to potential noise impacts.
9e)	The night-time noise limit of 28 dBA LAeq, 15 mins was designed to protect against the impacts of background noise creep as discussed in Coal Seam Gas Activities: Noise Criteria Review – Review of Alternate Noise Criterion for Night-Time Drilling and is based on the threshold background level of 25 dBA (as discussed in DES's Planning for Noise Control Guideline). As drill rigs are mobile temporary equipment and variable noise sources, the potential for drill rigs and associated equipment to impact long term noise creep is minimal.

10) Air:

a. **Provide further information on potential air impacts to environmental values associated with high point vents.**

b. **Provide further information regarding vertical pathways for gas migration from the former Linc site within the coal seams. DES understands that vertical permeability has been enhanced by fracturing of the Macalister seam which would exacerbate the vertical migration of gases.**

Table 9 - Information Request Item 10

<table>
<tr><th>Information Request Reference</th><th>Response</th></tr>
<tr><td>10a)</td><td>Coal seam gas is comprised of predominantly methane with trace quantifies of nitrogen, carbon dioxide and ethane. There are no air toxins or air pollutants present at levels above laboratory detection limits in coal seam gas. Results from laboratory sampling of coal seam gas is presented in the table below.

The primary ‘air pollutant’ of concern is methane as a greenhouse gas and contributor to climate change.

Measured Gas composition
<table><tr><th>Substance</th><th>Composition (mol%)</th></tr><tr><td>Methane</td><td>98.19 – 99.11</td></tr><tr><td>Ethane</td><td>0 – 0.01</td></tr><tr><td>Nitrogen</td><td>0.61 – 1.56</td></tr><tr><td>Carbon dioxide</td><td>0.2 – 0.25</td></tr></table>
Total methane emissions from high point vents and produced water are estimated to be 0.8707 t CO2-e per megalitre of water produced, determined through the Method 2 approach for measuring emissions prescribed in the National Greenhouse and Energy (Measurement Determination) 2008. Methane emissions from high point vents and the produced water process are estimated to contribute to 1.5 – 2.0% to total Scope 1 greenhouse gas emissions from upstream coal seam gas production.

Where practical, methane emissions from high point vents are recycled into the gas gathering lines to minimise emissions from the produced water stream.</td></tr>
<tr><td>10b)</td><td>The site assessment at the former Linc UCG site was undertaken by DES/DoR. Arrow Energy therefore has no information of its own on the site. From information provided to Arrow Energy it is understood that fracturing occurred</td></tr>
</table>

	around the gasifiers between the Macalister coal seam and the Springbok Sandstone and this provided a route for contaminants to move into the Springbok Sandstone. Whilst fracturing is understood to have occurred, as evident by wellhead gas pressures locally in monitoring bores within the Springbok Sandstone on Lot 40 DY85, the available data from bore logs from wells report limited direct evidence of fracturing, i.e. NB01D bore log reports limited fracturing visible only in the lower Macalister coal seam. Arrow Energy commissioned the University of Queensland to undertake dual phase modelling to assess the potential impact of field development on the gas phase within the Walloon Coal Measures and the overlying Springbok Sandstone at the former Linc UCG site. This report is included as Attachment D. This work showed that the residual gas plume is stable and a low likelihood that a full development of PL253 would alter the movement of residual gases around the former Linc Energy UCG site. It follows that the potential impact from the proposed field development plan would be even smaller at the surface than at the depth where the CSG impact is generated. Where a containment well is operated the reducing pressures caused by the well would also reduce gas pressures in the Macalister coal seam and Springbok Sandstone thereby leading to a reduction in upward gas flux.

11) Groundwater:

a. **What is the closest well distance to the former Linc site (Lot 40 DY85) and what aquifers will the proposed bores be accessing? In the previously withdrawn application submitted 6 July 2020, Arrow committed to not accessing the Macalister seam around the former Linc site (due to economic reasons) and proposed a staged development from the tenure boundary towards the former Linc site. Please provide further information about staged development of the 55 wells proposed, including location, timing and aquifer access.**

b. **Provide an update regarding Arrow's proposal to gain access to Lot 40 DY85.**

c. **DES notes that several of Arrow's proposed monitoring bores are marked to be plugged and abandoned by the Department of Resources (M14r, G4MWD, L22, and M15). Furthermore, DES' monitoring bores (HSMB6S, HSMB6D2, HSMB7S, HSMB7D) and the Department of Resources "NB" series bores have not been considered in the groundwater monitoring proposal. Page 123 of the application states that "Arrow will expand our monitoring program to validate and monitor the prosed activities and gas conditions". Provide further detail regarding how Arrow will maintain a sufficient monitoring network for groundwater pressure and quality that would detect groundwater changes in the vicinity of Lot 40 DY85.**

Table 11 - Information Request Item 11

Information Request Reference	Response
11a)	The closest well proposed in the current amendment is shown in Figure 5.2 of the model report provided in the amendment submission. Figure shows that the nearest of any wells will be approximately 3,570 m from the south-eastern corner of Lot 40DY85 and approximately 5,570 m from the closest gasifier. Figure also shows that the wells closest to the former Linc UCG site do not produce from the Macalister coal seam, but will produce from the deeper coal seams of the Walloon Coal Measures. The closest well accessing the Macalister seam assessed in the modelling is located approximately 4,940 m from the south-eastern corner of Lot 40DY85 and more than 6,100 m from the closest gasifier.

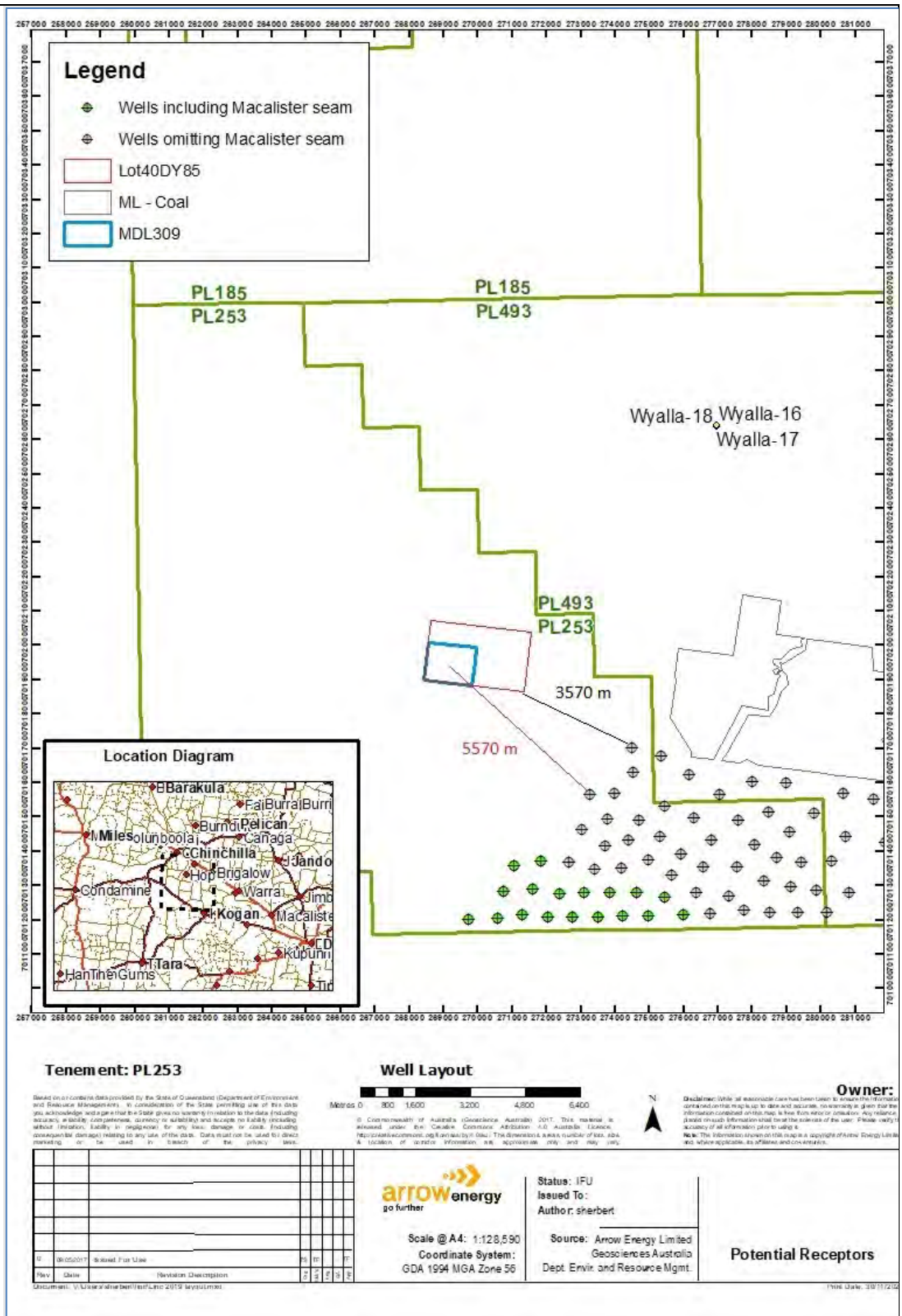


Figure 7 - PL253 Well Layout

The timing of the development of the proposed 55 wells as shown in Figure 8 indicates progressive development in 2024 and 2026 although timeframes may vary depending on landholder agreements.

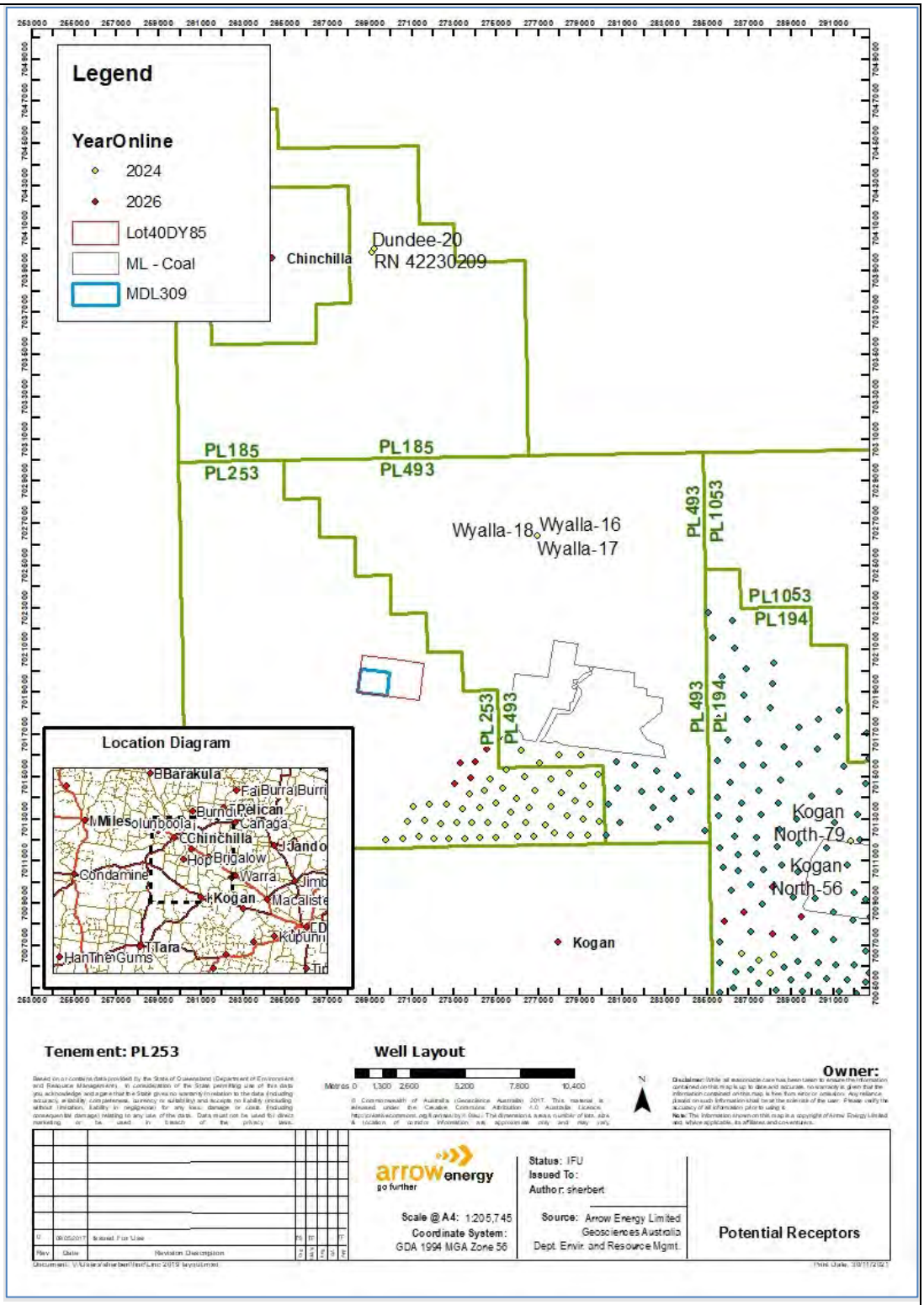


Figure 8 - PL253 Well Timing

11b)	Arrow currently holds an Authority To Prospect (ATP) over Lot 40 DY85 and can gain access for certain activities under this tenement. The ATP currently expires at the end of September 2022. Arrow has the avenue of applying for a Water Monitoring Authority to allow access to Lot 40 DY85 for either monitoring existing

water monitoring bores or installing additional water monitoring bores if required to supplement the existing monitoring bore network.

Arrow is also exploring additional options for accessing the site which are aimed at addressing:

– access to the site from the Department of Resources (DoR) and

- mechanisms by which Arrow can be conditioned to undertake containment if and when required

The mechanism options identified by Arrow are as follows –

- Authorisation to carry out activities under 'abandoned operating plant' provisions under the *Petroleum and Gas (Production and Safety) Act 2004 (P&G Act)*
- A development approval and no authorisation under the P&G Act
- Extending the PL over the relevant lot noting that this is not Arrow's preferred option

This work must be settled before the end of September 2022 when the ATP expires.

The following describes in greater detail the preliminary design of the groundwater containment and treatment system, to be installed and operated if there are any indications of changes in conditions which increase potential for movement of contaminants away from Lot 40 DY85 as a result of Arrow's activities. This includes the siting, construction and operational philosophy for a potential containment well(s) at Lot 40 DY85.

The following sections provide a description of the major elements of a containment system design and includes the following expectations and assumptions:

- The target zones for water production will include the Springbok sandstone and the Macalister coal seam.
- Hydraulic parameters fall within the range of those observed at the Hopeland pilot and interpreted from numerical models calibrated to observed data.

<u>Well Siting</u>

Groundwater modelling indicates extraction wells within both the Springbok Sandstone and Macalister Coal Seam located near the centre of Lot 40 DY85 (Figure 9) between the gasifiers will form a cone of depression extending to the edge of the site as shown in Figure 10. Contours in black on Figure 10 depict groundwater head within the Macalister Seam in 2042, with the green contour indicating the capture area within which groundwater flows into the site. The blue and magenta contours indicate the capture area for the P5% and P95% cases from the uncertainty analysis.

One of the key parameters for designing the containment system is the water yield, for which Arrow have no prior information on potential water production rates available from the site. However, CSG wells at the Hopeland pilot have produced water at rates of 30 to 200 m^3/day (0.3 to 2.3 L/s) for the full Walloon Coal Measure sequence, which together with hydraulic parameters obtained from calibration of the groundwater model, provides an indication of the anticipated water rates from the extraction wells.

As an adaptive management measure, upon installation of the extraction well(s), pumping tests would be undertaken whilst monitoring pressures in the monitoring bores and any remaining UCG development wells to assess the site specific hydraulic conditions and connectivity. This will indicate whether further containment well locations are required and where they may be situated. Current modelling suggests that 2 extraction wells will be sufficient to maintain the local inward gradient of groundwater movement towards the gasifiers.

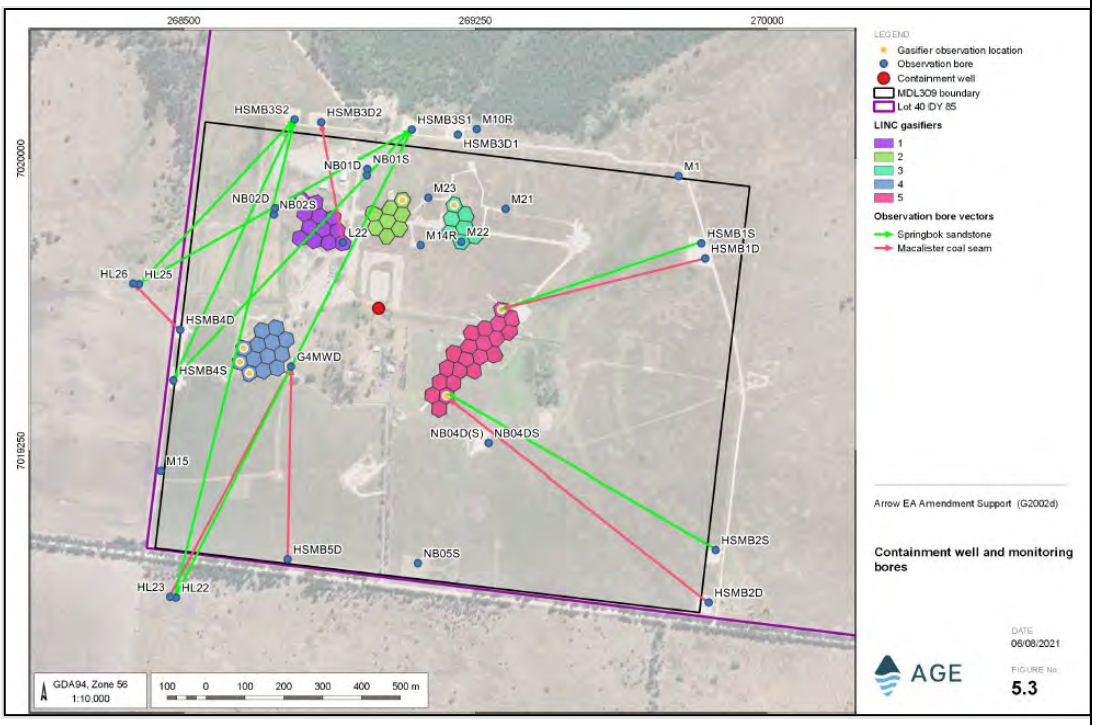


Figure 9: Location of Containment Bore

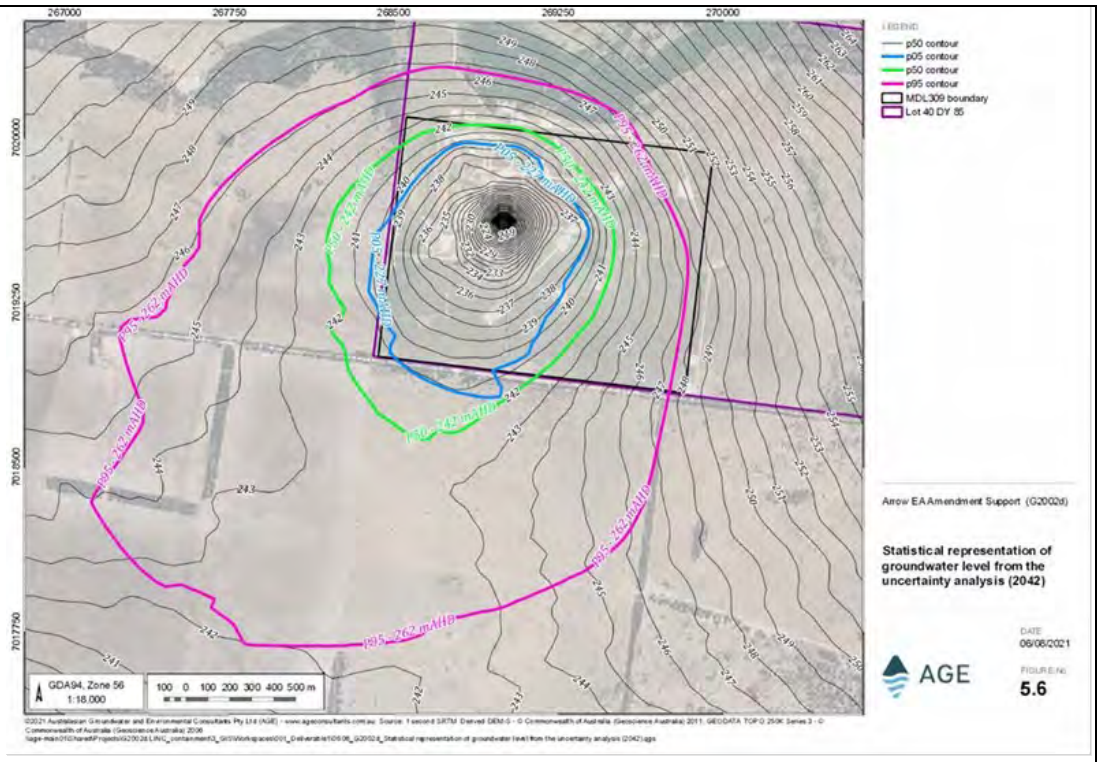


Figure 10: Containment Zone in Macalister Coal Seam from Uncertainty Analysis

Well Design

The extraction well(s) for the containment system would be constructed based upon the *Code of practice for the construction and abandonment of petroleum wells and associated bores in Queensland*. The base case for well design comprises vertical wells with surface and production casing strings, with wire wrapped screen and a sump below the base of formation to maximise water entry from the formation. Cement and casing strings will isolate the production zone from the overlying strata. An annular cement packer for the production casing string will be used to provide cement placement control, which together with the use of wire wrapped screens, minimise the potential for adverse effects that traditional cement and perforation operations can have on wellbore efficiency.

Well Pumps and Headworks

Headworks would be suited to the casing head pressure (CHP), as a safety factor the highest pressure of the monitored units will be used to determine the minimum CHP.

Wells would be equipped with rod string progressive cavity pumps (PCP), set in the target zones in the Springbok Sandstone and Macalister Coal Seam. Pumps will be selected with variable speed capability and lift capacity for a worst case of lifting the maximum water yield from base of formation to surface.

Operational Philosophy

The purpose of the operation of a containment well(s) is to maintain the hydraulic gradient locally toward the site, which is the contaminant source. Water extracted to maintain this hydraulic gradient will be treated prior to disposal.

	Disposal can include introduction to the Arrow Energy CSG water gathering network or removal to a permitted treated water disposal location depending on timing of implementation of the containment system relative to field development. The use of PCP pumps and a sump would allow pumping of water/gas mixtures even at low water levels. If water levels are achieved below the base of the gasifiers then potential for groundwater migration will be negated. <u>Treatment System</u> *Components* Arrow has undertaken a design and sizing options assessment with Enviropacific Services Pty Ltd for the water treatment system. The proposed treatment system will comprise the following components: • Raw water balance tank, to maintain consistent system input flow; • Lamella dissolved air flotation (LDAF), for removal of volatile organic compounds to a flare; • Filter feed tank, to maintain inflow to filter treatment; • Filter and granular activated carbon (GAC) tanks, to remove suspended solids and dissolved phase organic compounds respectively; and • Treated water tank to store water for disposal. *Adaptive Capacity* The proposed treatment system is designed to be able to treat up to 300 m^3/day (3.5 L/s) of water providing enough capacity for up to 10 extraction wells, so well above the expected requirement of 2 extraction wells based on Arrow modelling. Redundancy would enable easy turndown when required and be able to treat the full flow of the plant. The addition of two parallel trains also enables production to continue whilst one train is taken offline for maintenance. There were considerations of providing a smaller capacity plant sized for the typical flows with buffering for intermittent higher flow rates. However, the proposed full capacity system can sustain peak flows for extended periods of time between routine maintenance activities. Preliminary design of the treatment system is provided diagrammatically in Figure 11 below. The design incorporates the use of duty, assist and standby arrangements to allow flexible operation and high reliability of the system.

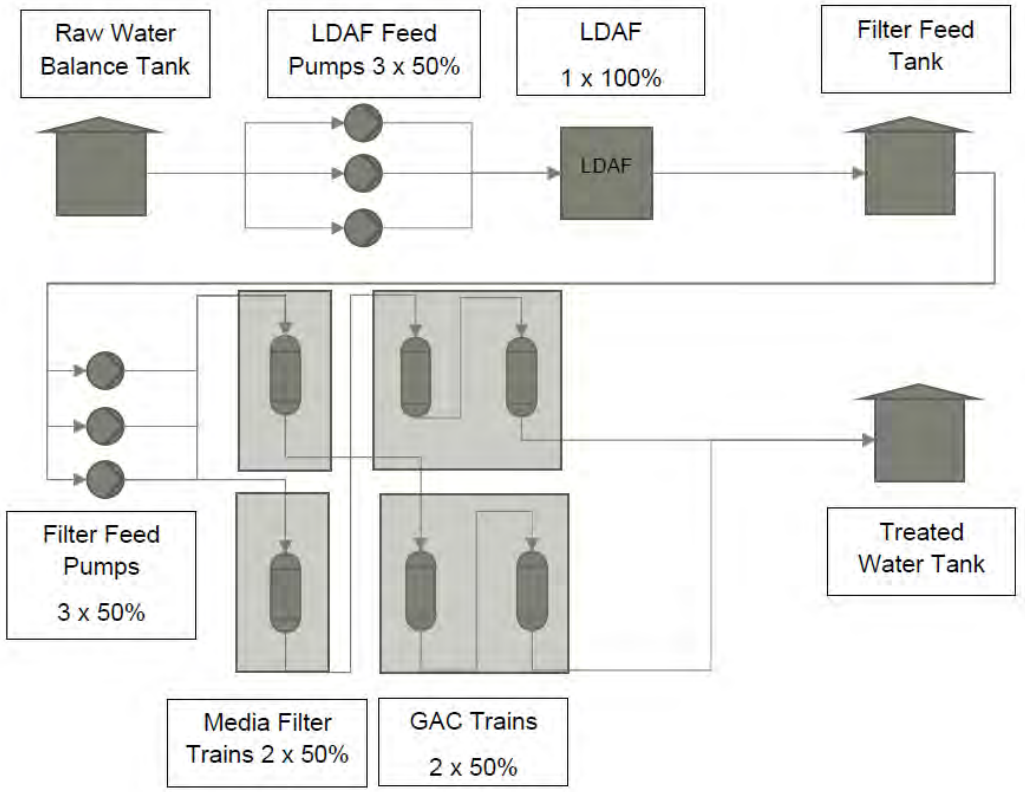


Figure 11: Flow diagram of water treatment system, including duty, assist and standby.

Timing

The overall timeline for implementation of the containment system including access to the site, design, procurement, and construction will be in the order of 18 months to 2 years however this can be shortened by completing access agreements in 2022 while in parallel undertaking system design (wells and surface facilities) and procurement of the surface containment system. This will then allow the future execution of the wells and surface construction scope to be executed within a period of 6 to 9 months. Noting that the proposed 55 wells will not start producing water / gas until 2024.

Additional DES Queries (see email at Attachment A)

Arrow has received miscellaneous queries from DES regarding a number of issues, these are addressed below.

Query 1

Arrow relies on using monitoring data from bores that are Department of Resources (DoR) bores and Linc legacy bores. DES understands that DoR has decommissioning plans for a number of bores on the former Linc site moving forward, and that these plans are subject to change at any time e.g. change in monitoring frequency, P&A of various wells based on risk profiling. How will Arrow keep informed of DoR's decommissioning plans?

Response

	Arrow Energy has held regular meetings with DoR and DES, and will continue to engage regularly with DoR as DES transitions away from investigation of the UCG activities conducted on Lot 40 DY85. Query 2 How does Arrow intend to comply with potential EA groundwater monitoring conditions that may require a set frequency of monitoring at specific wells when these wells may be decommissioned at any time? Also include comment on what Arrow will do if DoR change frequency of groundwater sampling or analytes sampled or bores being sampled. For example G4MWA is not being sampled by DoR or DES moving forward and is likely to be P&A. Response Arrow Energy will continue to engage regularly with DoR to understand and be informed as soon as possible of any changes in management by DoR of Lot 40 DY85 prior to the changes occurring. Arrow Energy anticipates that potential EA groundwater monitoring conditions would, rather than being prescriptive of the monitoring network and potential containment system, provide for the engagement of a Suitably Qualified Person (SQP) to ensure risks to human health and the environment have been appropriately managed, and appointment of a Contaminated Land Auditor (CLA) to provide independent oversight that the management plan objective, methods and measures are appropriate to risk from Arrow's activities. This management approach would then identify if and when decommissioned monitoring bores would need to be replaced. Arrow Energy will also request access to the site for a SQP and CLA to undertake monitoring and review the DoR site management plan, assessing the impact of changes to the available bores on the goals of the Arrow Energy monitoring program, namely, to provide early notification of changes in groundwater flow direction and quality in relation to groundwater conditions on Lot 40 DY85 as a result of Arrow's activities. This will include liaising with DES to amend conditions if they are prescriptively defined in the EA, such as by substitution of existing monitoring wells or installation of new monitoring wells if required, whilst maintaining the goals of the monitoring program. As the changes on-site due to Arrow Energy activities will propagate from production wells located off-site, the data collected from production wells and off-site monitoring bores Hopeland 20-27 will provide early indication that pressures around the site are decreasing. Arrow Energy has access to the production wells and monitoring bores and has a SQP to conduct sampling. Arrow Energy understands that the HSMB series and NB wells inside the site will remain available for sampling by DoR and/or an SQP, and constitute the majority of on-site monitoring bores incorporated in Arrow's proposed adaptive management program, as updated elsewhere in this RFI response. If G4MWA is plugged and abandoned, as one of the pressure monitoring sites selected for identifying

	changes in gradient this monitoring bore would be replaced by Arrow before Arrow commenced extraction from the 55 development wells. Arrow Energy will also use an SQP and CLA to review the existing site management plan (SMP) or remediation action plan (RAP) held by DoR to understand the risks posed by the site (that is risks not attributable to Arrow's activities) and modify the currently proposed regime as required whilst achieving the goal of the EA condition. Query 3 As Linc legacy bores are decommissioned, how will the groundwater model be affected? Response Arrow will use an SQP and CLA to assess the impact on the model and the goals of the program and respond to ensure goals of the monitoring program are maintained. Query 4 Arrow's management strategies rely on being able to undertake groundwater monitoring on the former Linc site. On what legal basis does Arrow have access to conduct monitoring on the former Linc site? Response See response at 11 b) Query 5 Has Arrow factored in approval timeframes for getting legal access? Response Arrow is working with both DoR and DES to facilitate the mechanisms and agreements required to access the site. That timeframe is governed by the expiry of ATP676 in September 2022. Query 6 What management strategies are Arrow proposing to implement if access is not granted to the former Linc site? And how do these ensure that there will be no offsite movement of contaminants? Consideration should be given to the influence that decommissioning wells on the former Linc site will have on the changes in groundwater. Response Arrow Energy modelling has shown that Arrow activities are predicted to have minimal impact to the movement of groundwater contaminants at the site. An SQP/CLA would assess these predictions and the suitability of off-site options for hydraulic control. Off-site options would include hydraulic containment through vertical or deviated interception wells aligned adjacent to the property boundaries of Lot 40 DY85,

<table>
<tr><td></td><td>with or without off-site water injection to maintain hydraulic gradients. These options have been provided to DES previously.</td></tr>
<tr><td>11c)</td><td>The management measures proposed by Arrow Energy provides an adaptive management program based upon NEPM (2013). This included use of G4MWD, L22, M15 and M14r as monitoring locations. Therefore, to maintain the proposed program the on-site monitoring bores M14r, G4MWD, L22 and M15 will be replaced by monitoring wells that provide information about pressure recovery between the gasifiers and the boundary monitoring wells.

Based on data currently available to Arrow Energy this would require the wells to be replaced by monitoring at the wells listed in table below and shown in Figure 12. If G4MWA is plugged and abandoned, as one of the pressure monitoring sites selected for identifying changes in gradient this monitoring bore would be replaced by Arrow before Arrow commenced extraction from the 55 development wells.

<table>
<tr><th>Current Monitoring Location</th><th>Unit Monitored</th><th>Proposed Monitoring Location</th><th>Unit Monitored</th></tr>
<tr><td>L22</td><td>Macalister</td><td>NB02D</td><td>Macalister</td></tr>
<tr><td>M15</td><td>Macalister</td><td>NB03D</td><td>Macalister</td></tr>
<tr><td>M14r</td><td>Macalister</td><td>NB01D</td><td>Macalister</td></tr>
<tr><td>G4MWD</td><td>Macalister</td><td>G4MWA</td><td>Macalister</td></tr>
</table>
Replacement Monitoring Bores</td></tr>
</table>

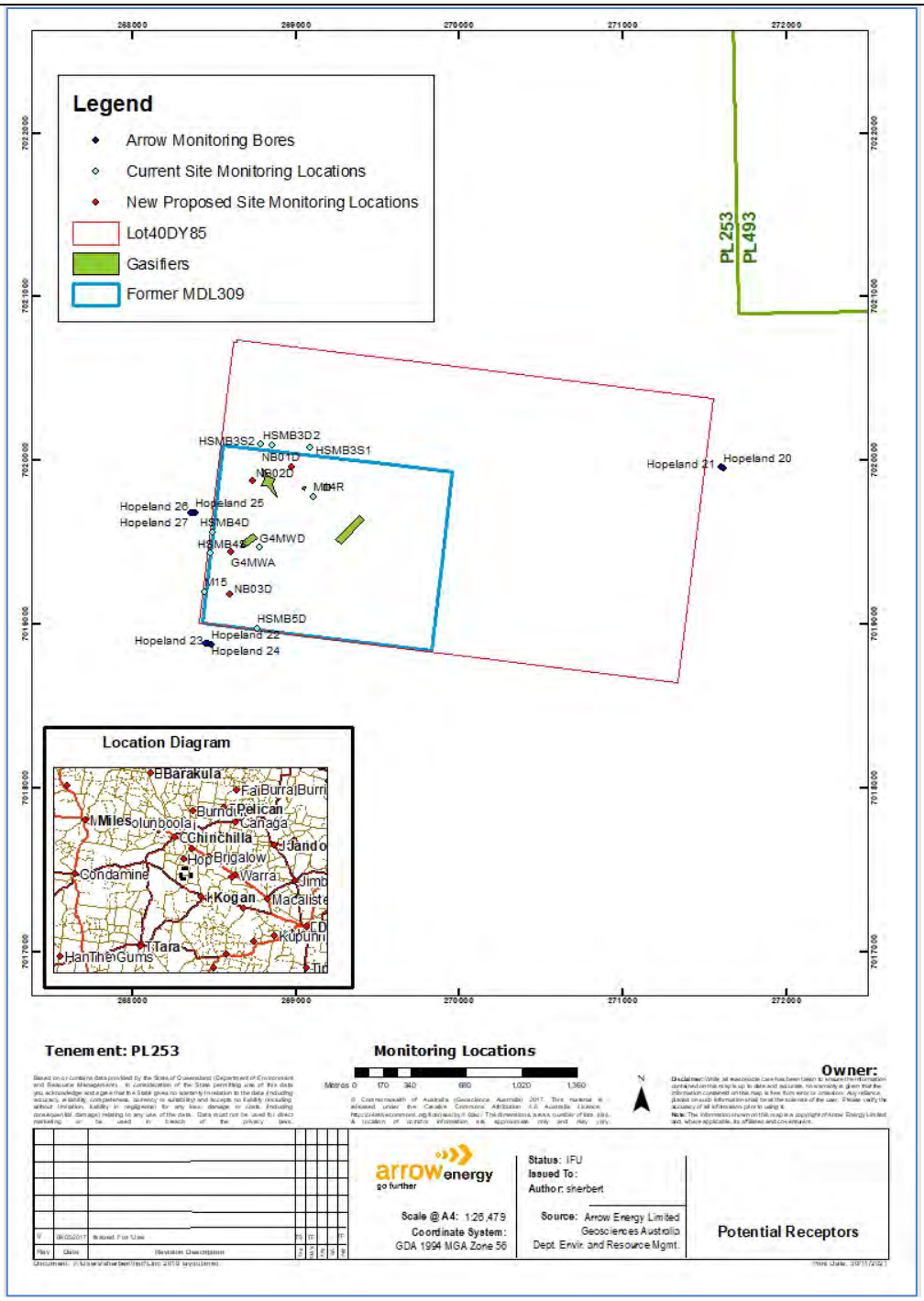


Figure 11 - Monitoring Locations

The HSMB6 and 7 series bores are distal from the site and do not indicate if recovery at the site is progressing and hence were not included in monitoring to assess changes at the site.

Attachment A - Information Request received from the DES (dated 18 November 2021) and email from DES (dated 4 February 2022)

Notice

Environmental Protection Act 1994

Information request

This information request is issued by the administering authority under section 140 of the Environmental Protection Act 1994 *to request further information needed to assess an amendment application for a site-specific environmental authority.*

ARROW CSG (AUSTRALIA) PTY LTD
Level 39
111 Eagle Street
BRISBANE CITY QLD 4000

scott.nairn@arrowenergy.com.au

ATTN: Scott Nairn

Your reference: A-EA-AMD-100138467

Our reference: C-EA-100138470

Further information is required to assess an amendment application for a site-specific environmental authority

1. Application details

The Amendment Application for a site-specific environmental authority was received by the administering authority on 06 October 2021.

The application reference number is: A-EA-AMD-100138467.

Land description: PL253.

2. Information request

The administering authority has considered the abovementioned application and is writing to inform you that further information is required to assess the application (an information request).

The information requested is provided below:

1) On page 11 of the application supporting material, Arrow CSG (Australia) Pty Ltd (Arrow) has detailed the proposed changes to General 1 Table 1 of the existing EA. Please confirm the following:
    a) Whether additional sediment ponds are required;
    b) Whether additional disturbance for raw water pipelines are required; and
    c) The disturbance (in hectares) of gathering pipelines being applied for.
2) Arrow proposes to amend the definition of Essential Petroleum Activities to include communications towers. Please provide an indication of how many communications towers are required, what infrastructure is involved, the maximum size of disturbance/footprint required for each and what impact this may have on environmental values.

3) Arrow proposes to amend the definition for Essential Petroleum Activities to allow disposal of residual drilling material to occur in areas of pre-existing disturbance in the primary protection zones of Category B environmentally sensitive areas that are 'endangered' regional ecosystems and Category C environmentally sensitive areas other than 'nature refuges' or 'koala habitat' areas. Please provide the following:

    a) Quality characteristics of the drilling material, including an assessment of whether the material constitutes a regulated waste;

    b) Method for undertaking the disposal of drilling material;

    c) A risk assessment prepared by a suitably qualified person that identifies the possible impacts due to the proposed activity and all associated risks (including contamination risks) to environmental values. This is to include:

        i. An assessment of any additional risk in undertaking disposal of drilling material within primary protection zones of Category B and Category C environmentally sensitive areas;

        ii. An assessment of any additional risk associated with shallow groundwater, and potential for any seepage or contamination to occur based on the soil structure and quality within the project area;

        iii. Details of additional rehabilitation requirements;

        iv. Consideration of the waste and resource management hierarchy in the *Waste Reduction and Recycling Act 2011* and describe why all other strategies (avoid, recycle, reuse or recover) would be unsuitable; and

        v. Strategies to monitor and mitigate any identified risks to environmental values, including land and groundwater contamination.

    Note: Mix-bury-cover of residual drilling materials may trigger Notifiable Activity 20: Landfill—disposing of waste (excluding inert construction and demolition waste) as listed in Schedule 4 of the *Environmental Protection Act 1994.*

4) Section 28 of the *Human Rights Act 2019* recognises the cultural rights of Aboriginal and Torres Strait Islander peoples. Section 4.4 of the application supporting material lists the various stakeholders that Arrow has undertaken engagement with, including traditional owner groups. The material mentions native title, but it has not specifically stated whether there is a current native title claim in the proposed disturbance area. Furthermore, the application material does not indicate whether there are other Aboriginal peoples, who may have a connection with the land under Aboriginal tradition, which does not require the establishment of native title. Please provide further information regarding the engagement with all Aboriginal people or groups relevant to this proposal.

5) Provide further information to justify an amendment to condition Water 13(f) from "at least biannually" to "at least annually". This includes an impact assessment of risks to environmental values, especially groundwater.

6) Deviated Wells

    a. Provide further information regarding whether proposed deviated wells will go off tenure (subsurface).

b. Provide further information on whether proposed deviated wells will result in an increased rate of dewatering/depressurisation and how this may impact the structural integrity of the formations. Consideration should also be given as to whether there will be an increased potential for fracturing to occur.

7) Biodiversity:

a) Appendix C of the Amendment Application Report contains a Terrestrial Ecology Report (Ecosmart Ecology, June 2017) for the entire Surat Gas Project (SGP) area. This appears to be a summary only. Please provide further details of the ecological assessment relevant to PL253 that includes, but is not limited to:

i. Methodology of ecological surveys undertaken including details and justification where survey methodology has deviated from methods detailed within current Queensland Guidelines; including but not limited to the following Guidelines:

a. 'Methodology for surveying and mapping regional ecosystems and vegetation communities in Queensland (V5.0)' (Neldner et al. 2019);

b. 'Flora Survey Guidelines - Protected Plants (V2.01)' (DES 2019b);

c. 'Management of endangered plants' (Cropper 1993);

d. 'Terrestrial Vertebrate Fauna Survey Guidelines for Queensland (V3.0)' (Eyre et al. 2018); and the

e. 'Queensland Targeted species survey guidelines' available: https://www.qld.gov.au/environment/plants-animals/biodiversity/vertebrate-survey#download

ii. Details of how the ground-truthed biodiversity values differ from Queensland government mapping e.g., locations, amount (hectares), composition, habitat features;

iii. Detailed assessment results;

iv. A thorough, evidence-based, justification for any presence/absence determinations for matters of State environmental significance (MSES), particularly where that deviates from the Queensland government records;

v. Details regarding the level of survey effort undertaken for flora and fauna values within the proposed disturbance area for the amendment as the provided Terrestrial Ecology Report (Ecosmart Ecology, June 2017) mapping indicates that no fauna surveys and limited flora surveys were undertaken within the area of PL253 that is proposed to be disturbed. If no additional survey effort has been undertaken, provide justification for the suitability of the Terrestrial Ecology Report (Ecosmart Ecology, June 2017);

vi. The Terrestrial Ecology Report (Ecosmart Ecology, June 2017) is dated 2017, the database searches that were undertaken as part of the ecological assessment are from this time period, please provide updated database searches for all ecological values, in particular updated mapping showing MSES and Matters of National Environmental Significance (MNES) fauna and flora species records; and

vii. The Terrestrial Ecology Report (Ecosmart Ecology, June 2017) is four years old with surveys occurring over five years ago. Provide justification of the suitability for this assessment given the time lapsed.

b) Table 6-3 of the Amendment Application Report (page 76) lists the proposed significant residual impacts to prescribed environmental matters. To determine the appropriateness of these values, the department requests the following:

i. A GIS layer of proposed disturbance;

ii. Detailed justification of the significant residual impact (SRI) assessment on prescribed environmental matters, including connectivity areas;

iii. The scale and extent of the activity planned for those areas that would result in a SRI on prescribed environmental matters; and

iv. The status of the Offset Strategy under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) that may be relevant to the application.

v. Further detail is sought regarding the proposed significant residual impacts to prescribed environmental matters; please provide guidance if the assessment is limited to the additional impact approval or if the assessment has considered the cumulative impact of the proposed disturbance and the SGP on all prescribed environmental matters associated with the SGP area.

c) The Amendment Application Report (page 49) identified that MSES also listed as MNES under the EPBC Act will be dealt with at a Federal Level. Provide further detail regarding the following:

i. The EPBC Referral Decision in place for the Project, including the date of the original EPBC Referral Application;

ii. How the Offset Strategy under the EPBC Act provides for MNES species that <u>were not</u> listed under the EPBC Act at the time of the decision but are also considered MSES for the SGP. In particular, how the strategies/measures described within the Offset Strategy will ensure that MSES species will be appropriately offset.

d) It is identified that terrestrial groundwater dependent ecosystems (GDEs) in the form of riparian vegetation may be present along significant reaches of some watercourses and their tributaries. It is indicated that a groundwater drawdown within PL253 would be less than 0.2m. Provide further detail regarding;

i. The tree species associated with the terrestrial GDEs;

ii. The current depth of the groundwater in relation to these terrestrial GDEs;

iii. How the drop of 0.2m in groundwater would not result in the current groundwater levels exceeding the tree species root uptake zones;

iv. Whether the proposed activities have the potential to lower the current groundwater quality, and whether any change in groundwater quality may affect the identified terrestrial GDES;

v. The potential of GDEs occurring outside of the tenure being affected by changes to groundwater depth and quality as a result of the proposed activities.

e) In relation to offsets for PL253, provide further information as follows:

i. Details of whether suitable offsets exist for the proposed impacts to prescribed environmental matters, including the endangered *Hemiaspis damelii* (Grey Snake);

ii. If already determined, the proposed offset delivery mechanism, i.e., land-based, financial payment or a combination of both. Where financial payment is proposed, the values to which the financial payment relates and the quantity (as determined by the offset financial calculator). Where land-based offsets are proposed, provide an assessment of 'habitat quality' of the impact area and offset area; and

iii. Details of whether the proposed impacts / offsets will be undertaken in full prior to the impacts occurring, or whether they will be staged over the life of the project. If staged impacts / offsets are proposed, identify what those stages are, which impacts are proposed for each stage and the anticipated timeframe for each stage.

8) Subsidence has been cited as an indirect impact of coal seam gas activities.

   a. Provide further information regarding the potential impacts to land and its use that may occur as a result of the activities. This should include mitigation measures to manage the impacts to land and details of any current or planned subsidence monitoring.

   b. Provide further information regarding the potential impacts to surface drainage and overland flow as a result of the activities. Consideration should be given to the potential changes to the direction and rate of surface flow and impacts to environmental values that these changes may have.

9) Noise:

   a. Arrow propose to increase the night time noise limit for drilling activities. Table 6.12 in section 6.5 lists 30dBA as the proposed night time outdoors limit. In other components of section 6.5, a night time outdoors limit of 33 dBA is mentioned. Confirm what outdoors night time drilling noise limit that Arrow is applying for.

   b. Arrow has not provided details of what separation distance between the drill rig and receptor is required for noise increases from 28dB(A) so that sensitive receptors are not impacted. It is unclear whether Arrow considers implementing separation distances a feasible management measure and how it aligns with the management hierarchy for noise in the Environmental Protection (Noise) Policy 2019.

   c. Arrow has not demonstrated what avoidance measures other than entering into alternative arrangements have been considered in the first instance in accordance with the management hierarchy for noise in the Environmental Protection (Noise) Policy 2019. Provide further information regarding what avoidance measures are used prior to considering alternative arrangements.

   d. Arrow's assessment focuses on noise impacts to sleep, however the environmental values to be enhanced or protected by the Environmental Protection (Noise) Policy 2019 are also the ability of individuals to study or learn, and be involved in recreation, including relaxation and conversation, as well as protecting the amenity of the community. It should be noted that while the Environmental Protection (Noise) Policy 2019 acoustic quality objectives to be enhanced or protected has health and wellbeing in relation to the ability to sleep as an environmental value for night time, this does not mean other environmental values do not apply during this time, for

example the amenity of the community. Provide further information to address other impacts to environmental values.

e. The application has not addressed how the proposal will not result in background creep in areas where petroleum activities will occur. This also involves Arrow demonstrating how the consideration of façade reduction will not result in background creep in an area.

10) Air:

a. Provide further information on potential air impacts to environmental values associated with high point vents.

b. Provide further information regarding vertical pathways for gas migration from the former Linc site within the coal seams. DES understands that vertical permeability has been enhanced by fracturing of the Macalister seam which would exacerbate the vertical migration of gases.

11) Groundwater:

a. What is the closest well distance to the former Linc site (Lot 40 DY85) and what aquifers will the proposed bores be accessing? In the previously withdrawn application submitted 6 July 2020, Arrow committed to not accessing the Macalister seam around the former Linc site (due to economic reasons) and proposed a staged development from the tenure boundary towards the former Linc site. Please provide further information about staged development of the 55 wells proposed, including location, timing and aquifer access.

b. Provide an update regarding Arrow's proposal to gain access to Lot 40 DY85.

c. DES notes that several of Arrow's proposed monitoring bores are marked to be plugged and abandoned by the Department of Resources (M14r, G4MWD, L22, and M15). Furthermore, DES' monitoring bores (HSMB6S, HSMB6D2, HSMB7S, HSMB7D) and the Department of Resources "NB" series bores have not been considered in the groundwater monitoring proposal. Page 123 of the application states that "Arrow will expand our monitoring program to validate and monitor the prosed activities and gas conditions". Provide further detail regarding how Arrow will maintain a sufficient monitoring network for groundwater pressure and quality that would detect groundwater changes in the vicinity of Lot 40 DY85.

3. Actions

The abovementioned application will lapse unless you respond by giving the administering authority -

(a) all of the information requested; or
(b) part of the information requested together with a written notice asking the authority to proceed with the assessment of the application; or
(c) a written notice –
    i. stating that you do not intend to supply any of the information requested; and
    ii. asking the administering authority to proceed with the assessment of the application.

A response to the information requested must be provided by 30 June 2022 (the information response period). If you wish to extend the information response period, a request to extend the period must be made at least 10 business days before the last day of the information response period.

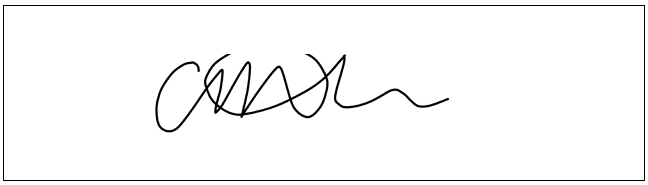
The response to this information request or a request to extend the information response period can be submitted to the administering authority by email to EnergyandExtractive@des.qld.gov.au.

If the information provided in response to this information request is still not adequate for the administering authority to make a decision, your application may be refused as a result of section 176 of the *Environmental Protection Act 1994,* where the administering authority must have regard to any response given for an information request.

4. Human rights

A human rights assessment was carried out in relation to this decision/action and it was determined that no human rights are engaged by the decision/action.

If you require more information, please contact Amelia Sellars on the telephone number listed below.



Signature

18 November 2021

Date

Clancy Mackaway
Department of Environment and Science
Delegate of the administering authority
Environmental Protection Act 1994

Enquiries:
Energy and Extractive Resources
GPO Box 2454, BRISBANE QLD 4001
Phone: (07) 3330 5715
Email: EnergyandExtractive@des.qld.gov.au

From: Amelia Sellars
To: Suzanne Ferguson
Cc: Clancy Mackaway; Rachel Copp; Michael Ryan; Andrew Hall
Subject: Information Request - PL253 Stage One EA Amendment
Date: Friday, 4 February 2022 1:35:43 PM
Attachments: image001.png
image002.png

[External Email]

This email was sent from outside the organisation – be cautious, particularly with links and attachments.

Hi Suzanne

I've provided some additional comments below that Arrow should consider addressing in the Information Request response:

- Item 2 – communications towers:
  - The response to the IR notes that the tower may be located in an area of regrowth that may provide koala habitat. It is recommended that further explanation is included of how avoidance and mitigation measures have been considered in determining an appropriate location.
- Item 7 – biodiversity:
  - Please provide the GIS datasets that show proposed disturbance on PL253.
- Item 11 – groundwater:
  - Arrow relies on using monitoring data from bores that are Department of Resources (DoR) bores and Linc legacy bores. DES understands that DoR has decommissioning plans for a number of bores on the former Linc site moving forward, and that these plans are subject to change at any time e.g. change in monitoring frequency, P&A of various wells based on risk profiling
    - How will Arrow keep informed of DoR's decommissioning plans?
    - How does Arrow intend to comply with potential EA groundwater monitoring conditions that may require a set frequency of monitoring at specific wells when these wells may be decommissioned at any time? Also include comment on what Arrow will do if DoR change frequency of groundwater sampling or analytes sampled or bores being sampled. For example G4MWA is not being sampled by DoR or DES moving forward and is likely to be P&A.
  - As Linc legacy bores are decommissioned, how will the groundwater model be affected?
  - Arrow's management strategies rely on being able to undertake groundwater monitoring on the former Linc site. On what legal basis does Arrow have access to conduct monitoring on the former Linc site?
  - Has Arrow factored in approval timeframes for getting legal access?
  - What management strategies are Arrow proposing to implement if access is not granted to the former Linc site? And how do these ensure that there will be no offsite movement of contaminants? Consideration should be given to the influence that decommissioning wells on the former Linc site will have on the changes in groundwater.

Please let me know if you have any questions.

Kind regards

Amelia Sellars
Principal Environmental Officer
Energy and Extractive Resources
Environmental Services and Regulation
Department of Environment and Science

E Amelia.Sellars@des.qld.gov.au

From: Suzanne Ferguson <Suzanne.Ferguson@arrowenergy.com.au>
Sent: Tuesday, 1 February 2022 1:02 PM
To: Clancy Mackaway
Cc: Michael Ryan; Andrew Hall
Subject: Information Request - PL253 Stage One EA Amendment

Hi Clancy.

Just following up from the meeting on 20 January 2022. DES were going to send through to Arrow any other information to be included in the Information Request for the Stage One EA Amendment. Could you please let me know how that is progressing and when you expect to send that through?

Would appreciate your advice. As you know, we would like to be able to close this out as soon as we can.

Thanks heaps.

Suzanne

Suzanne Ferguson
Tenure Manager

Arrow Energy Pty Ltd
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Attachment B - Updated desktop assessment results using state and federal databases

Queensland Government

WildNet species list

Search Criteria: Species List for a Specified Point
Species: All
Type: All
Queensland status: Rare and threatened species
Records: All
Date: Since 1980
Latitude: -26.9833
Longitude: 150.7167
Distance: 10
Email: Jeromy.claridge@attexo.com.au
Date submitted: Tuesday 18 Jan 2022 14:07:19
Date extracted: Tuesday 18 Jan 2022 14:10:08

The number of records retrieved = 10

Kingdom	Class	Family	Scientific Name	Common Name	I	Q	A	Records
animals	birds	Apodidae	*Hirundapus caudacutus*	white-throated needletail		V	V	1
animals	birds	Cacatuidae	*Calyptorhynchus lathami*	glossy black-cockatoo		V		1
animals	birds	Cacatuidae	*Calyptorhynchus lathami lathami*	glossy black-cockatoo (eastern)		V		1
animals	insects	Lycaenidae	*Jalmenus eubulus*	pale imperial hairstreak		V		2
animals	mammals	Phascolarctidae	*Phascolarctos cinereus*	koala		V	V	1
animals	mammals	Pseudocheiridae	*Petauroides armillatus*	central greater glider		E	V	1
animals	reptiles	Diplodactylidae	*Strophurus taenicauda*	golden-tailed gecko		NT		3
animals	reptiles	Elapidae	*Hemiaspis damelii*	grey snake		E		1
plants	land plants	Myrtaceae	*Eucalyptus curtisii*	Plunkett mallee		NT		2/2
plants	land plants	Rutaceae	*Philotheca sporadica*			NT	V	426/11

CODES

I - Y indicates that the taxon is introduced to Queensland and has naturalised.

Q - Indicates the Queensland conservation status of each taxon under the *Nature Conservation Act 1992.*
The codes are Extinct (EX), Extinct in the Wild (PE), Critically Endangered (CR), Endangered (E), Vulnerable (V), Near Threatened (NT), Special Least Concern (SL) and Least Concern (C).

A - Indicates the Australian conservation status of each taxon under the *Environment Protection and Biodiversity Conservation Act 1999.*
The values of EPBC are Extinct (EX), Extinct in the Wild (XW), Critically Endangered (CE), Endangered (E), Vulnerable (V) and Conservation Dependent (CD).

Records - The first number indicates the total number of records of the taxon (wildlife records and species listings for selected areas).
This number is output as 99999 if it equals or exceeds this value. A second number located after a / indicates the number of specimen records for the taxon.
This number is output as 999 if it equals or exceeds this value.

Australian Government

Department of Agriculture, Water and the Environment

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

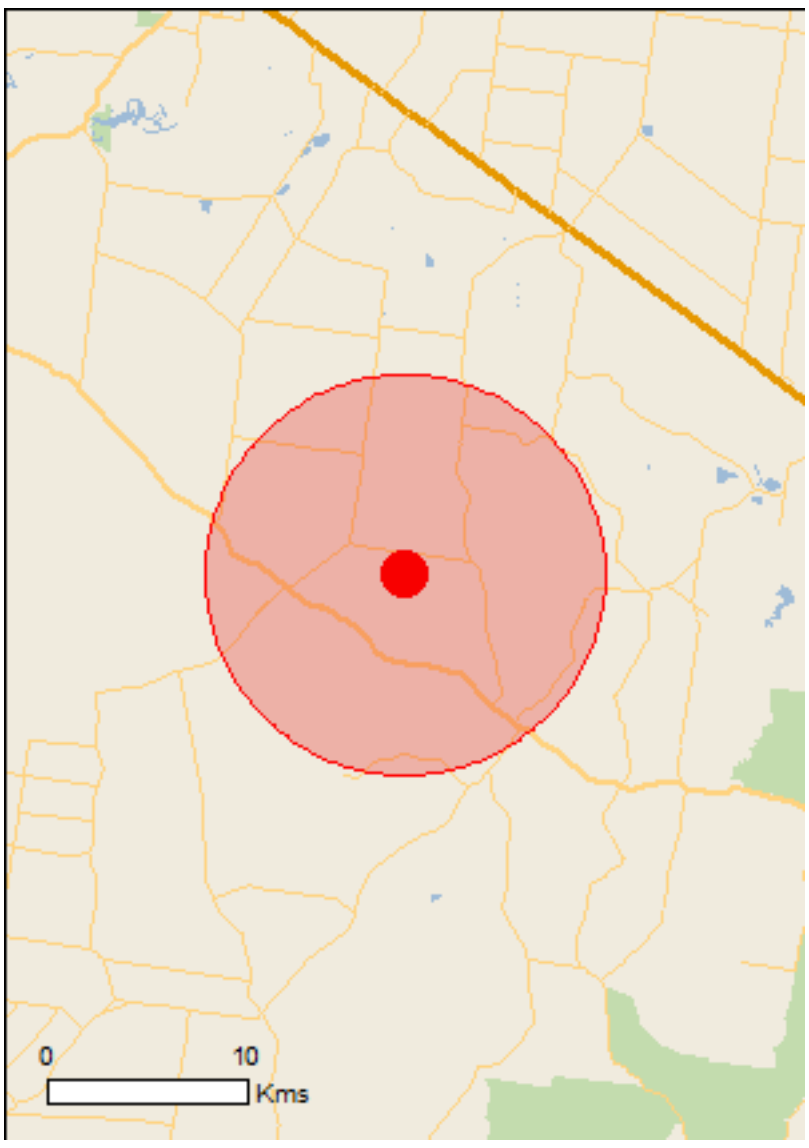
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 18/01/22 15:05:50

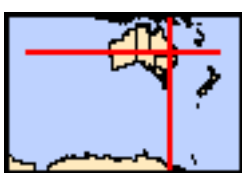
Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements



Coordinates

Buffer: 10.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	4
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	5
Listed Threatened Species:	26
Listed Migratory Species:	12

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	17
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	19
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Wetlands of International Importance (Ramsar) [Resource Information]

Name	Proximity
Banrock station wetland complex	1200 - 1300km
Narran lake nature reserve	400 - 500km upstream
Riverland	1100 - 1200km
The coorong, and lakes alexandrina and albert wetland	1400 - 1500km

Listed Threatened Ecological Communities [Resource Information]

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Name	Status	Type of Presence
Brigalow (Acacia harpophylla dominant and co-dominant)	Endangered	Community known to occur within area
Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions	Endangered	Community likely to occur within area
Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland	Critically Endangered	Community likely to occur within area
Poplar Box Grassy Woodland on Alluvial Plains	Endangered	Community likely to occur within area
Weeping Myall Woodlands	Endangered	Community likely to occur within area

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Erythrotriorchis radiatus Red Goshawk [942]	Vulnerable	Species or species habitat likely to occur within area
Falco hypoleucos Grey Falcon [929]	Vulnerable	Species or species habitat likely to occur within area
Geophaps scripta scripta Squatter Pigeon (southern) [64440]	Vulnerable	Species or species habitat may occur within area
Grantiella picta Painted Honeyeater [470]	Vulnerable	Species or species habitat likely to occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat may occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat likely to occur

Name	Status	Type of Presence within area
[Turnix melanogaster](#) Black-breasted Button-quail [923]	Vulnerable	Species or species habitat may occur within area
Fish		
[Maccullochella peelii](#) Murray Cod [66633]	Vulnerable	Species or species habitat may occur within area
Mammals		
[Chalinolobus dwyeri](#) Large-eared Pied Bat, Large Pied Bat [183]	Vulnerable	Species or species habitat likely to occur within area
[Dasyurus hallucatus](#) Northern Quoll, Digul [Gogo-Yimidir], Wijingadda [Dambimangari], Wiminji [Martu] [331]	Endangered	Species or species habitat may occur within area
[Nyctophilus corbeni](#) Corben's Long-eared Bat, South-eastern Long-eared Bat [83395]	Vulnerable	Species or species habitat likely to occur within area
[Petauroides volans](#) Greater Glider [254]	Vulnerable	Species or species habitat may occur within area
[Phascolarctos cinereus (combined populations of Qld, NSW and the ACT)](#) Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) [85104]	Vulnerable	Species or species habitat likely to occur within area
[Pteropus poliocephalus](#) Grey-headed Flying-fox [186]	Vulnerable	Foraging, feeding or related behaviour may occur within area
Other		
[Adclarkia cameroni](#) Brigalow Woodland Snail [83886]	Endangered	Species or species habitat likely to occur within area
[Adclarkia dulacca](#) Dulacca Woodland Snail [83885]	Endangered	Species or species habitat likely to occur within area
Plants		
[Cadellia pentastylis](#) Ooline [9828]	Vulnerable	Species or species habitat may occur within area
[Dichanthium setosum](#) bluegrass [14159]	Vulnerable	Species or species habitat may occur within area
[Homopholis belsonii](#) Belson's Panic [2406]	Vulnerable	Species or species habitat may occur within area
[Lepidium monoplocoides](#) Winged Pepper-cress [9190]	Endangered	Species or species habitat may occur within area
[Xerothamnella herbacea](#) [4146]	Endangered	Species or species habitat may occur within area
Reptiles		
[Anomalopus mackayi](#) Five-clawed Worm-skink, Long-legged Worm-skink [25934]	Vulnerable	Species or species habitat may occur within area
[Delma torquata](#) Adorned Delma, Collared Delma [1656]	Vulnerable	Species or species

Name	Status	Type of Presence
		habitat may occur within area
Egernia rugosa Yakka Skink [1420]	Vulnerable	Species or species habitat likely to occur within area
Furina dunmalli Dunmall's Snake [59254]	Vulnerable	Species or species habitat may occur within area

Listed Migratory Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Cuculus optatus Oriental Cuckoo, Horsfield's Cuckoo [86651]		Species or species habitat may occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat may occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Species or species habitat likely to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat may occur within area
Migratory Wetlands Species		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Species or species habitat likely to occur within area
Pandion haliaetus Osprey [952]		Species or species habitat may occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Birds		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat may occur within area
Anseranas semipalmata Magpie Goose [978]		Species or species habitat may occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Species or species habitat may occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat may occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Chrysococcyx osculans Black-eared Cuckoo [705]		Species or species habitat likely to occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Species or species habitat likely to occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat likely to occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Species or species habitat likely to occur within area
Pandion haliaetus Osprey [952]		Species or species habitat may occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Rostratula benghalensis (sensu lato)		
Painted Snipe [889]	Endangered*	Species or species habitat likely to occur within area

Extra Information

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Acridotheres tristis		
Common Myna, Indian Myna [387]		Species or species habitat likely to occur within area
Columba livia		
Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Lonchura punctulata		
Nutmeg Mannikin [399]		Species or species habitat likely to occur within area
Passer domesticus		
House Sparrow [405]		Species or species habitat likely to occur within area
Streptopelia chinensis		
Spotted Turtle-Dove [780]		Species or species habitat likely to occur within area
Sturnus vulgaris		
Common Starling [389]		Species or species habitat likely to occur within area
Frogs		
Rhinella marina		
Cane Toad [83218]		Species or species habitat known to occur within area
Mammals		
Canis lupus familiaris		
Domestic Dog [82654]		Species or species habitat likely to occur within area
Felis catus		
Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Lepus capensis		
Brown Hare [127]		Species or species habitat likely to occur

Name	Status	Type of Presence within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Rattus rattus Black Rat, Ship Rat [84]		Species or species habitat likely to occur within area
Sus scrofa Pig [6]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Lycium ferocissimum African Boxthorn, Boxthorn [19235]		Species or species habitat likely to occur within area
Parthenium hysterophorus Parthenium Weed, Bitter Weed, Carrot Grass, False Ragweed [19566]		Species or species habitat likely to occur within area
Pinus radiata Radiata Pine Monterey Pine, Insignis Pine, Wilding Pine [20780]		Species or species habitat may occur within area
Salix spp. except S.babylonica, S.x calodendron & S.x reichardtii Willows except Weeping Willow, Pussy Willow and Sterile Pussy Willow [68497]		Species or species habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-26.98333 150.71667

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Attachment C - Coal Seam Gas Activities: Noise Criteria Review – Review of Alternate Noise Criterion for Night-Time Drilling.

Report

Safe Work. Strong Business.

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Coal Seam Gas Activities: Noise Criteria Review

Review of Alternate Noise Criterion for Night-Time Drilling

Version	1.0
Released	3 August 2018
Document Author	Senior Advisor Environment & Carbon
Document Status	Final
Security Classification	Restricted

Please see document administration section for more information

arrow energy go further

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1 Introduction

Arrow has undertaken a review of noise criteria that are suitable to regulate noise emissions from Coal Seam Gas (CSG) projects. The review has included Queensland's regulatory framework, CSG specific noise criteria (as have been developed in Australia and overseas in recent years). This report includes a summary of this review.

The objective of the analysis is to support an alternative night time noise limit for temporary construction activities (drilling) that occur in a CSG gas field that also provides adequate protection against impacts to relevant noise environmental values.

It is considered that drilling activities do not contribute to 'long term' background noise creep as the activity is temporary in nature and is a mobile infrequent activity at any one location in a gas field. In order to protect against impacts to health and wellbeing, in relation to the ability to sleep (sleep disturbance), criteria for this acoustic value may be considered appropriate.

In order to support an alternative night time noise criterion for drilling, a summary of the following key considerations is presented in this report:

- Current Queensland noise regulatory framework is presented including a review of noise criteria for protection against various environmental aspects relevant to noise
- A summary of implementation issues with current noise conditions
- A summary of noise complaints received by DES from the CSG industry

2 General Environmental Duty

There is a general environmental duty to prevent and minimise environmental harm under the *Queensland Environmental Protection Act 1994* (EP (Act)). The EP (Act) specifically states:

> *A person must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practicable measures to prevent or minimise the harm (**the general environmental duty**).*

To decide what meets your environmental duty in accordance with the EP (Act), the following issues should be considered:

- The nature of the harm or potential harm;
- The sensitivity of the receiving environment;
- The current state of the technical knowledge for the activity;
- The likelihood of successful application of the different measures to prevent or minimise environmental harm that might be taken; and
- The financial implications of the different measures as they would relate to the type of activity.

3 Existing EA Streamlined Condition (Noise 1)

The streamlined noise condition Noise 1 provides noise limits designed to protect the acoustic values of a sensitive receptor in rural or isolated areas and to satisfy the acoustic quality objectives of the EPP (Noise) whilst considering cumulative impacts and background creep.

The streamlined noise condition is:

Noise 1

Notwithstanding condition (General 21), emission of noise from the petroleum activity(ies) at levels less than those specified in **Protecting acoustic values, Table 1 – Noise nuisance limits** are not considered to be environmental nuisance.

Protecting acoustic values, Table 1 – Noise nuisance limits

Time Period	Time of Day	Metric	Short-term	Medium-term	Long-term
6:00 am – 7:00 am	Morning	$L_{Aeq, adj, 15\ min}$	40 dBA	38 dBA	35 dBA
7:00 am – 6:00 pm	Daytime	$L_{Aeq, adj, 15\ min}$	45 dBA	43 dBA	40 dBA
6:00 pm – 10:00 pm	Evening	$L_{Aeq, adj, 15\ min}$	40 dBA	38 dBA	35 dBA
10:00 pm – 6:00 am	Night-time	$L_{Aeq, adj, 15\ min}$	28 dBA	28 dBA	28 dBA
		Max $L_{pA, 15\ mins}$	55 dBA	55 dBA	55 dBA

The noise limits in Table 1 have been based on the following deemed background noise levels (L_{ABG}):
6:00 am – 7:00 am: 30 dBA
7:00 am – 6:00 pm: 35 dBA
6:00 pm – 10:00 pm: 30 dBA
10:00 pm – 6:00 am: 25 dBA

In accordance with the streamlined noise condition, the following definition of short, medium and long term noise events are stated:

- **Short** – is a noise exposure, when perceived at a sensitive receptor, persists for an aggregated period not greater than eight (8) hours and does not re-occur for a period of at least seven (7) days.
- **Medium** – is a noise exposure, when perceived at a sensitive receptor, persists for an aggregated period not greater than five (5) days and does not reoccur for a period of at least four (4) weeks.
- **Long** – is a noise exposure, when perceived at a sensitive receptor, persists for an aggregated period of greater than five (5) days, even when there are respite periods when the noise is inaudible within those five (5) days.

With respect to the short and medium term noise events, re-occurrence is deemed to apply where a noise of comparable level is observed at the same receptor location for a period of one (1) hour or more, even if it originates from a different source or source location.

Arrow advises that the re-occurrence aspect of the short and medium term noise event definitions, as well as the specific time durations associated with the noise limits have by and large, prevented the use of these limits for those activities for which they are intended (i.e. construction and well development activities which are short term in nature). The practical limitations of these duration definitions are discussed further in Section 5.

Given the constraints of the current noise limits and noise event definitions, a practical alternative night-time noise limit for drilling activities, which would reasonably allow Arrow's well development to be undertaken in an efficient manner (while still protecting amenity) is investigated in this paper.

4 Noise Criteria Review

The following section provides an overview of current Queensland policies and guidelines for similar activities (i.e. construction and well development).

4.1 Queensland Regulatory Framework

The two most relevant legislative documents which outline the regulatory framework for addressing noise emissions in Queensland are the EP (Act) and the Environmental Protection (Noise) Policy 2008 (EPP(Noise)).

Arrow has also reviewed and made reference to the Department of Environment and Heritage Protection (DEHP) published noise guideline *Prescribing Noise Conditions for Environmental Authorities for Petroleum and Gas Activities* (EAPGA).

Development projects within Queensland have previously been assessed as having a construction phase (i.e. a temporary activity) and an operational phase (i.e. a permanent activity). These two phases of projects generally have very different impacts which results in different noise criteria developed to assess and manage their respective noise sources. This approach is outlined in the EP (Act) and EPP (Noise) with the relevant sections of these documents described below.

4.1.1 Environmental Protection Act (1994)

The EP (Act) provides noise criteria to regulate various noise related activities. The EP (Act) includes a section for building work (i.e. construction noise) in Section 440R. The EP (Act) does not provided quantitative noise criteria, but rather, it provides time restriction within which construction activities as far as reasonable and practicable should be conducted. The section relevant to noise from construction (ie Building Works) is provided below.

440R Building Work

> *(a) A person must not carry out building work in a way that makes an audible noise on a business day or Saturday, before 6.30 am or after 6.30 pm; or*
> *(b) on any other day, at any time.*

Section 440R of the EP (Act) is commonly used to regulate noise emissions from construction activities in Queensland. It is generally accepted that by having no quantitative daytime noise criteria during the construction phase and protecting amenity at night, this allows for a balance between allowing development to occur whilst allowing for sleep and relaxation during the evening and night-time periods.

4.1.2 Environmental Protection (Noise) Policy (2008)

The EPP (Noise) defines the values to be protected as the qualities of the acoustic environment that are conducive to:

a. Protecting the health and biodiversity of ecosystems.

b. Human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following
   - Sleep
   - Study or learn
   - Be involved in recreation, including relaxation and conversation
c. Protecting the amenity of the community.

The EPP (Noise) refers to the following management hierarchy with respect to an activity involving noise:

(a) Firstly – Avoid;
e.g. locating an industrial activity in an area that is not near a sensitive receiver
(b) Secondly – minimise, in the following order of preference–
(i) firstly – orientate an activity to minimise noise
eg facing a part of an activity that makes noise away from a sensitive receiver
(ii) secondly – use best available technology
(c) Thirdly – manage.
e.g. using heavy machinery only during business hours

The EPP (Noise) includes two separate noise criteria as outlined below:

Background Creep

To the extent it is reasonable to do so, noise from an activity must not be–

For a noise that is continuous noise measured by LA90,T – more than nil dBA greater than the existing acoustic environment measured by LA90,T; or

For a noise that varies over time noise measured by LAeq,T – more than 5 dBA greater than the existing acoustic environment measured by LA90,T.

Acoustic Quality Objectives

The acoustic quality objectives are intended to be progressively achieved as part of achieving the EPP (Noise) policy over the long term. The long term acoustic quality objectives for residential dwellings are presented in Table 1.

Table 1: EPP (noise) – Acoustic Quality Objectives

Sensitive Receptor	Time of Day	Acoustic Quality Objectives (Measured at the Receptor) dBA			Environment Value
		$L_{Aeq,adj,1\ hr}$	$L_{A10,adj,1\ hr}$	$L_{A1,adj,1\ hr}$	
Dwelling (for outdoors)	Daytime and Evening	50	55	65	Health and wellbeing
Dwelling (for indoors)	Daytime and Evening	35	40	45	Health and wellbeing
	Night-time	30	35	40	Health and wellbeing, in relation to the ability to sleep

4.1.3 Streamlined Model Conditions/Prescribing Noise Conditions for Environmental Authorities for Petroleum and Gas Activities (EAPGA) (Noise 1)

The DEHP EAPGA gives recommended noise emission limits specific to petroleum and gas activities as presented in Table 2. These noise limits are consistent with the Noise 1 streamlined condition.

Table 2: Streamlined Model Conditions – Noise Emission Limits

Time Period	Time of Day	Metric	Short-term	Medium-term	Long-term
6:00 am – 7:00 am	Morning	$L_{Aeq,\ adj,\ 15\ min}$	40 dBA (30^ + 10 dBA	38 dBA (30^ + 8 dBA	35 dBA (30^ + 5 dBA)
7:00 am – 6:00 pm	Daytime	$L_{Aeq,\ adj,\ 15\ min}$	45 dBA (35^ + 10 dBA	43 dBA (35^ + 8 dBA	40 dBA (35^ + 5 dBA)
6:00 pm – 10:00 pm	Evening	$L_{Aeq,\ adj,\ 15\ min}$	40 dBA (30^ + 10 dBA)	38 dBA (30^ + 8 dBA)	35 dBA (30^ + 5 dBA)
10:00 pm – 6:00 am	Night-time	$L_{Aeq,\ adj,\ 15\ min}$	28 dBA (25^ + 3dBA)	28 dBA (25^ + 3dBA)	28 dBA (25^ + 3dBA)
		Max $L_{pA,\ 15\ mins}$	55 dBA	55 dBA	55 dBA

The DEHP guideline EAPGA states that the deemed background noise level is applicable unless measurements show that the existing background noise level is higher than the deemed background noise level.

The guideline and streamlined model conditions provide some respite to short and medium term noise events. However, the Short Term activity is less than 8 hours and the Medium Term activity is between 8 hours and 5 days. This essentially means that most CSG construction activities such as construction of compressor stations etc will fall under the Long Term (i.e. operational) category. Well development activities such as drilling, workovers and completions will typically fall under the medium term category when assessed in isolation. However, gas field development will require multiple wells to be drilled sequentially and as a result drilling will actually fall under the long term category.

The guideline was designed such that short term and medium term events would be applied to activities such as drilling and well activities such as well workovers and completions (Ron Rumble, 2011). However, CSG construction activities such as drilling do not fit into the time period definitions of short-term or medium term provided in the streamlined conditions or guideline (refer to Section 5 for more detail).

As such the streamlined model noise conditions provide no achievable relaxation of noise limits for short term noise events. It is also noted that short term noise events such as construction and drilling are not at risk of affecting long term background noise creep (due to the nature of the activity being short term, temporary and mobile).

4.2 World Health Organisation (WHO)

The WHO Guidelines for Community Noise are based on the outcomes of the WHO expert taskforce meeting held in London in 1999. A summary of the recommended noise levels in the Guideline has been included here as it is probably the most esteemed and referenced document relating to health effects of noise impacts in the world.

The Guideline provides detailed background information and cover various health-related effects from noise such as hearing impairment (occupational noise), annoyance, sleep disturbance, speech interference, increased stress and cardiovascular and physiological effects. Recommendations from the WHO Guidelines for various sources and situations, which are relevant for a project such as the Arrow Energy project, are provided in the sections below.

4.2.1 Day and Evening period

For the daytime and evening periods the Guideline recommends noise levels to protecting against annoyance as well as allowing for good speech communication.

To protect against annoyance responses the WHO guidelines recommend outdoor noise levels during the day period as follows:

- 55 dBA L_{Aeq} to “protect the majority of people from being seriously annoyed”.
- 50 dBA L_{Aeq} to “protect the majority of people from being moderately annoyed”.

In addition, the guidelines states that noise levels during the evening and night should be 5 – 10 dBA lower than during the day.

To protect against speech interference the WHO guidelines states the following:

- “Speech in relaxed conversation is 100% intelligible in background noise levels of about 35 dBA, and can be understood fairly well in background levels of 45 dBA.”
- “Speech with more vocal effort can be understood when the background sound pressure level is about 65 dBA.”

In addition, the guidelines nominate an internal noise level inside dwellings of 35 dBA L_{Aeq} for the purposes of allowing good speech intelligibility and moderate annoyance.

4.2.2 Night Period – Sleep Disturbance

The WHO Guidelines generally prescribe two noise levels at residential locations to ensure that sleep is not adversely affected, being:

- 30 dBA L_{Aeq} for continuous noise.
- 45 dBA L_{Amax} for single events (maximums).

The above noise levels are at the persons ear (i.e., within the residential building). The WHO night-time noise limit aims to protect sensitive receptors from sleep disturbance.

With regards to the maximum noise levels, the WHO guideline also states that it is important to take into account the character of the noise, i.e. number of noise events and the difference between the maximum noise level and the background noise level. It is identified that for a good night sleep, the criterion of 45 dBA L_{Amax} should not be exceeded more than 10 – 15 times per night. The corresponding external noise level, assuming partially closed windows is 52 dBA max L_{pA}, measured in the free field, which corresponds well to the recommended noise limit in DES's Guideline of 55 dBA (DES, 2004).

The noise limits for continuous sources recommended by WHO are consistent with the night-time noise limit in the EPP (Noise) (i.e. 30 dBA internal). There is no sleep disturbance noise limit for the day and evening periods.

The WHO guidelines state:

> *"Measureable effects on sleep start at background noise levels of about **30 dB L_{Aeq}**. Physiological effects include changes in the pattern of sleep stages, especially a reduction in the proportion of REM sleep. Subjective effects have also been identified, such as difficulty in falling asleep, perceived sleep quality, and adverse after-effects such as headache and tiredness. Sensitive groups mainly include elderly persons, shift workers and persons with physical and mental disorders.*
>
> *Where noise is continuous, the equivalent sound pressure level should not exceed 30 dBA indoors, if negative effects of sleep are to be avoided.*
>
> *If the noise is not continuous, LAmax or SEL are used to indicate the probability of noise induced awakenings. Effects have been observed at individual LAmax exposures of 45 dBA or less…. Therefore, the guidelines should be based on combination of values of 30 dBA LAeq, 8hr and 45 dB LA, max.*

The WHO guidelines do note that to protect, sensitive persons, a still lower guideline value would be preferred when the background level is low.

However, the night-time noise limit currently proposed by DES to cover drilling activities is 28 dBA ($L_{Aeq, adj, 15\ min}$) (external). Assuming a 5 dBA façade reduction for a bedroom with wide open windows (as per DES's *Planning for Noise Control Guideline*), this is equivalent to an indoor internal noise limit **of 23 dBA ($L_{Aeq, adj, 15\ min}$)**.

This noise limit is a lot lower than the recommended noise limit provided by the WHO and considered overly stringent given literature for the protection of sleep disturbance (even considering the quiet rural environment) and the temporary nature of drilling activities.

5 Implementation Limitations of Current Noise Limits

5.1 Review of Defined Time Durations in Noise 1 and CSG Activities

A comparison of the event duration definitions (including the definition of re-occurrence) in the EHP Model Condition in Noise 1 and Arrow's historical gas field activity demonstrates that very few CSG activities fit into the short term or medium term definitions. Therefore, it appears the intent of the different noise limits to allow slightly relaxed limits for temporary activities is not effective in practice. It is considered that the intent of the short term and medium term noise limits was to ensure that those activities that are shorter term are not penalised with more stringent noise limits which are more relevant to long-term / permanent noise sources. In other words, noise sources which do not inherently contribute to long-term background creep are allowed to operate under less stringent noise limits.

The fundamentals of this approach are sound; however the practical workings have shown that very few activities Arrow (or their Contractors) has undertaken have been classed as short or medium term noise events. The key reason is that very few activities can reasonably and practicably occur in isolation without re-occurring in-line with the 're-occurrence' definition in the EA (see Section 0), and therefore result in perceived noise emissions at a sensitive receptor for greater than 5 days (even when not continuously audible during the perceived period).

Table 3 below details those CSG activities which historically have been assessed against the short, medium and long-term noise limits. Arrow's main concern is that the current EA model noise condition is not suitable for what are broadly speaking 'shorter term' events such as well development and construction activities (though they may be applicable for longer term noise events such as well field operation which can contribute to background creep).

Table 3: Historical Arrow activities assessed against short, medium and long-term noise limits

Duration Noise Limit	Activity
Short term	Pipeline blow downs Commissioning phase emergency flare tests
Medium term	
Long term	Drilling (including sub-processes such as cementing) Completions (including sub-processes such as venting) Cavitations (including sub-processes) Work-overs (including sub-processes) Rig Camps (including setup, operation and demobilising) Well pad preparation Gas gathering construction Major facilities' construction (e.g. CGPF, WTF, dams) Laydown yard construction and usage Construction camps (including construction, operation and demobilising) Fixed facilities operations (e.g. CGPF, WTF, power generation) Operational camps (including construction and operation) Commissioning activities including flaring Well operations E&A seismic surveys Pipeline construction Horizontal directional drilling

5.2 Review of Well Development Activities

Well development activities like drilling and completions, which typically take 3 days per well, often occur in a sequence on a property as this is the most cost effective way to operate drill rigs (i.e. sequenced wells on the same property minimises lost time between drill rig relocation), and the total duration of time spent on a given landholder's property is minimised.

A landholder / sensitive receptor therefore has the potential to be subjected to perceived drilling / completions noise for a period of greater than 5 days due to numerous wells being drilled / completed in sequence. Based on the historical durations of well drilling / completions, it would only take two (2) wells in sequence to result in the long term noise duration and thus the most stringent noise limits being triggered. The result is that broadly speaking 'shorter term' noise events such as drilling are required to comply with the same noise limits which are applicable to long term noise sources (such as a CGPF) which could emit noise for the life of the project (i.e. 20 years).

Within Arrow's well development activities, there are sub-processes which occur for a brief period of time (i.e. 1-2 hours in duration) and occur only a limited number of times in a typical well development cycle. An example of such an event is cementing which occurs twice during a typical drilling event, and typically only lasts for 1-2 hours. Cementing should be an activity that by broad terms is assessed against a short-term noise limit. However because of the EA noise duration definitions and because cementing re-occurs when more than 1 well is drilled sequentially, cementing historically has never been assessed against a short-term noise limit and has always been assessed against long-term noise limits (along with the remaining drilling activities).

5.3 Modelled Noise Levels from Drill Rigs

Arrow has conducted numerous noise modelling studies for CSG drill rigs. A summary of the noise modelling results for a nominal drill rig and various sub-drill rig operations is shown in Table 4.

Table 4: Modelled noise levels from a typical drill rig operation at various separation distances

Activity	Weather Condition[a,b]	Predicted Noise Level at Buffer Distance (LAeq dBA)					
		100 m	250 m	500 m	1,000 m	2,000 m	3,000 m
Drilling including Mud Pumps	Neutral	71	59	49	39	28	21
	Adverse	71	61	53	44	34	27
Completion/Work Over	Neutral	72	60	50	41	30	23
	Adverse	72	63	54	45	35	29
Cementing	Neutral	72	60	51	41	29	22
	Adverse	72	63	55	46	35	28

[a] Neutral weather conditions are summarised by a wind speed of 0 m/s and Pasquil-Gifford atmospheric stability class of D

[b] Adverse weather conditions are summarised by a wind speed of ~ 2m/s from the noise source to the receptor and Pasquil-Gifford atmospheric stability class of F

[c] Note that estimated separation distances vary depending on the drill rig and operating conditions. Modelled separation distances are presented for a typical drill rig.

Applying a night-time noise limit of 28 dBA results in a required separation distance from a workover/completion rig of just over 3,000 metres. However, the modelled separation distance that is considered sufficient to protect against potential sleep disturbance (35 dBA external) is estimated to be 2,000 metres. The potentially affected areas to achieve each night-time noise limit for a drill rig operation is shown in Table 5.

Table 5: Difference in separation distances required to achieve night time noise criteria

Night-time noise criteria	Separation Distance (m)	Drill Rig Separation Diameter (m)	Area per drilling operation (m^2)	Area (ha)
28 dBA	2000	4000	12,566,371	1,257
35 dBA	3000	6000	28,274,334	2,827
			Ratio of difference in drill rig separation "area"	**2.25**

[a] Note that estimated separation distances vary depending on the drill rig and operating conditions. Modelled separation distances are presented for a typical drill rig.

Arrow is concerned by the significantly increased area required for each drilling operation to achieve the 28 dBA noise criterion when compared to achieving the sleep disturbance criterion of 35 dBA.

Whilst Arrow agrees with the 28 dBA night-time noise criterion for fixed plant and equipment, the application of this criterion to temporary drilling activities appears overly stringent.

Application of a noise criterion to protect against the impacts of sleep disturbance is considered adequate protection for this temporary activity. Drilling activities are not considered to have a significant impact or risk on 'long term' background creep.

6 Review of CSG Noise Complaints

In 2016, DES (formerly EHP) reviewed all CSG noise complaints received between 2012 and July 2016. The review found that noise complaints relate predominantly to night time or evening noise nuisance and have been largely due to fixed plant operation as shown in Table 6. Noise complaints due to fixed plant operation significantly increased in 2016 but have remained fairly low and stable for drilling and construction activity.

These complaints were validated by DES, in that no noise complaints received were deemed to be frivolous or vexatious to date. This indicates that the complaints likely occurred at times when noise levels at the receptor were in exceedance of relevant EA noise criteria.

Review of noise criteria for CSG activities indicates that a significant number of operating wells (and presumably drilling activity) in Queensland were regulated under the EAs EPPG00853013 and EPPG00797813 (totalling approximately 1,300 operating CSG wells). A review of noise conditions for these CSG activities shows that an alternative noise condition is applied to drilling activities for night time activities consistent with the sleep disturbance criteria of 30 dBA (internal).

Table 6: Noise Complaints received by DES for CSG Activities [a]

Nature	2012	2013	2014	2015	2016 (to July)
Drill Rig	2	4	5	4	3
Fixed Plant	6	5	5	5	22
Construction	1	5	0	2	0
Total	**9**	**14**	**10**	**11**	**25**
Number of Qld CSG Wells Drilled [b]	700	1,300	1570	850	690

[a] Source: P&G Quarterly Meeting Minutes: Noise 06 March 2017

[b] Source: Queensland's petroleum and coal seam gas 2015-16, Department of Natural Resources and Mines

Despite a significant number of operating wells regulated using an alternative night-time noise criteria for drilling between 2012 and 2016, noise complaints from drilling activities have remained low.

This analysis supports Arrow's position that the key environmental value to protect for temporary drilling activity is sleep disturbance and a night-time 30 dBA (internal) noise criterion is effective at providing protection against impacts to this value. It also may indicate that drilling/construction has less risk of generating a noise complaint when compared to fixed plant due to the temporary nature of the noise generating activity which is consistent with literature.

7 Conclusion

Based on the review of noise criteria and levels for adequate protection against adverse impacts Arrow applies for the following modification to the Streamlined Noise 1 condition for DES consideration.

Table 1 — Noise nuisance limits

Time period	Metric	Short term noise event[1]	Medium term noise event[1]	Long term noise event[1]
7:00am — 6:00pm	$L_{Aeq,adj,15\ min}$	45 dBA	43 dBA	40 dBA
6:00pm — 10:00pm	$L_{Aeq,adj,15\ min}$	40 dBA	38 dBA	35 dBA
10:00pm — 6:00am	$L_{Aeq,adj,15\ min}$	28 dBA	28 dBA	28 dBA
	Max $L_{pA,\ 15\ mins}$	55 dBA	55 dBA	55 dBA
6:00am — 7:00am	$L_{Aeq,adj,15\ min}$	40 dBA	38 dBA	35 dBA
Drilling activities undertaken from 10:00 pm – 7:00 am	$L_{Aeq,\ adj,\ 15\ min}$	28 dBA[2] must be measured indoors at any sensitive receptor		

1. The noise limits in Table 1 have been set based on the following deemed background noise levels (L_{ABG}):
   7:00am—6:00 pm: 35 dBA
   6:00pm—10:00 pm: 30 dBA
   10:00pm—6:00 am: 25 dBA
   6:00am—7:00 am: 30 dBA
2 Measured indoors at any sensitive receptor or 33 dBA externally

The alternative night-time noise criterion for drilling:

- Takes into account literature and recommended values for the protection against sleep disturbance; and
- Considers WHO's recommendation that slightly lower noise criteria levels may be appropriate in areas with low background noise levels, and
- Is consistent with the requirements of both the EP Act and the EPP Noise, including the General Environmental Duty.

This is considered a fair and considered noise criteria in order to protect against potential noise impacts from temporary and mobile drilling activity that does not present a significant risk to 'long-term' background noise creep.

8 Document Administration

Revision history

Revision	Revision Date	Revision Summary	Author
1.0	August 2018	Initial report prepared	K. Bawden

Acceptance and release

Author

Position	Incumbent	Release Date
Senior Advisor Environment & Carbon	Kelsey Bawden	3 August 2018

Contributors and reviewers

Position	Incumbent	Review Date
Regulatory Approvals Specialist	Darryl Patching	3 August 2018

Attachment D - Dual Phase Modelling Report

Attachment D

Centre for Natural Gas

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CREATE CHANGE

Arrow Energy PL253 and PL493 Production License Modelling Support

Report Date: 09/03/2021

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Executive Summary

This report documents multi-phase modelling concerning possible future movement of residual gases beneath the former Linc Energy site at 357 Kummerows Rd, Chinchilla. The aim of the work is to answer the following questions and requests posed by Queensland Department of Environment and Science (DES):

1. "What is the fate of 'free gas' and water pressures at the former Linc UCG site on PL253 under two scenarios:
    a. Current development with no further Arrow production in PL253/493;
    b. Proposed development with Arrow production in PL253/493.
2. What is the uncertainty in the prediction of the fate of 'free gas' and water pressures in these scenarios?
3. Undertake a dual phase model that incorporates groundwater and gas movement that will demonstrate how gas movement may influence groundwater movement. Model gas movement, including up dip movement (Condamine bubbles), given that gas is more actively moving due to fracturing."

Linc Energy (Linc) undertook Underground Coal Gasification (UCG) activities on the site between 1999 and 2013 which have left residual gases within the upper seams of the Walloon Coal Measures and the lower Springbok Sandstone. Arrow Energy (Arrow) are developing coal seam gas (CSG) fields in Petroleum Leases PL253 and PL493 surrounding the site, and Arrow and DNRME wish to understand the impact of CSG development on residual gases at the Linc site.

The questions and request are addressed using multi-phase numerical simulations of free gas movement using CMG's GEM compositional simulator. The work considers movement of methane, as the primary gas observed on site and was completed by the University of Queensland's Centre for Natural Gas.

The approach to modelling was to represent a 3.5km x 3km domain around the former Linc Energy site in detail, incorporating site specific data where available. The model has 8 layers, representing the interval from surface, through the Springbok Sandstone to the Wambo Coal of the Walloon Coal Measures. The layering permits representation of the individual Macalister coal seams target by UCG operations. The structure of the multi-phase model was based on a geological/structural model provided by Arrow Energy. A "gasification" period was simulated, then models were run from the end of Linc operations in 2013 to 2019 and compared to observations of pressure recovery. Models were rejected as unrealistic if they were unable to replicate a key observation: that pressures at the Linc site have not recovered by 2019, with 30 to 40 m of residual drawdown remaining.

For predictive/forward models, boundary conditions that replicate pressure heads simulated by larger scale groundwater modelling (AGE, 2020) are applied around the model perimeter and base. Two versions of these boundary conditions represent the difference between two main scenarios of current development with no further Arrow production in PL253/493, and with Arrow development. An inert tracer is added to the free gas phase in the model to allow "contaminant" gases remaining after gasification to be identified.

The sensitivity of multiple parameters that control gas movement was tested. This included models with enhanced permeability (horizontally, and vertically into the Springbok), transmissive or sealing faults, higher saturation (adsorbed gas content) of the coal, and models with an enhanced pressure gradient across the model.

Results in the base case (Figures 1 and 2) and the sensitivity analysis suggest Arrow's Field Development is unlikely to significantly alter the behaviour of any residual gases that remain around the former Linc Energy site. The pressure head plots in Figure 1, corresponding to 2013 and 2019, show gradients oriented inward toward the site with groundwater flow toward the gasifier locations. This inflow causes pressures to increase over time with residual gas being compressed. Within coals, the pressure rise causes methane to be (re)adsorbed onto the coal matrix, becoming trapped. This is the opposite of the behaviour seen in Coal Seam Gas operations, where pressures are reduced (by dewatering) to cause desorption and release

trapped gas. Methane adsorption leads to an apparent increase in tracer concentration as methane adsorbs, and the non-adsorbing tracer remains in the free gas phase.

In Figure 2 for 2043 the pressure head plots differ by approximately 10 m of water pressure due to Arrow development of PL253/493. The predicted gas saturations are low, due to re-adsorption of methane from UCG operations and there is little to no difference in the distribution of remaining gas between the development scenarios. This base case simulation shows Arrow's proposed development to be unlikely to significantly alter the behaviour of residual gases on the former Linc site. Multiple sensitivity scenarios produced similar results with little change in predicted residual gas distributions or concentrations.

The results can be understood by considering the physical processes occurring at the site. Initially, the area around the gasifiers is depleted compared to the surrounding area with an inward pressure gradient mostly towards the gasifiers. Actual groundwater flow is at very low rates, due to a combination of the low intrinsic permeability of the rock, and the low relative permeability to water. This behaviour is consistent with the site observations in 2019, which indicate the site remains depleted; pressures had not recovered in the six years since gasification operations ended. Buoyancy does cause some gas movement in the models; however, this is limited by the low permeability, or low relative permeability to gas, around the site. Note that conceptually gasifiers would be 100% gas saturated at the end of gasification whilst coals in the far field, at sufficient distance from gasification, remain 100% water saturated. Between these end members, coal cleats will be partially saturated with both gas and water, and the relative permeability to each fluid may act to impede flow.

These processes mean that whether the Arrow Field Development is included in the models or not, the majority of residual gas in the models becomes trapped, either by adsorption, or due to small structures (traps) within the structure of the Macalister A seam. Simulation and sensitivity results indicate that free gas that is not trapped by these mechanisms is still unlikely to move, due to low permeability, or low relative permeability, even if subjected to the increased pressure (groundwater head) gradient predicted to occur due to Arrow's Field Development. The modelling result of very minor future gas movement, with or without Arrow development, may appear counter-intuitive when considered in the Surat Basin context of gassy groundwater bores, bubbles in rivers and recent coal exploration hole fluxes. However, in the context of CSG development, the number and spacing of CSG wells and the very low bottom hole pressures applied to produce gas, the results are more in line with expectation. The major CSG projects typically have permitting for many thousands of production wells, with typical initial spacings of 750 m. Infill drilling frequently reduces this to 350 to 400 m. To rapidly produce gas, wells are typically dewatered with bottom hole pressures 200 to 300 m lower than hydrostatic. Effective gas production requires gas migration to wells, and this necessitates high pressure gradients, and close well spacing. The pressure gradients acting at the former Linc site, with or without further Arrow development, are insufficient to promote horizontal gas migration.

Groundwater movement is predicted to be inward toward the site for a further 10 or more years as pressures recover. After this time, groundwater movement is predicted to be influenced by Arrow development (AGE 2020). But with low residual gas saturations at this time, there is likely to be little influence of gas on groundwater flow.

From the data available and modelling work reported here the following conclusions are drawn and answers provided:

- The work undertaken has shown a low likelihood that Arrow Energy's proposed future Field Development plan will alter the movement of residual gases present around the former Linc Energy site.
- The main fate of free gas is re-adsorption within coal seams. Groundwater pressures are predicted to continue to recover, taking a further 5 to 15 years to approach pre-production levels. (i.e. groundwater will flow towards the gasifiers for another 5 to 15 years).

- Uncertainty of the predictions has been assessed by sensitivity analysis that considers a range of values for uncertain parameters and boundary conditions. The sensitivity analysis results show low uncertainty for these scenarios, suggesting a degree of confidence in the main result of minimal additional gas migration. However, there may be other factors acting at site unaccounted for in this work that may still promote gas movement. One such mechanism is via enhanced permeability pathways, particularly vertically toward surface.
- Arrow development is predicted to cause some minor depressurisation across the site (AGE, 2020). Depending on coal properties and gas saturation, this could induce minor future desorption of methane gas and if this occurred, the movement of this gas would be expected to be limited by the relatively poor flow properties around the site.
- In summary, dual phase modelling of water and gas has been completed and no significant gas movement is predicted in the base case or in the sensitivity scenarios considered.

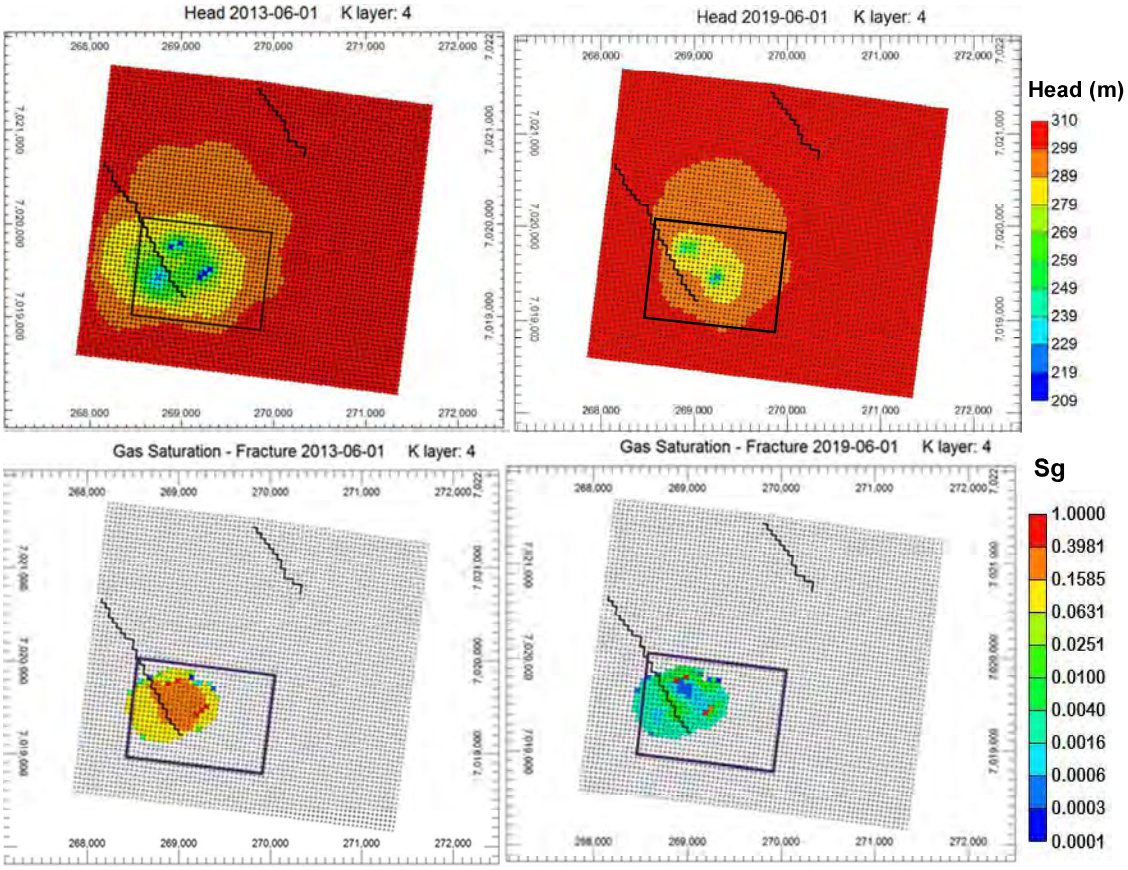


Figure E1 Groundwater pressure head (top), and gas saturation, Sg, (bottom) in Macalister seam A in 2013 (left) and 2019 (right)

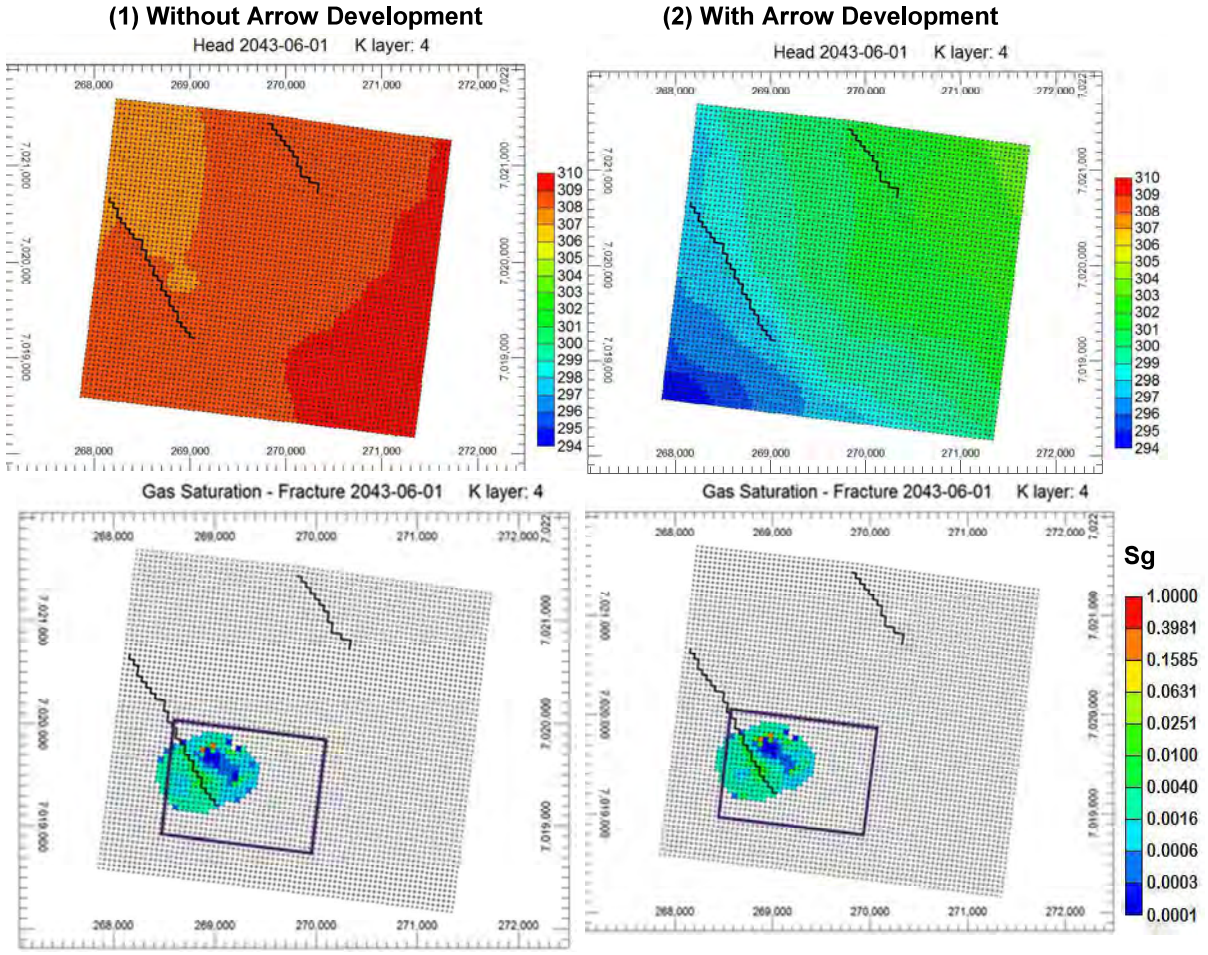


Figure E2 Groundwater pressure head (top), and gas saturation (bottom) in Macalister Seam A for without (left) and with (right) Arrow development in 2043

1. Introduction

This report documents multi-phase modelling work by The University of Queensland Centre for Natural Gas (UQ-CNG) for Arrow Energy (Arrow) concerning possible future movement of residual gases beneath the former Linc Energy site at 357 Kummerows Rd, Chinchilla

Linc Energy (Linc) undertook Underground Coal Gasification (UCG) activities on the site between 1999 and 2013 which have left residual gases within the upper seams of the Walloon Coal Measures and the lower Springbok Sandstone. Arrow Energy are developing coal seam gas (CSG) fields in Petroleum Leases PL253 and PL493 surrounding the site and Arrow and DNRME wish to understand the impact of CSG development on residual gases at the Linc site.

1.1 Aims

The aim of the work is to answer the following questions and requests posed by the regulator (DNRME):

1. "What is the fate of 'free gas' and water pressures at the former Linc UCG site on PL253 under two scenarios:
    a. Current development with no further Arrow production in PL253/493;
    b. Proposed development with Arrow production in PL253/493.
2. What is the uncertainty in the prediction of the fate of 'free gas' and water pressures in these scenarios.
3. Undertake a dual phase model that incorporates groundwater and gas movement that will demonstrate how gas movement may influence groundwater movement. Model gas movement, including up dip movement (Condamine bubbles), given that gas is more actively moving due to fracturing."

1.2 Data sources

Data sources available to this work include Arrow Energy models and recently drilled wells, with other data sourced from publicly available data. The key data provided by Arrow Energy included:

- AGE groundwater models, including predicted head changes (drawdown) due to Arrow Energy Field Development.
- Petrophysical data from the Hopeland 21, 24 and 27 CSG wells, including DST/MDT data
- Petrel geological (structural) model of the area around the Linc Site.
- Water levels and completion reports for AECOM bores around the Linc Site.
- Linc Energy Hydrogeological Study (Golder).
- Reservoir engineering information from Arrow Energy studies.

Examples of other data sources include:

- Linc Energy ASX releases (resource and production estimates), from the early 2000's to 2013.
- Published public literature, including Shell studies, and SPE journal and conference papers on the Walloon Coal Measures.

We understand that the historical information available to this project regarding the Linc site is not exhaustive. The ASX documents indicate that substantial additional drilling was completed by Linc Energy and we believe that further monitoring information also exists for the site. The uncertainty introduced by not having access to additional information is considered in Section 5.

1.3 Previous Assessments

Two previous studies the cover the Linc site were provided to assist with this work:

- 'Arrow Hopeland Groundwater Study Groundwater Modelling Report - PL253', GHD, November 2019; and
- 'Production Licensing Modelling Support, Arrow Energy', AGE, June 2020.

These report consider potential impacts to groundwater from the former Linc Energy site, using single phase simulations. The AGE 2020 report and outputs of the groundwater model it describes are used to inform this work, particularly to inform boundary conditions.

1.4 Report Structure

Section 2 provides details of the physics of dual phase flow and the interaction of coals, methane gas and groundwater, with the intent of introducing multi-phase flow concepts and some of the parameters required for modelling. Section 3 describes strategy adopted for the modelling, including history matching. The design, build and initialisation of the model is also documented together with the method by which free gas is generated at site as a proxy to UCG operations.

Section 4 presents a Base Case and 9 sensitivity analysis scenarios. These first consider the period post Linc operation from 2013 to 2019 and then out to 2043. Cases with and without Arrows proposed development are considered and compared in order to discern changes in gas occurrence and movement due to development.

A summary and discussion of the work is provided in Section 5 together with conclusions directly answering the questions and points posed by regulators. Section 6 documents assumptions made in the work.

2. Coal, Gas and Water

This section details some of the key aspects of multiphase modelling of water and gas. The intent is to introduce multi-phase flow concepts and some of the parameters required in for the modelling described in Sections 3 and 4.

2.1 Methane, Sorption and Isotherms

An important aspect of the former Linc Energy site is that much of the residual free gas is likely to be methane, in both coal seams and UCG cavities. This interpretation is supported by analysis of near surface gases at the Linc site[1]. Near surface soil vapour measurements fall into two groups, those with relatively high concentrations of combustion derived volatile organic compounds (VOCs), and those with low or no VOCs. The high VOC samples all contain methane at concentrations of 65 to 95% by volume. The low or no VOC samples have low methane occurrence, less than 1% or less than 0.1% by volume.

The objective of this work is to determine the effect of proposed Arrow CSG development on gases at the former Linc site. Coals are a plausible pathway for gas migration due to their relatively high permeability, and also a pathway for propagation of pressure reductions associated from Arrow's proposed development. This section outlines some key behaviours associated with coal reservoirs that may impact gas migration.

Coal has very low active porosity, typically less than 4%, and as low of 1 to2 %. This porosity is mainly in the form of naturally occurring fractures, called cleats, which are pervasive throughout the coal. Normally such low porosity would mean that rock would be unable to contain significant quantities of gas. However, as coal is highly carbonaceous and contains extremely small (nanometre scale) pore spaces, it is able to store some gases such as CO_2 and methane in an adsorbed state; that is bound at a molecular scale to the coal matrix. This "gas" is immobile while adsorbed on the coal matrix.

Desorption is a phenomenon whereby a substance is released from or through a surface. The process is the opposite of adsorption. Some porous materials such as coal and shale can adsorb/desorb certain gases such as CH_4 (or CO_2) within specific ranges of pressure.

One example of gas desorption is methane desorption in coal seams as pressure declines. In coal seam gas reservoirs, which is one of the primary unconventional hydrocarbon sources, pressure decline is applied by water production. This triggers gas desorption within the coal matrix. Desorption isotherms relate the amount of desorbed gas to reservoir pressure. The Langmuir isotherm (equation 1) is the most commonly applied model:

$$C_g = \frac{V_L P}{p_L + P} \quad (1)$$

Where C_g, P, V_L, and p_L are respectively gas content, pressure, Langmuir volume and Langmuir pressure. The Langmuir volume is the maximum amount of gas that can be adsorbed on coal at infinite pressure, and the Langmuir pressure is the pressure at which one half of the Langmuir volume can be adsorbed.

Figure 1a represents depressurisation in a coal reservoir where the coal is fully saturated, that is the gas content of the coal is at the value predicted by the Langmuir isotherm. Any depressurisation will cause gas to desorb as the adsorption capacity of the coal decreases. In the example shown in Figure 1a, dropping the pressure by 8,000 kPa would reduce the gas content of the coal by 4 m³/tonne. This gas would be desorbed, and released into the coal cleats, where it would be able to flow around the reservoir (depending on the permeability of the coal).

[1] Contained in file 'Linc Soil Vapour Results 2019 Summary Table.xlsx' dated 01/07/2020

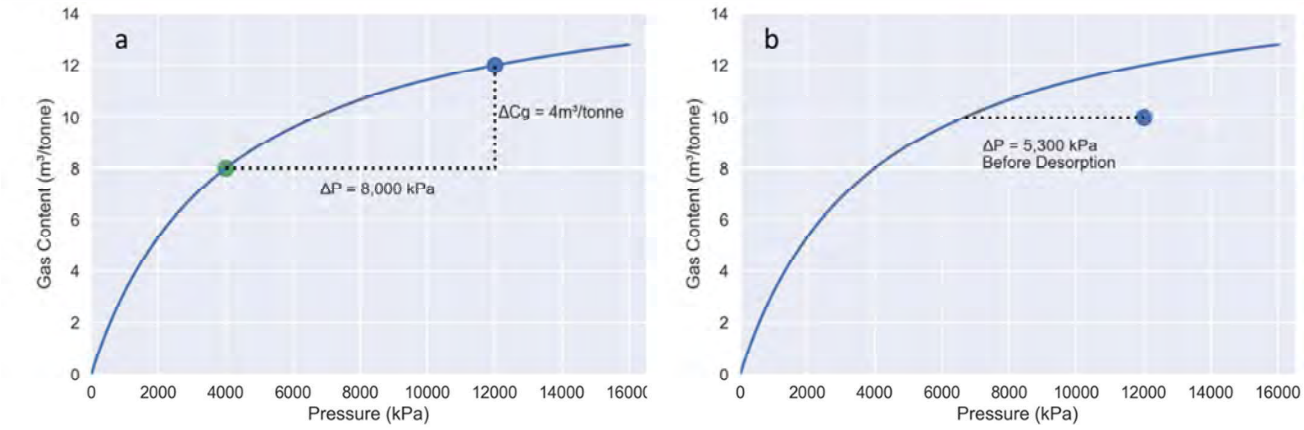


Figure 1. Example Langmuir Isotherms. (a) represents depressurisation of a fully saturated coal, while (b) represents the depressurisation (dewatering) phase of an undersaturated coal

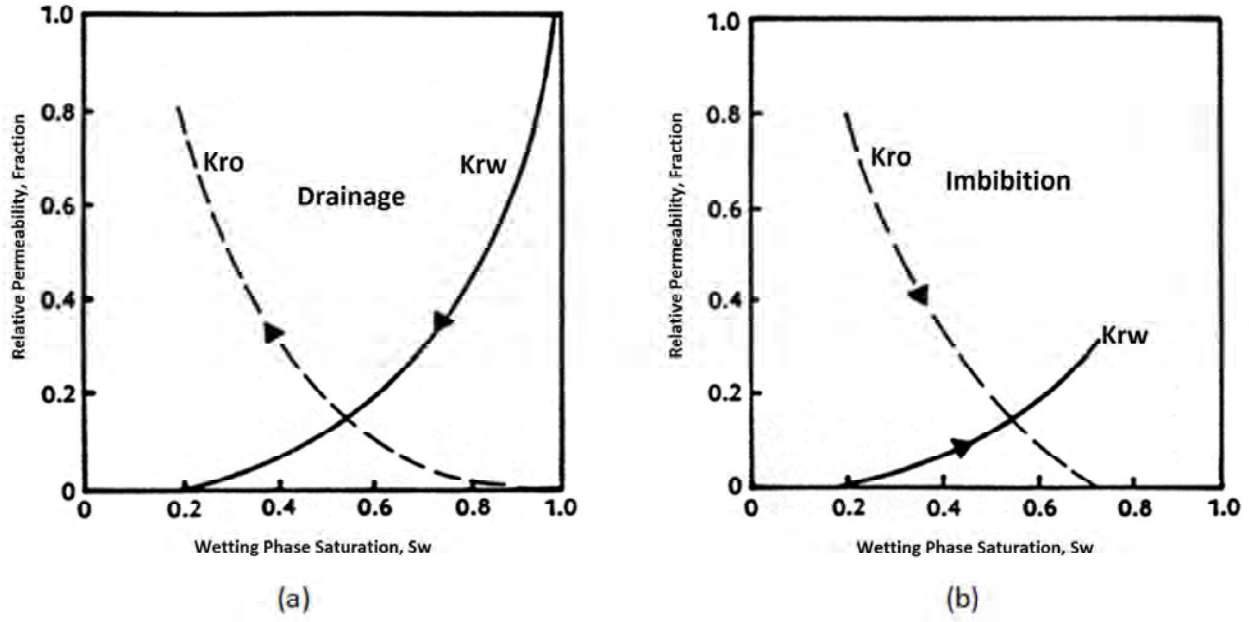


Figure 2. Example relative permeability curves for (a) drainage and (b) imbibition.

Many coals are undersaturated (as represented in Figure 1b). This means the coals contain less gas than they are capable of storing at the current in-situ pressure (represented by the blue point in Figure 1b). In this case, the coal would need to be depressurised until it reaches the critical desorption pressure, which is the pressure at which the coal gas content would be as calculated on the isotherm (in Figure 1b this is around 6,300kPa, 5,700 kPa below the initial reservoir pressure). This depressurisation is achieved in CSG wells by dewatering.

Importantly, undersaturated coal, or coal where the reservoir pressure is rising, has capacity to adsorb additional gas. This can include other gases such as CO_2 and N_2, as well as methane. This is potentially significant as pressure continue to recover at the former Linc site meaning that residual gases may end up being trapped in an adsorbed state. Combustion gases may include CO_2, which preferentially adsorbs ahead of methane.

Note that in some reservoir modelling codes (simulators), including CMG-GEM *"matrix pressure",* is a term used to indicate the saturation of the coal. This is not really a pressure, it instead indicates the pressure at which the coal would be fully saturated (i.e. when the gas content lies on the isotherm).

The desorbed gas occurs in the rock matrix, held in place by relatively weak Van der Waals type intermolecular forces primarily on organic surfaces such as coal or organic-rich shale. During coal seam gas development, the gas is extracted from the subsurface via a production well that produces water to lower the formation pressure to a critical desorption pressure. At or below this critical desorption pressure, gas desorbs from coal forming a free gas phase in the coal cleat fracture system.

2.2 Gas Movement, Viscosity and Permeability

Four migration mechanisms are considered to contribute to the transport of methane towards a production well:

1. Molecular diffusion;
2. Buoyancy (gravity);
3. Viscous flow; and
4. Capillarity.

Molecular diffusion only contribute to the methane transport in coal matrix at low rates. It is often neglected while simulating multiphase flow in field scale.

Buoyancy is *"the tendency of a body to float or to rise when submerged in a fluid"*[2]. Buoyancy in multiphase flow occurs due to the density difference between the fluids and causes the fluids to segregate with less dense fluids (i.e. gas) floating and more dense fluids (i.e. water) sinking. In the subsurface, buoyancy promotes gas to move upwards vertically until a barrier to flow, such as a lower permeability overlying formation, or a formation with high capillary entry/threshold pressures, is encountered. When such a barrier is reached, the behaviour of the gas depends on the geometry of the barrier. In the unlikely case where the barrier was perfectly flat, the gas would accumulate as a plume and spread laterally. With a sloping barrier layer, gas will start to migrate up-dip, moving towards shallower lower pressure areas while remaining beneath the barrier. With strata in the Surat Basin having a principal dip direction to the south-west, including in the Walloon Coal Measures, buoyancy is a potentially important mechanism for movement of gas at the Linc site.

As well as causing gas to migrate both vertically and laterally, buoyancy can also contribute to the trapping of gas within structures in the subsurface. This form of trapping occurs when the geometry and properties of a barrier (or combination of barriers) result in a situation where the only way to "escape" the trap is for fluids to flow down-dip. As buoyancy acts to drive lower density fluids (gas) up-dip, this prevents these fluids from

[2] https://www.merriam-webster.com/dictionary/buoyancy

escaping the trap, resulting in accumulations of gas forming. This may be important in the area around the former Linc Energy site, as the trapping of gas in this way could limit migration, unless sufficient pressure gradients are exerted to overcome buoyancy.

Viscous flow refers to the flow caused due to a pressure difference between two locations. Darcy's law (equation 2) related the volumetric flux of each phase (V_i) to the gradient of its flow potential $\nabla(P_i - \rho_i \mathbf{g})$ that includes both buoyancy and viscous terms:

$$V_i = \frac{\mathbf{k}.k_{ri}}{\mu_i}\nabla(P_i - \rho_i \mathbf{g}) \quad i = water, gas \tag{2}$$

where $\mathbf{k}$, k_{rw}, k_{rg}, μ_w, μ_g, ρ_w, ρ_g, P, and $\mathbf{g}$ are absolute permeability, water relative permeability, gas relative permeability, water viscosity, gas viscosity, water density, gas density, fluid pressure, and gravitational acceleration, respectively.

Viscosity (μ) is a measure of a fluid's resistance to flow, and is another important property for multiphase modelling. Higher viscosity fluids are "stiffer" and have greater resistance to flow (under the same conditions) than lower viscosity fluids. Water has a viscosity of around 1 centipoise at 20°C (1cp = 0.01 Pa.s), varying slightly depending on temperature (and pressure, although this has less effect). The viscosity of gas also varies with temperature, pressure, and composition, but is typically around 0.015 to 0.03 cp, and significantly less than water. This lower viscosity enhances the mobility of gas compared to water.

Intrinsic (or absolute) permeability is a property of a rock, and refers to the ability of the rock to allow fluid to flow through it. When considering different fluids such as water and gas, we must consider the effective phase permeability. That is, the permeability to a specific fluid taking into account the presence of one or more other immiscible fluid (or fluids) in the pore space. As the saturation (i.e. how much pore space is taken up by each fluid) changes, the effective phase permeability also changes due to the different fluids occupying more, or less, of the available flow pathways. The relative permeability of a fluid at any saturation is the ratio of the effective phase permeability at that specific saturation to the intrinsic permeability of the rock.

Relative permeability can be measured in laboratory experiments, or by estimated by history matching of reservoir models, resulting in curves indicating the relative permeability of each fluid at different saturations. The shape of these curves is dependent on a number of factors relating to the pore structure of the rock, the interaction between the fluids and the rock surface, and the saturation history (i.e. which fluid is replacing the other in the pore space). "Drainage" refers decreasing saturation of the wetting phase[3], while the opposite is "imbibition".

Example relative permeability curves for these two cases are shown in Figure 2. Figure 2a represents drainage, where the saturation of the wetting phase is declining. This could perhaps be gas migrating into a fully water-saturated reservoir, where water is the wetting phase and gas is the non-wetting phase. Initially, the reservoir is saturated with water, so *Sw* is 1 (i.e. at the right hand side of Figure 2a) and the effective permeability to water is simply the intrinsic permeability of the rock, so the relative permeability to water (*krw*) is also 1. As gas moves into the system, the saturation of water will decrease. The relative permeability to water will also decrease as an increasing amount of the available pore space becomes occupied by gas. This will coincide with an increase in the relative permeability to gas (*krg*). The relative permeability to water decreases towards zero as *Sw* approaches the irreducible water saturation (*Swi*) - the saturation at which the remaining water is immobile. However, *Sw* may not reach *Swi* if differential pressures are not sufficiently high, and *krw* may become effectively zero before *Swi* is reached. *Sw* when *krw* becomes zero is the residual water saturation (*Swr*) at the specified differential pressure. At this point, *Sw* cannot be reduced

[3] The wetting phase is the phase that is more attracted to a solid surface, and will tend to spread on the surface (while the non-wetting phase would "bead"). In different rock types the same fluid could be either the wetting or non-wetting phase, depending on the "wettability" of the rock.

further without increasing the differential pressure, and thus the maximum gas saturation (and maximum *krg*) is reached.

If water was displacing gas in the system (say by flowing in to fill the pore space in a gas reservoir), this would be imbibition, as represented by Figure 2b. As the saturation of water increases, *krg* will decrease (moving left to right on Figure 2b). However, this will not follow the same relative permeability curve defined for the displacement case because some gas will become trapped within the pore network by pore-scale processes, leaving a residual saturation of the non-wetting phase that drives relative permeability hysteresis effects. This residually trapped gas occupies a portion of the pore space (i.e. reduces the water saturation) but means an increasing fraction of the gas is immobile and thus reduces *krg*. Eventually the non-wetting phase residual saturation is reached where *krg* is equal to zero, and any remaining gas is immobile (it is trapped in the pore space). This "residual trapping" is considered an important mechanism for CO_2 storage, where a "trail" of residual CO_2 remains trapped as a CO_2 plume moves through a reservoir. The same mechanism may act to limit gas migration around the former Linc site.

It is also important to note that the relative permeability to water when the non-wetting phase residual saturation is reached can be much less than 1. As *krg* is equal to zero (and the non-wetting phase is unable to flow) this will mean the overall flow can be very limited compared to the original reservoir conditions (where Sw = 1, krw = 1 and krg = 0). At the Linc site, this could potentially increase the time it takes for pressure recovery to occur, as residually trapped gas limits the flow of water into the area.

Groundwater models will not typically consider viscosity. Instead, the parameters used in hydrogeology take account of the fluid (water) properties, including the viscosity. In hydrogeology hydraulic conductivity ($\boldsymbol{K_H}$) is used to describe the ability of porous media (rock) to transmit water. It is defined as

$$\boldsymbol{K_H} = \frac{\rho \boldsymbol{kg}}{\mu} \tag{3}$$

Assuming a medium is fully saturated with water at standard condition, a hydraulic conductivity of 0.001 m/d approximates an intrinsic permeability of 1 mD.

2.3 Compressibility and Capillary Pressure

Compressibility describes the relative change in volume, and thus density, of a fluid (or solid) caused by a unit change in pressure. Water has very low compressibility, around 4.35 x 10^{-7} kPa^{-1} at reservoir conditions. This means a 10 MPa change in pressure (approximately equivalent to 1,000m head) causes a volume change of less than half a percent. This is comparable to the compressibility of most reservoir rocks, with the exception of coal which is typically more compressible. Gas is significantly more compressible than water, and the compressibility itself changes with pressure and temperature. If we consider the gas to be ideal and temperature to be constant, then Boyle's Law applies, so the volume of gas is inversely proportional to pressure ($P \propto \frac{1}{V}$). This means the same mass of gas that would occupy 1 m³ in a reservoir at a pressure of 1,000 kPa (a typical pressure encountered around 100 m below surface) would occupy 10 m³ at surface (where pressure will be around 101.3kPa), while 1 m³ of water in the same reservoir would only increase in volume by around 0.0004 m³ when brought to the surface. In reality, gases do not always behave as ideal and the compressibility of both water and gas is also affected by temperature (albeit less-so for water), but the difference in compressibility of the two fluids remains extremely significant.

The difference in compressibility between water and gas impacts how pressure changes as fluids flow around in the subsurface. The presence of gas, with high compressibility, will increase the "storage" in a reservoir, meaning more fluid has to be produced, or injected, to cause the same pressure change that would be seen if the gas wasn't present (this is basically the principle behind gas-cap drive in conventional reservoirs). It will also decrease hydraulic diffusivity, slowing the rate at which fluid pressure propagates through the reservoir.

In groundwater modelling, which considers single-phase flow, compressibility is not typically used directly within numerical simulations. Instead, compressibility of both the rock and fluid is accounted for as specific storage. Specific storage is usually defined as a property of the reservoir, so can vary spatially (due mainly to variations in the rock compressibility), but will not usually vary with time. This is a valid assumption when single-phase flow is expected. In multiphase reservoir simulation models explicitly defined compressibilities for the rock and fluids (water and gas) are required to allow more accurate representation of pressure changes over time.

In dual-phase flow, pressure is different between the phases. Capillary pressure, P_c, is the difference between the pressure of the non-wetting phase (P_g) and wetting phase (P_w), and is the function of phase saturation

$$P_c = P_g - P_w \tag{4}$$

We can consider the pore network within rock as similar to a complex combination of capillary tubes with varying radii. As a non-wetting phase enters the pore network, it will only enter pores where the pore throat radius is greater than the value of *r* which equates to the current pressure based on the Young-Laplace equation. This means that for any specific pressure, there is a threshold radius for pore throats, and the non-wetting phase will be unable to enter pores with throat radii smaller than this threshold, which limits the saturation of the non-wetting phase at any pressure. If the pressure is increased, the threshold radius decreases and the saturation of the non-wetting phase will increase (as it is able to enter smaller pores). The capillary pressure curve for a pair of fluids in a rock sample indicates how the pressure and saturation are related, and will vary depending on the rock and fluid interactions, and the distribution of pore throat sizes in the rock.

Capillary pressures are important when considering trapping of hydrocarbons in the subsurface. Membrane seals prevent hydrocarbon migration due to capillary effects, not simply due to extremely low permeability. If the pressure is below the capillary threshold pressure[4] then the non-wetting phase (gas) will be unable to flow through the seal. If this pressure is overcome (e.g. if a column of hydrocarbons becomes sufficiently large that the pressure due to buoyancy is equal to the threshold pressure) a membrane seal can fail and leak.

Available software packages such as Eclipse and CMG, use Dual Porosity (DP) approach to model multiphase flow in adsorbing/desorbing fractured rocks, i.e. coal. In this approach, the fractured rock is divided into two separate domains of fracture and matrix where the matrix blocks are surrounded by parallel equally-spaced fractures in different directions. This simplified model must hold the same equivalent permeability as the actual rock sample. The equations described above are combined with the mass conservation equation and solved separately for fracture and matrix continua, to determine fluid pressure over the model domains (fracture and matrix) with time. Having determined the fluid pressure, adsorbed/desorbed gas is calculated using Langmuir isotherm (equation 1). A transfer function enables flow transfer between these domains based on capillary, viscous and buoyancy potentials. A shape factor is used to calculate transmissibility in the transfer function, taking the geometrical shape of the matrix blocks into account.

[4] The pressure at which "a continuous thread of non-wetting fluid extends across the sample" (Underschultz 2007), and thus the pressure at which the fluid can actually move through the rock.

3. Model strategy, design and build

The focus of this investigation is on the movement of gas present at the former Linc Energy site. Specifically, the focus is on future changes to this gas that may be caused by the Arrow Energy's planned developments. To assess how Arrow's development may cause changes, such as migration of free gas or changes in gas concentration, multiphase numerical simulations are used. These simulations need to first create free gas at the Linc site, imitating UCG processes, then predict the evolution of free gas and its future movement.

To determine any effect caused by Arrow's development, scenarios are required both with out and without the drawdown impact of Arrows future CSG extraction. Future drawdown or pressure change impacts due to Arrow's development have been assessed previously by AGE (2020) following a groundwater modelling methodology similar to that applied by The Office of Groundwater Impact Assessment. We use the AGE predictions of future drawdown caused by Arrow development at the Linc site as the basis from which to assess how Arrow may effect free gas. Figure 3 shows the location of the Linc site and Arrow tenements.

This Section describes the strategy adopted for the modelling and the model build, its initialisation and reproduction of Linc operations that generated free gas within the site. Scenarios using the model are described in Section 4.

3.1 Strategy

The future of free gas at the Linc site is predicted by multiphase numerical simulations using CMG's GEM compositional simulator. This allows multiphase effects such as buoyancy and relative permeability, and other behaviours associated with gas in coal seams, particularly adsorption / desorption, to be represented numerically.

The approach with the model is to represent the site in sufficient resolution to permit multiphase simulation that incorporates relevant site specific data; the resolution adopted permits representation of individual gasifiers.

The workflow adopted for the multiphase simulations differs from a typical groundwater modelling workflow. We adopt a "soft" history match based on the key observations of sustained depletion (reduction of pressure) around the Linc site through to 2019, combined with the presence of free gas on site. These observations are used via a rejection sampling approach, where sets of model parameters are rejected if the model results failed to conform to the observations.

This approach was adopted since some field data observations were considered likely to corrupt a model calibration workflow based on fitting of individual observations. For example, several of the 2017/2018 AECOM bores monitoring the Macalister interval indicate water levels slowly rising in the 12 months since they were drilled. This may reflect reservoir pressures rising over this period, or may be due to the extremely slow recovery of the wells after drilling, due to low permeability.

Besides the 'soft' history match observations, the approach also respects field measurements and observations of properties, such as layer thickness or permeability.

3.2 Model Domain

The spatial extent of the model domain was determined after considering how far free gas could potentially move over the next 20 years due to buoyance induced by the dip of coal seams. The idea was to use this calculation to ensure that free gas at the Linc Site could not reach the edges of the model domain in this time. The analytically calculation of gas buoyancy (detailed in Figure 4) uses the gradient of the top of the Macalister coal Seam A using the dip angle of geological surfaces received from Arrow Energy and AGE (2020) estimated permeabilities. The result of the calculation informed setting model boundaries 1500m from the North and East and 500m from the South and West of the Linc site as shown on Figure 5 (top).

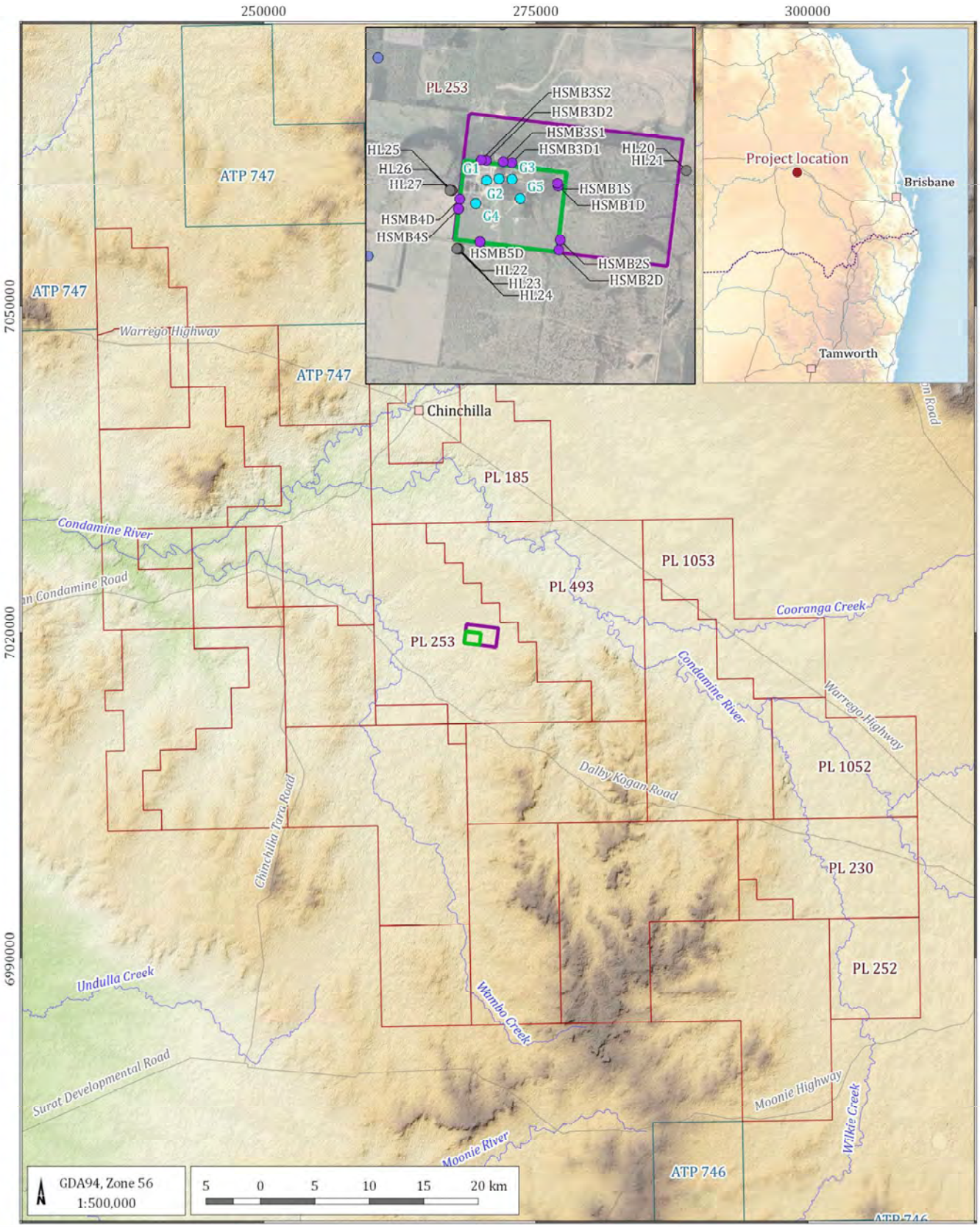


Figure 3. Site location (Reference: the AGE report)

$$V^i = -\frac{K^i}{\mu}\left(\nabla P^i + \rho g sin\theta\right) = -\frac{K^i}{\mu}\rho g \nabla H^{Ti}$$

Viscous Source Gravity Source: Buoyancy in 2-phase is $\Delta\rho g$

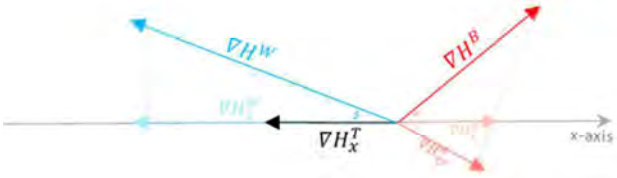
$$\nabla H^B_{xy} = \frac{(\rho_{water}-\rho_{gas}).g.\sin(\theta)}{\rho_{water}.g} \approx \sin(\theta)\ [\text{m/m}]$$

$$\nabla H^T_x = \nabla H^B_{xy}\sin(\alpha) + \nabla H^{Wt}_x \sin(\beta^t)$$

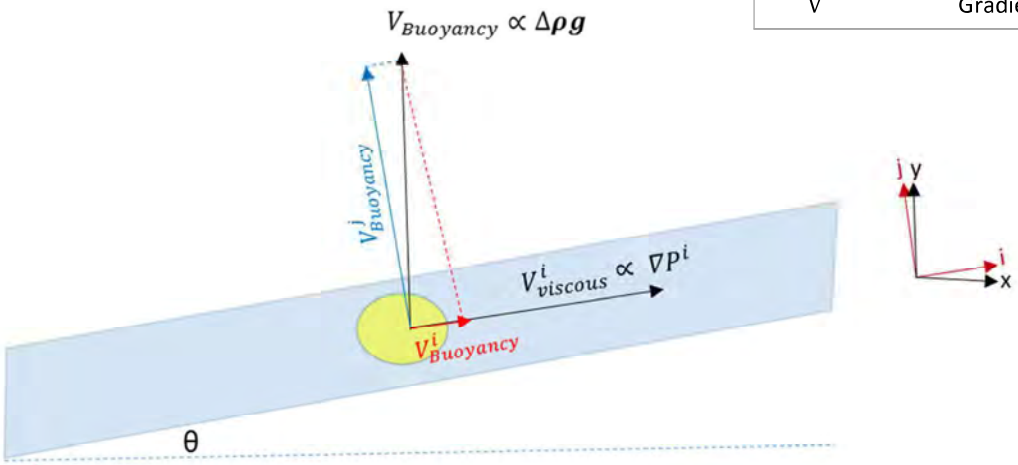
$$\nabla H^T_y = \nabla H^B_{xy}\cos(\alpha) + \nabla H^{Wt}_y \cos(\beta^t)$$

$$< \nabla H^t > = \left(\nabla H^{T2}_x + \nabla H^{T2}_y\right)^{0.5}$$

$$\emptyset = \tan^{-1}(\nabla H_y/\nabla H_x)$$



Symbol	Description
H	Head
ρ	Density
θ	Dip angle
α	Azimuth of the slope
α	Azimuth of head gradient
∅	Azimuth of net gradient
B	Buoyancy
T	Total
t	Time
x	x direction
y	y direction
∇	Gradient operator



$$V^i_{Buoyancy} = V_{Buoyancy}.Sin(\theta)$$

$$V^j_{Buoyancy} = V_{Buoyancy}.Cos(\theta)$$

$$V^i_{Net} = V^i_{viscous} + V^i_{Buoyancy}$$

Figure 4. Analytical calculation of net gradient determination approach

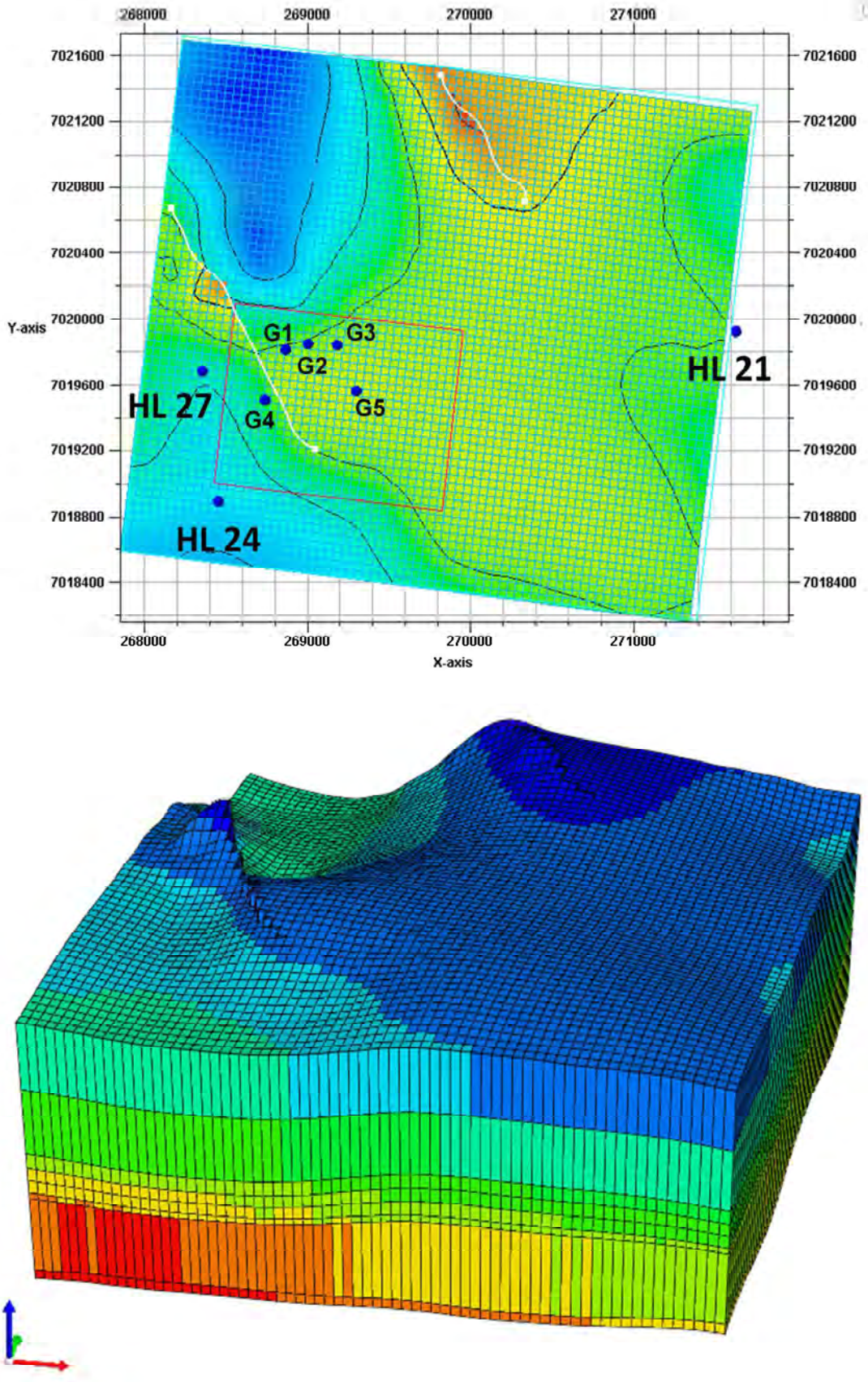


Figure 5. Model domain, layering and grids

Within this domain a rectilinear model mesh of 63×71 grids cells 50×50m is defined (Figure 5 bottom). The 50x50 m mesh resolution means individual gasifiers are represented by a number of cells, whilst maintaining a total mesh count that is numerically tractable.

The model layering includes the upper portion of the Walloon Coal Measures, and the Springbok Sandstone from the Wambo Coal Seam to surface. The Wambo seam is included such that propagation of depressurisation of the seam, due to Arrow's proposed developments can be represented. Note that Arrow are not proposing to develop the uppermost Macalister seams within the study area. The model includes detailed representation of the Macalister coals, with layers for individual seams.

Modelling layering is based from Top Springbok, Top Macalister and Top Wambo horizons (geological surfaces) provided by Arrow, informed by recent drilling and completion reports for wells on and around the site, specifically: AECOM (HSMB1S, HSMB1D, HSMB2S, HSMB2D HSMB3S1, HSMB3D1, HSMB3S2, HSMB3D2, HSMB4S, HSMB4D, HSMB5D) and Hopeland (HL21, HL, 24, and HL27) as shown on Figure 3.

The model has 8 layers, defined from petrophysical data provided by Arrow:

- **Layers 1-3**: Springbok (and Kogan) with no coal
- **Layer 4:** Seam A with 100% coal
- **Layer 5:** Interburden with 40% coal
- **Layer 6:** Seam B with 80% coal
- **Layer 7:** Interburden with No coal
- **Layer 8:** Wambo with 100% Coal

The Arrow geological (static) model includes faults traces across site. These were incorporated to the model geometry using Petrel software and were set by default to be fully transmissible. The fluid flow behaviour of the faults is explored in sensitivity analysis.

The five Linc Gasifiers (G1-5) locations were added to the model, and based on AGE (2020) modelling, five nearby CSG wells within the model domain were placed in Wambo layer. These wells are planned to operate from 2027 onwards and depressurise the underlying Wambo Coal Seam. They are not completed or represented in the Macalister seams.

Table 1. CSG wells in Wambo seam represented in the model

Well name	Easting (mE)	Northing (mN)	Layer	Elevation	First year
50887	268768	7020744	8	136.74	2032
50890	269714.6	7020580	8	142.92	2032
50889	270605.7	7020037	8	154.21	2031
50877	270887.9	7018838	8	151.29	2027
50488	271064.9	7021272	8	165.95	2032

3.3 Model Properties

The Walloon Coal Measures are a heterogeneous unit, comprising of mudstone, shale and some sandstone with coal packages that typically comprise 8-12% of a unit 250-350 m thick. Within the Walloon sequence, most of the permeability is associated with coals. The coals themselves are patchy with variable continuity and connectivity. Closely drilled CSG wells have shown some coals to be discontinuous over a scale of

50 m, whereas in other locations pressure declines have propagated indicating connectivity over multiple kilometres. More typically coals persist and are connected over scales of 100s of metres to 1-2 km.

If gas is to migrate from the former Linc Energy site the two plausible pathways are: vertically upward through the Springbok through induced fracturing associated with the UCG process; and (approximately) horizontally through coal seams. The vertical pathway will result in transport of gas to the soil zone and likely emission to atmosphere which is shown to be happening by high methane readings in soil vapour bores on site. Arrow's future development are highly unlikely to affect the vertical pathway. The migration of free gas horizontally through coal seams is the principal pathway explored in this work. For that reason the representation of coals and permeability are key to the study.

The permeability of the Walloon Coal Measures is highly variable and is scale-dependent with faults and discontinuities potentially contributing to bulk permeability. AGE (2020) indicate two-orders of magnitude difference between median DST horizontal permeability and values estimated by the Office of Groundwater Impact Assessment via model inversion (OGIA 2019). There is evidence of permeability lower than 0.01 mD to higher than 1000 mD in coal intervals in the area, including in HL 21, 24, 27 (Figure 3).

The spatial variation of coal permeability across the Linc Site and surrounding is not known. There is also little information on faults, below the resolution of seismic surveys. For these reasons coal permeability is modelled using spatially varying permeability fields and a workflow that enables multiple permeability realisations to be tested against the "soft" history match criteria of sustained 30-40 m of depletion (reduction of pressure) on and around the Linc site through to 2019. A rejection sampling approach is used where model simulations that over or under predicting recovery, and fail to produce 30-40 m of depletion in 2019, are rejected.

Table 2 summaries the range and values for coal permeabilities and other parameters.

Table 2. Model property values / ranges and data sources

Property	Value or Range	Source
Coal permeability (mD)	0.01 – 1000	AGE report, HL 21, 24, and 27 Petrophysical analysis. Head observations from Site.
Non-coal permeability (mD)	Highly varied Unlikely to be greater than 0.1	AGE report, HL 21, 24, and 27 Petrophysical analysis. Head observations from Site, SPE-167025-MS
Vertical to horizontal permeability ratio for non-coal	0.00001	HL 21, 24, and 27 Petrophysical analysis. Head observations from Site. AGE report.
Coal porosity (%)	1.5	QGC (Woleebee Creek GW4)
Non-coal porosity	15	QGC (Woleebee Creek GW4)
Langmuir volume (scf/ton)	578	Arrow
Langmuir pressure (kPa)	5000	Arrow
Coal relative permeability	N/A	Arrow
Non-coal relative permeability	N/A	Arrow

There is little available data on coal porosity. The Arrow Hopeland pilot history match suggests 3% porosity. Lagendijk and Ryan[5] suggest coal porosity be 1-5%. QGC suggest 0.5-3.0%. Porosity in Springbok and

[5] SPE-137651

interburden layers is also highly variable. QGC data suggests porosity be 5-25%, most often around 15%. The adopted base value for porosity are given in Table 2.

Porosity at the location of the gasifiers is assumed to be locally much higher due to coal combustion and void creation. From Linc ASX reports on the mass of coal consumed, the void volume around the location of the gasifiers was determined to be:

- For Gasifier 1 and 2 a combined void volume between 19,000 and 26,000 m^3 is estimated, based on 32,000 tonnes of coal consumed. This gives the porosity (Ø) of 80% at the location of G1 and G2 in our model.
- For Gasifier 3 a total void volume between 1,300 and 1,600 m^3, based on 2,000 tonnes of coal converted, which gives an estimated porposity of 10%.
- For Gasifier 4 a total void volume between 6,000 and 8,000 m^3, based on 10,000 tonnes of coal converted and an estimated Ø=15%.
- And for Gasifier 5 a total volume of 15,000 and 20,000 m^3 is estimated based on planned operation giving Ø=38%.

The porosity of model cells in the Macalister Seam A at the gassifier locations were modified to take account of voids using the values listed.

The Langmuir volume (VL) and pressure (PL) values for coal are 578 scf/ton and 5000 kPa, based on the data (Petrel file) received from Arrow. The Langmuir volume for non-coal was set to zero, which means no adsorption/desorption is modelled in non-coal.

Coal and non-coal receive different sets of relative permeability curves. Coal relative permeability curves were given by Arrow and non-Coal relative permeability curves were set to a typical curve set for shaly sandstones available in Petrel software (Schlumberger).

A Peng-Robinson equation of state at constant temperature of 25 C was used to build the fluid model using WINPROP software (CMG). Water density, viscosity, and compressibility were set to 990 kg/m3, 0.9 cp, and 4.35e-7 1/kPa at the reference pressure of 101.325 kPa. Methane solubility was inactivated. This assumption that methane is insoluble in water is conservative, as methane dissolving in groundwater is a mechanism that would reduce future gas volumes and movement.

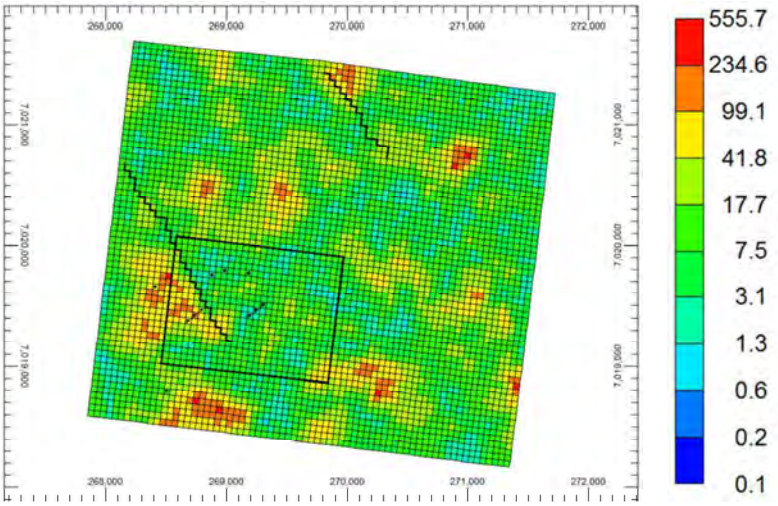
Permeability in Springbok Sandstone is also varied. There is evidence of limited more permeable portions of the Springbok (500mD in HL27) in AGE report. Depletion seen in Springbok in HL 27 suggests there may be some lateral connectivity over distances of 250-300 m.

Walloon Coal Measures interburden has low to very low permeability. At site this is confirmed by very slow build up in AECOM bores. Away from site, head observation by QGC indicates very low vertical permeability for the interburden. Core analyses done by QGC (Woleebee Creek GW4) indicates vertical permeability be lower than 0.1mD. AGE modelling suggests median anisotropy ratios (kh/kv) be in the 100,000s.

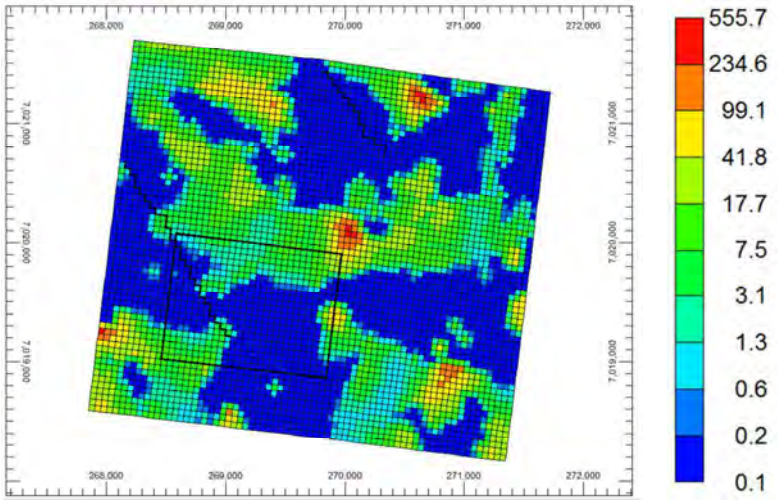
Static property distributions were generated for multiple model realisations using Python scripts based on parameters from UQ-Centre for Natural Gas project on geostatistics of the Walloon Coals. These scripts generate static properties, including permeability and rock type (coal/non-coal). The permeability field was conditioned with data at known locations (e.g. permeability values measured in wells HL21, HL24 and HL27) Figure 6 shows the base case model permeability fields for model layers 4 to 6 representing the Macalister A and B seams and the interburden between. Vertical to horizontal permeability for coal and non-coal were respectively set to 0.01 and 0.00001. The mean and standard deviation of permeability distribution for the base case are 10mD and 0.5, respectively.

Permeability

Permeability (mD) —Layer 4 (Seam A)



Permeability (mD) —Layer 5



Permeability (mD) —Layer 6 (Seam B)

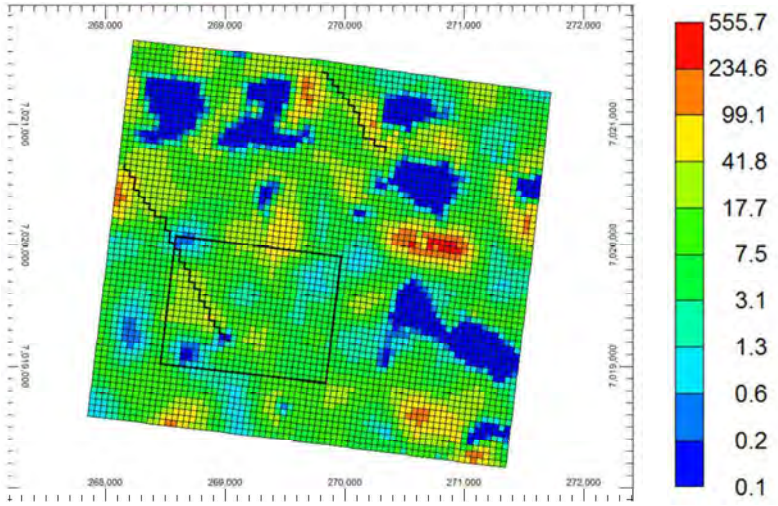


Figure 6. The permeability map of the base case, layers 4 (seam A), 5, and 6 (seam B), with the mean value of 10mD and the standard deviation of 0.5.

3.4 Model Boundaries

Two sets of boundary conditions were generated based on the heads modelled by AGE as part of their groundwater modelling work. Heads were extracted from the AGE MODFLOW model results. The mechanism used to replicate AGE model pressures around the perimeter of the model is to use injection and production wells at the boundary. This method enables us to replicate the variable pressures around the site and their evolution over time. The AGE model results define the bottom-hole pressure (BHP) applied to control the injection and production wells.

The first set of boundary wells (representing a case without Arrow's proposed field development plan) remained at constant pressure throughout. The second set of boundary wells varied over time to represent the calculated difference between the heads in the AGE models that did, and did not, include the Arrow FDP. This meant the boundaries should represent the *change* in pressure, and pressure gradient, across the Linc Energy site caused by Arrow Energy's FDP.

3.5 Model Initialisation

Initial pressure is assumed hydrostatic and initial water saturation is equal to 1, meaning no gas is present. The first step of initialisation is to simulate a long period of 100 years with all boundary conditions constant such that the modelled stochastic permeability field and boundary pressures from the AGE modelling equilibrate. After this time no further changes in pressure due to boundary and permeability effects are detected. The resulted pressure is extracted and is used to define the initial fracture pressure (Pf) for modelling of the gasification process using dual-porosity approach in CMG-GEM.

Coal can be saturated or under-saturated with respect to adsorbed methane content as described in Section 2.1. For saturated coal, gas is immediately generated by any decline in pressure. For under-saturated coal, gas is desorbed only when pressure decline is sufficient to meet the Landmuir isotherm. Coal saturation in CMG-GEM is set by matrix initial pressure (Pm). The matrix starts to produce gas once fracture pressure reaches to Pm. Initial matrix pressure is set 300 kPa lower than the initial fracture pressure. So Pf needs to decrease 300 kPa to induce gas desorption. This is indicative of a semi-saturated coal reservoir. The impact of this assumption is explored via sensitivity analysis.

The simulation workflow described, from model build to initialisation and simulation of gasification is outlined in Figure 7.

3.6 Representation of UCG and Post Gasification to 2019

UCG is a complex process with solid, liquid and gas phases present, multiple chemical reaction pathways, and many physio-chemical processes (Perkins, 2018). These occur in a domain that moves over time. The representation of UCG is directed to reproducing observations of gas in the subsurface that persist through to 2019. For this we represent the depressurisation of coal seams caused by UCG, and create free gas by desorption of gas from the coal matrix. This approach ignores combustion and assumes constant temperatures.

3.6.1 Representation of UCG

Operation in Linc site started in 1999 and was abandoned in 2013.The gasifiers worked intermittently and not necessarily simultaneously. Based on information in the AGE report based on Perkins et al (2013), we simplified site operational period by simulating gasifiers operation over a 6 year period. As the gasifiers did not work simultaneously or continuously this may overestimate the amount of the gas on site. Gasifiers are represented as gas wells producing from model layers 4 and 6 with constant bottom-hole pressures of 200 kPa.

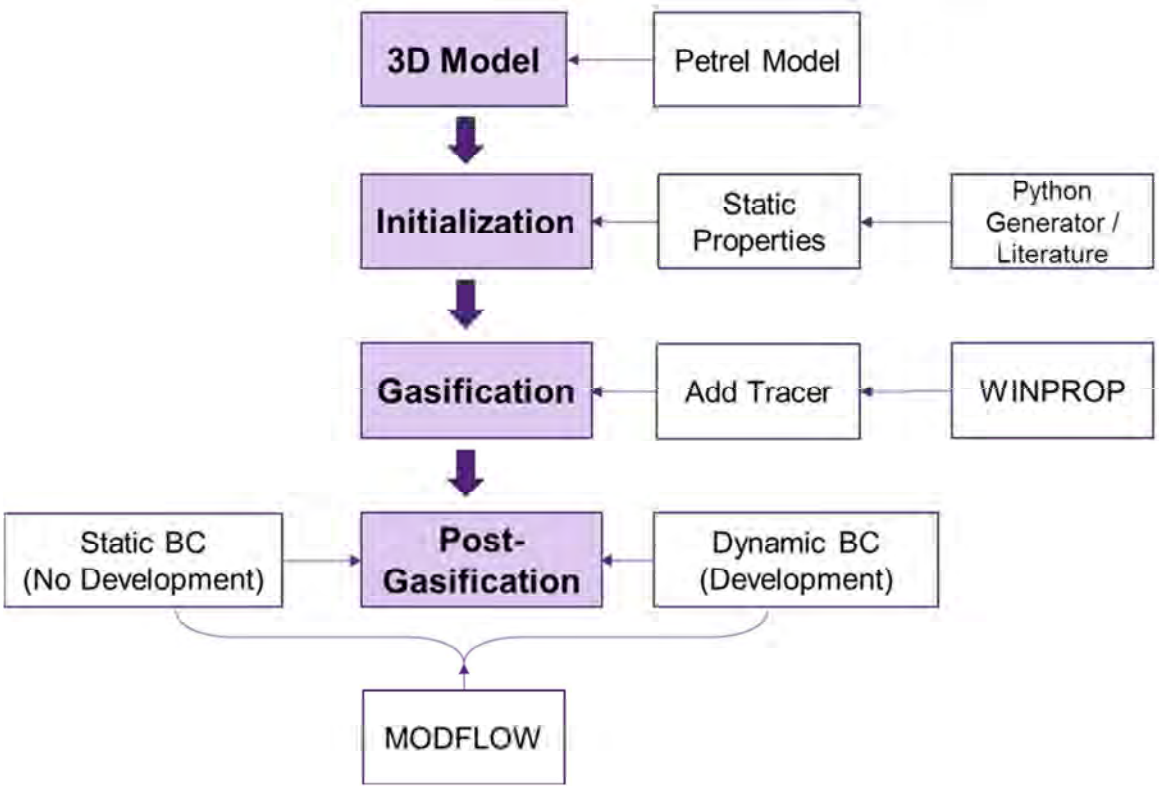


Figure 7. The simulation workflow of this research

Gas is generated as a result of depressurisation and gas saturation starts to increase. After 6 years the final fracture pressure, matrix pressure and gas saturation are extracted and are used as initial condition of the post gasification period, starting from 2013.

3.6.2 Post gasification history match

Pressures have not recovered at the Linc site. In 2019, 30 to 40 m of residual drawdown remained (AGE 2020). For the “soft” history match, the producing gas wells are turned off (shut-in) and the model run from 2013 to 2019 with constant boundary condition around site. As described in Section 3.3, a rejection sampling approach was adopted to select models that reproduced the observed levels of residual site drawdown. The permeability realisation showed on Figure 6 were achieved after 12 trials of different sets of geostatistical descriptors (mean and standard deviation).

3.6.3 Post gasification prediction

For predictive scenarios simulations continue to 2042. Beyond 2019, there are two cases of boundary conditions applied:

- A "current" case, that is without the addition Arrow proposed development across PL253/493. This case uses a static boundary condition.
- A proposed development case that includes the impacts of Arrow’s proposed development. This scenario uses dynamic boundary pressures derived from AGE (2020) modelling.

3.7 Gas Tracer

The future movement of gas present at the former Linc site is partially of concern due to the presence of combustion gases that include known carcinogens such as the BTEX group of organic compounds. These have been detected in soil vapour on site.

The description of coal, gas and water in Section 2 set out how adsorption and desorption processes occur due to pressure changes. Whilst pressures on site continue to recover after UCG processes to 2013, there is a chance that they may then decline in the long term due to proposed development of PL253/493 by Arrow. Pressure decline has the potential to release adsorbed methane. In order to predict the fate of the gas based on the development plans, we need to distinguish between gas generated by Linc Energy during the UCG period and any gas that may be generated afterwards due to Arrow's development activities. To distinguish between these gas ‘sources’ we introduce a trace concentration of an inert gas at a mole fraction of 1% to act as a tracer within the gas plume (phase). This gas is introduced at the end of the gasification period in 2013. By doing this we can see the source of gas in our results and its evolution over time. We can also determine if the gas is due to UCG or future desorption.

4. Model Results

This Section describes model results. We start by presenting the base-case simulation (Scenario 1) considering two time frames: the soft history match from the ceasing of UCG operations in 2013 to 2019; and after 2019 through to 2042. The second period has two production scenarios, with and without Arrow development of PL253/493. We then present a series of eight further sensitivity scenarios that are described in Section 4.2.

Model results are mainly presented using contour plots of three model outputs:

- Groundwater head (mAHD), calculated from modelled pressures.
- Relative gas saturation between 0 and 1, where 0 indicates no gas and full groundwater saturation, and 1 is full gas saturation.
- Fractional tracer concentration between 0 and 1. The starting tracer ceoncetration in 2013 is 1%, or 0.01. As pressure continue to recover, methane is adsorbed and the concentration of the inert non-adsorbing gas increases.

These plots are presented for model Layer 4 corresponding to the Macalister A Seam, and upper UCG target. Additional outputs are provided for certain model scenarios.

4.1 Scenario 1 – Base Case

2013-2019

Figure 8 shows the evolution of groundwater head, gas saturation and tracer concentration for the base-case permeability model (shown in Figure 6) between 2013 and 2019, 6 years post-gasification. Head depletion in 2013 due to gasification is > 20m across almost the entire Linc area. Head decline has propagated farther in the north (~1km) than to the west (~0.5km) of the Linc site, although the decline is more intense in the west. This is due to the permeability distribution (Figure 6) that provides more connectivity to the north. The greatest depletion of 90 to 100 m occurs at the gasifier locations.

By 2019, 6 years after the end of gasification heads have partially recovered and the depletion in the site is mostly within 10-30m except for the areas very close the gasifiers where the head is still low. The head recovery is more rapid in the western part of the Linc site where permeability is higher.

Gas saturation in 2013 is highest at gasifiers (40 to 100%) and in the area in between the gasifiers (16 to 40%), where the highest head decline is observed. For this base case the difference between the initial fracture and matrix pressure is 300 kPa meaning that no gas is desorbed in areas with a head depletion lower than 30m. The extent of free gas is therefore smaller than the area of head depletion. From 2013 to 2019, gas saturation decreases to low values (<1%) except at Gasifiers 1, 2, and 5 where gas remains and porosity is high.

The inert tracer concentration is set constant at 0.01 mole fraction in 2013 when the post gasification starts. From 2013 to 2019, gas tracer concentration significantly increases, especially around the western part of the gas plume where the gas saturation has decreased due to more rapid pressure (head) recovery. This increase in saturation is due to adsorption of methane while the inert tracer component does not adsorb. As 99% of the gas plume is methane which can, and does adsorb onto coal, the relative concentration of inert tracer significantly increases.

Beyond 2019

There are two scenarios beyond 2019:

(a) Current development with no further Arrow production in PL253/493

(b) Proposed development with Arrow production in PL253/493

(a) Current Arrow development:

This is the continuation of the simulation described earlier after 2019. Figure 9 shows head, gas saturation and tracer concentration in 2033 and 2043 using the static boundary conditions. The results show that head continue to recover. The maximum head difference across the model is 8m and 3m (almost fully recovered) in 2033 and 2043, respectively. The results show that the structure of the fault, due to its offset, has some impacts on the shape of the head distribution in Linc area. This impact is minor though (~1m). The results show that the residual gas plume (fractions of 1% saturation) does not move after 2019. Its shape and saturation is static in the last 10 years of the simulation. The change in tracer concentration also negligible during this period. Tracer's high mole fraction in the final 10 years indicates that most of the gas has been adsorbed into the coal by 2033.

(b) Proposed Arrow development:

The simulated groundwater head for this case is totally different from the head in the previous case. Due to the proposed Arrow development plan, a head gradient (flow potential) towards south-west is generated (Figure 10). The direction of this head gradient is (~90 degrees) rotated with respect to the case without development, and the magnitude of this gradient increases with time. This significantly affects heads within the former Linc site, reducing heads (pressures) by ~ 5 m in the middle of the site in 2043 against the case without further development. This head decline is not significant enough to cause any new gas desorption in the model (Figure 10). Gas saturation and tracer concentration do not show any considerable gas desorption or movement and the plume is approximately stable in location. The results of this case are very close to the previous case. From the base case the proposed Arrow development does not lead to any gas movement within or off the Linc site.

4.2 Scenarios 2 to 9 – Sensitivity Analyses

Gas movement is sensitive to multiple factors, including: horizontal permeability; vertical permeability; connectivity through coals – which is related to stochastic distributions; structure and the transmissibility of faults; coal saturation; capillary pressure; and boundary conditions. In this section we describe sensitivity runs that test the initial base case results to uncertainties in these factors.

Table 3 presents a list of sensitivity cases investigated with the model that includes increasing horizontal permeability and different stochastic scenarios of coal distribution, fault transmissibility, the assumed initial coal saturation, vertical permeability in over and underlying units, and the hydraulic gradient across the site caused by the proposed Arrow development. The sensitivity analyses were chosen to test key assumptions made in the model design and to address known uncertainties thought to influence future gas movement.

For each sensitivity test, scenarios both with the current and the proposed development plans were run and results are compared.

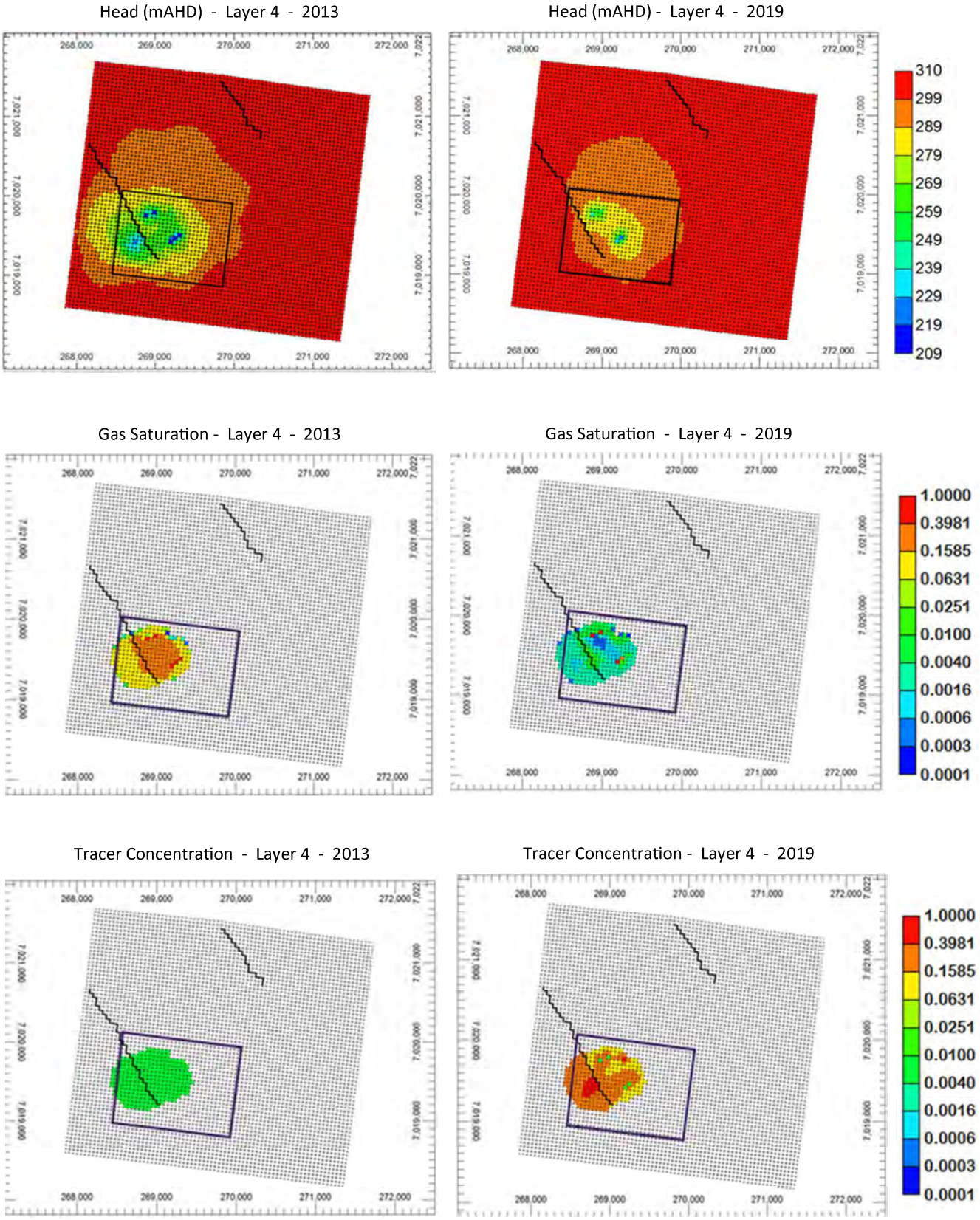


Figure 8. Water head, gas saturation, and tracer concentration in Macalister seam A in 2013 and 2019

Without Arrow Development of PL253/493

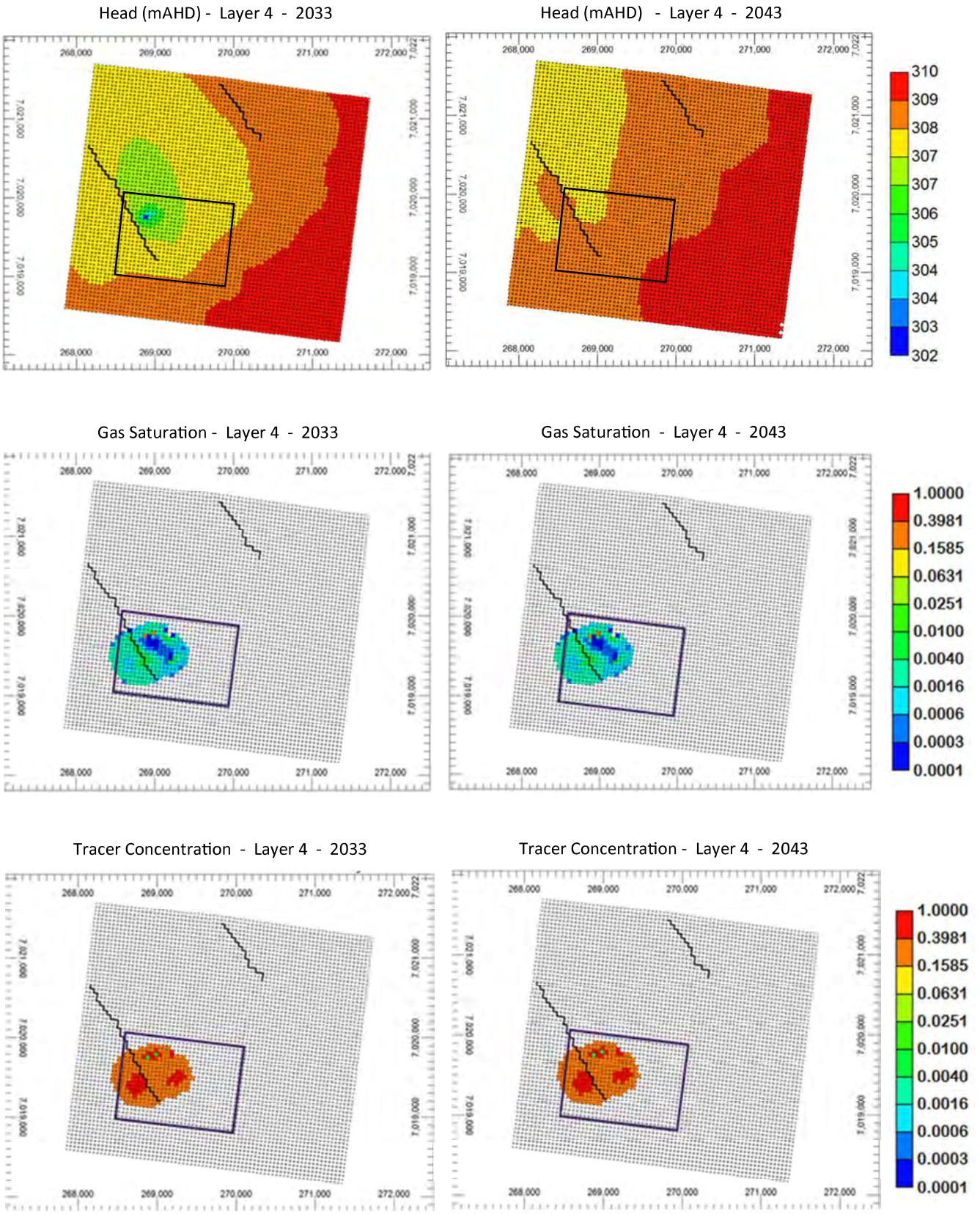


Figure 9. Water head, gas saturation, and tracer concentration in Macalister seam A in 2033 and 2043 for the current Arrow development case

With Arrow Development of PL253/493

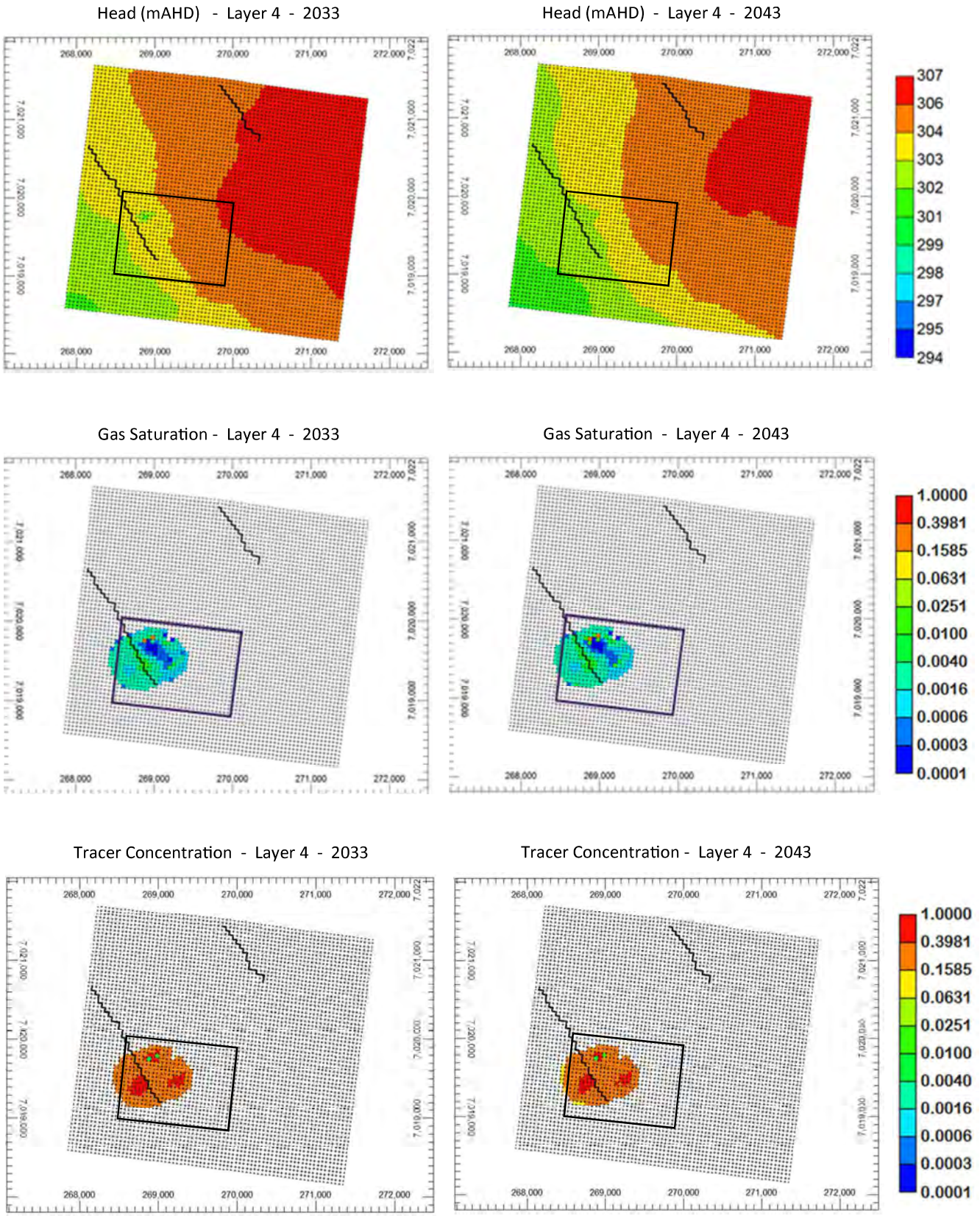


Figure 10. Water head, gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the proposed Arrow development case

Table 3: List of sensitivity scenarios considered. In all scenarios, cases were run with and without further Arrow development.

Scenario	Case	Modification from Base Scenario
1	Base Case	Model as described in text
2	Sealing Faults	Fault transmissibility set to 0
3	High Saturation	"Matrix pressure" increased to represent more saturated coal (i.e. containing more adsorbed gas)
4	Alternate Permeability Realisation	Alternate stochastically generated permeability field, using same statistical inputs.
5	Higher Permeability	Alternate stochastically generated permeability field, using higher mode for permeability (50md)
6	Enhanced Permeability around Gasifiers	Vertical permeability in Springbok around gasifiers increased by up to 6 orders of magnitude
7	Better Connectivity Through Interburden	Vertical permeability in layers between Macalister and Wambo increased by 3 orders of magnitude.
8	High Capillary Pressure in Interburden	Capillary pressure curves for interburden have 50 kPa entry pressure for gas.
9	Increased Pressure Gradient	Boundary condition modified to double the head *gradient* across the site.
10	Macalister topology	Smoother top to the Macalister A Seam

4.2.1 Scenario 2 – Sealing Faults

In the build of the model grid, faults based on seismic lines and mapped by Arrow Energy were structurally incorporated. The faults have connections between the grid faces across the faults defined. A transmissibility factor, from 0 to 1 is assigned to these connections, where 0 indicates no transmissibility across the faults (sealing) and 1 indicates full transmissibility. Fault transmissibility in CMG-GEM is set to 1, by defaults and this full connection was the value used in the base-case model. To investigate the effect of sealing faults on modelled predictions of future gas movement, in this scenario the fault transmissibility is set to zero.

2013-2019

Figure 11 shows the results of the first 6 years of post-gasification. Head decline is not consistent across the faults as a result of the faults' zero transmissibility. Head recovery in the south-western part of the fault (around Gasifier 4) occurs more quickly than the base case with transmissible faults (Figure 8). This happens as the sealing fault blocks the fast movement of water across it, towards Gasifiers 1,2,3,5. With more rapid pressure recovery, gas saturation in the south-western part of the model decreases faster than to the north-west of the fault. This contrasts with the north-eastern side where gas saturation is still high. Tracer gas concentration is higher to in the south-western side of the fault, due to very low residual gas saturation.

2020-2043 – current Arrow development

Continuing the simulation using static boundary conditions shows further decreases in gas saturation due to gas adsorption as pressure recovers (Figure 12). Head recovery is not consistent across the fault. In 2033, head in the south-western areas of the fault is fully recovered, however there still is a 10m depletion in the other side. By year 2043, there still is 3-4m depletion in the north of the fault. Despite this, gas saturation and tracer concentration are almost constant and, gas plume is static in location after 2033.

2020-2043 – proposed Arrow development

With the dynamic boundary conditions a head gradient is generated in NE to SW direction, increasing with time. Some pressure depletion remains in 2033 but by 2043, there is no noticeable depletion area within the Linc site. The presence of a sealing fault reduces the connection of part of the Linc site to the south-western

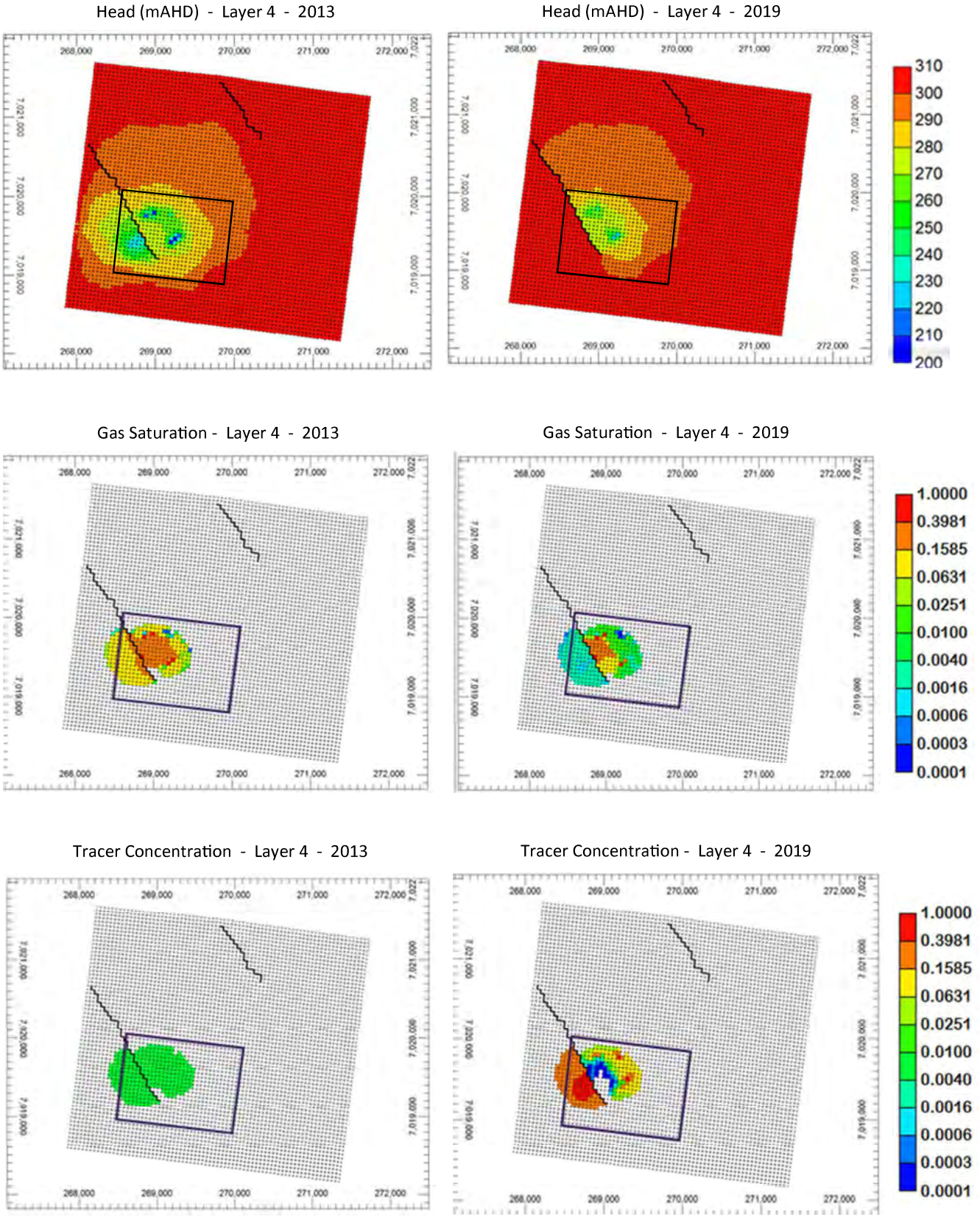


Figure 11. Water head, gas saturation, and tracer concentration of Macalister seam A in 2013 and 2019

Without Arrow Development of PL253/493

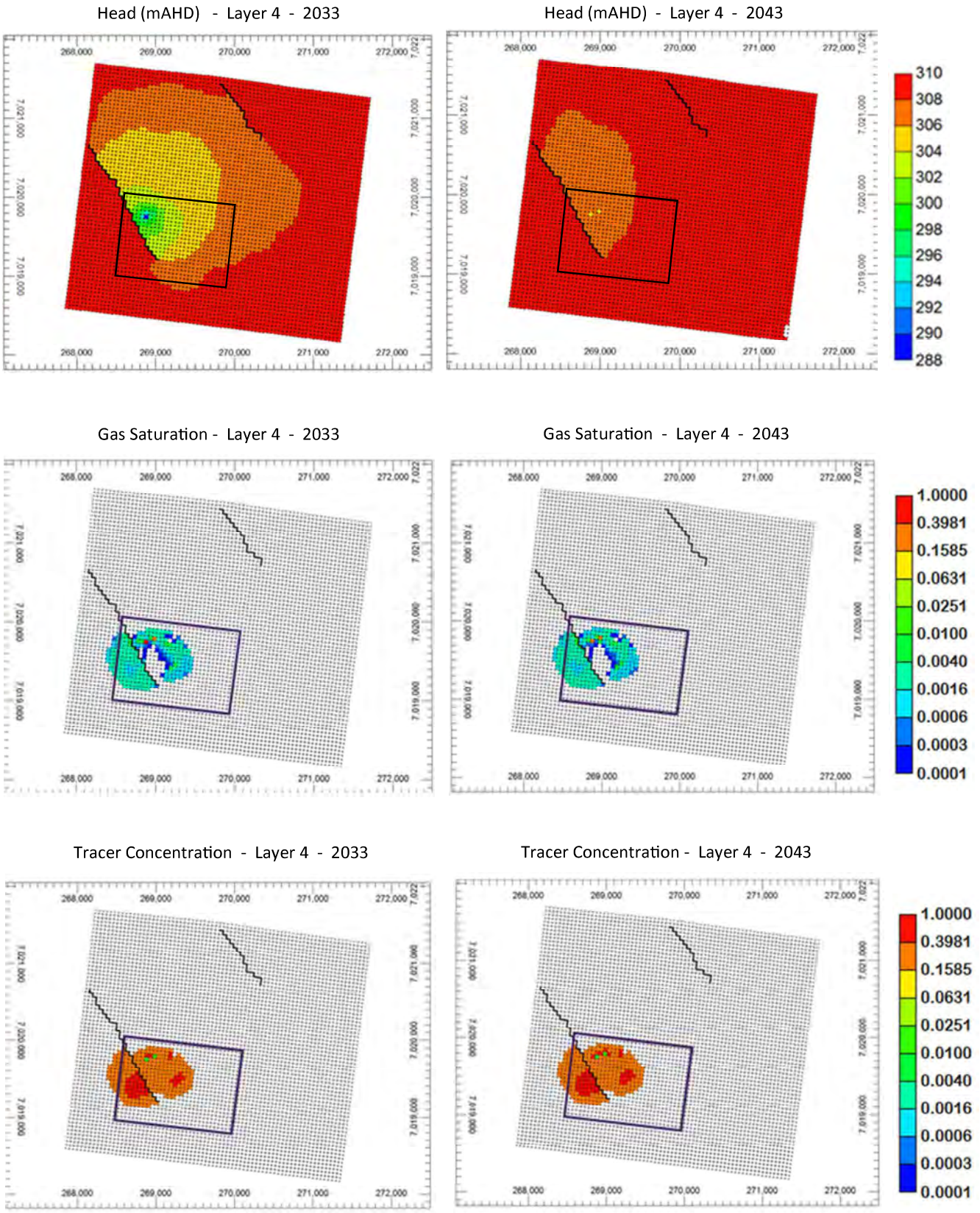


Figure 12. Water head, gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the current Arrow development case

boundary, and this delays both pressure recovery and the predicated decline due to Arrow production (Figure 13). Therefore, the head in 2033 in the north-eastern side of the fault within the Linc site is almost identical to the case with the current Arrow development plan at the same time. By 2043, the head gradient produced by the proposed Arrow development reaches site and the drawdown area around the gasifiers vanishes.

Despite more significant changes in head, there is little difference between the results of saturation in this case with the previous one. The gas plume stays effectively static and with differences in gas saturation or tracer concentration difficult to discern. This indicates that the effect of Arrow's proposed development on gas movement in the Linc site is very minor.

Figure 14 shows changes in pressure at a point (Grid 23, 23, 4) located between the gasifiers in the north-eastern side of the (a) transmissible fault (base case) and (b) sealing fault. The pressure effects of Arrow development is detected in the middle of the site from 2028 and shows a 100 kPa pressure difference by 2043 compared to the base case. The presence of sealing faults decreases the pressure decline at site, halving the final pressure difference in 2043 (Figure 14b). This is due to the effect of the fault's transmissibility on the connectivity of the Linc site to the model boundaries.

4.2.2 Scenario 3 – High Saturation

The difference between initial fracture and matrix pressure in the previous cases was 300 kPa, representing an under-saturated coal where a 30 m decline in groundwater head is requires before gas is desorbed. We do not know the natural saturation of the Macalister coals at site prior to Linc UCG activities. This scenario tests the effect of the proposed Arrow development if the coal was fully saturated on site, with a very small difference between fracture and matrix pressures. An issue with this scenario is that effectively any decline in pressure promotes gas desorption, meaning that gas generation may occur at model boundaries.

2013-2019

Figure 15 shows gas saturation and tracer concentration in the first 6 years after the end of the gasification. Gas is present over a larger area than in the base case Scenario 1, effectively covering the area with any drawdown due to Linc operations. In 2019 gas saturation decreases as a result of head recovery leading to gas adsorption. Since head recovery is not uniform everywhere, we see a non-uniform gas adsorption. Tracer concentration increases where the adsorption occurs.

2020-2043 – current Arrow development

Figure 16 shows that the area with gas present expands through to 2033 and 2043. This is due to continued re-equilibration of pressures, where any decrease in pressure results in gas being adsorbed. The tracer gas concentrations for this scenario help reveal the movement of gas present at site in 2013 and show a different and more limited distribution compared to the uppermost gas saturate plots in Figure 16.

2020-2043 – proposed Arrow development

With the coals set as fully saturated, and any small pressure decline causes gas desorption, the results for the proposed Arrow development in Figure 17 show increasing gas saturations across the model domain in 2033 and 2043. This is due to pressure reductions being applied at the model edges to replicate depletion predicted by AGE. The pressure reduction of 2 to 5 m of groundwater head can be seen by comparing the head contour plots in Figures 9 and 10 for the Base Case scenario.

The tracer gas concentration, which shows the location of gas present in 2013 is zero where new gas is generated. These plots show that the gas which was already in the Linc site stays essentially stable under the high saturation scenario. Comparison of tracer gas concentrations between Figures 16 and 17 show very little change in tracer concentration and distributions between the development scenarios.

With Arrow Development of PL253/493

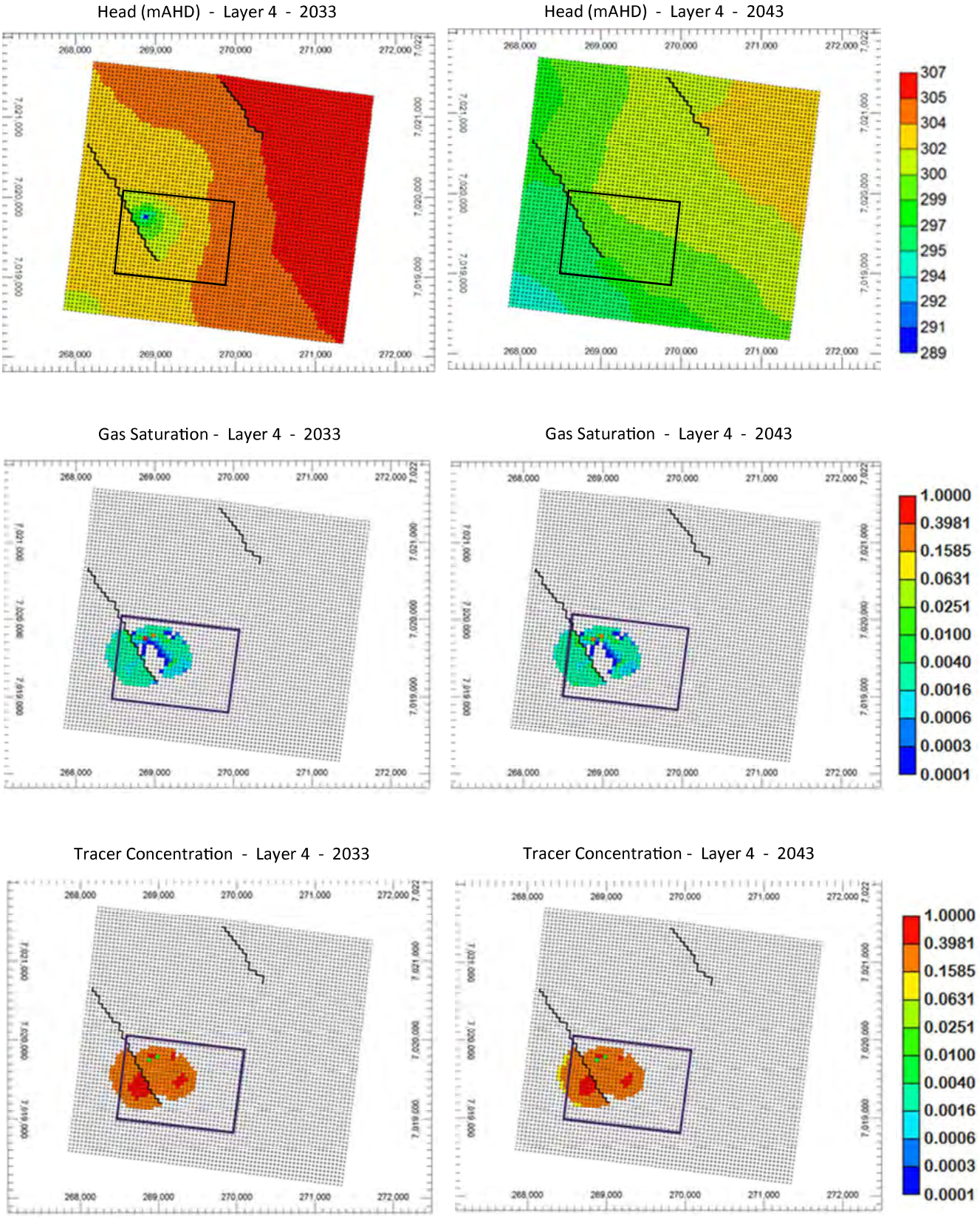


Figure 13. Water head, gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the proposed Arrow development case

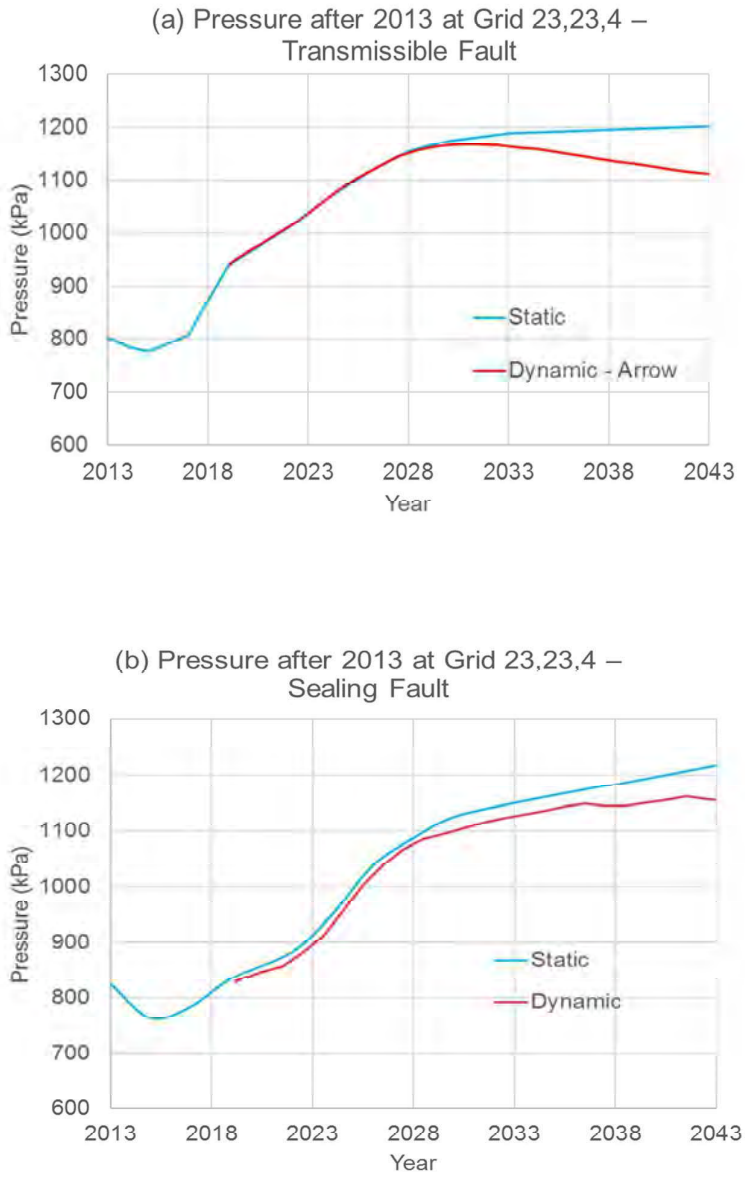


Figure 14. Pressure at Grid 23, 23, 4 with time for (a) transmissible and (b) sealing faults.

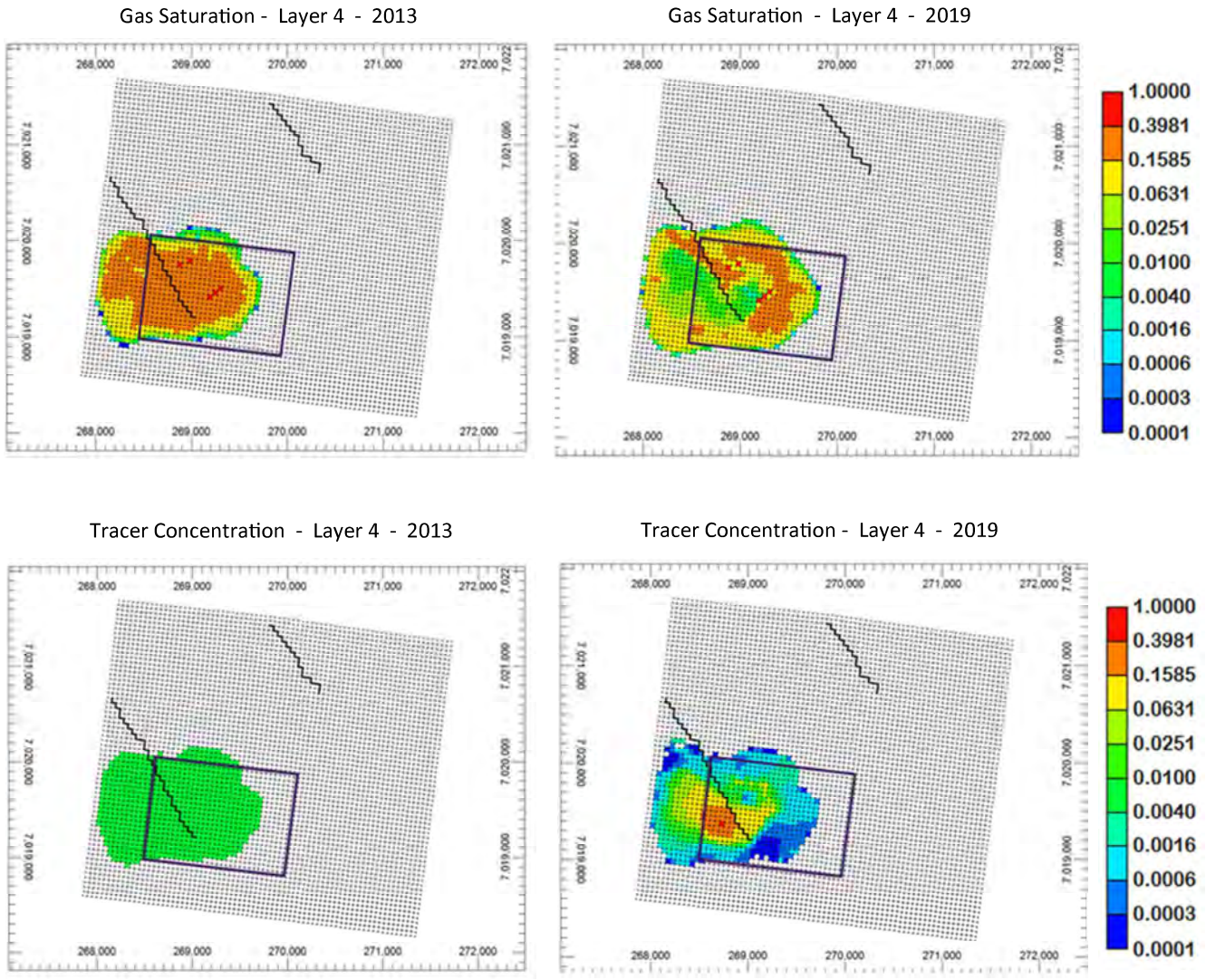


Figure 15. Gas saturation and tracer concentration in Macalister seam A in 2013 and 2019

Without Arrow Development of PL253/493

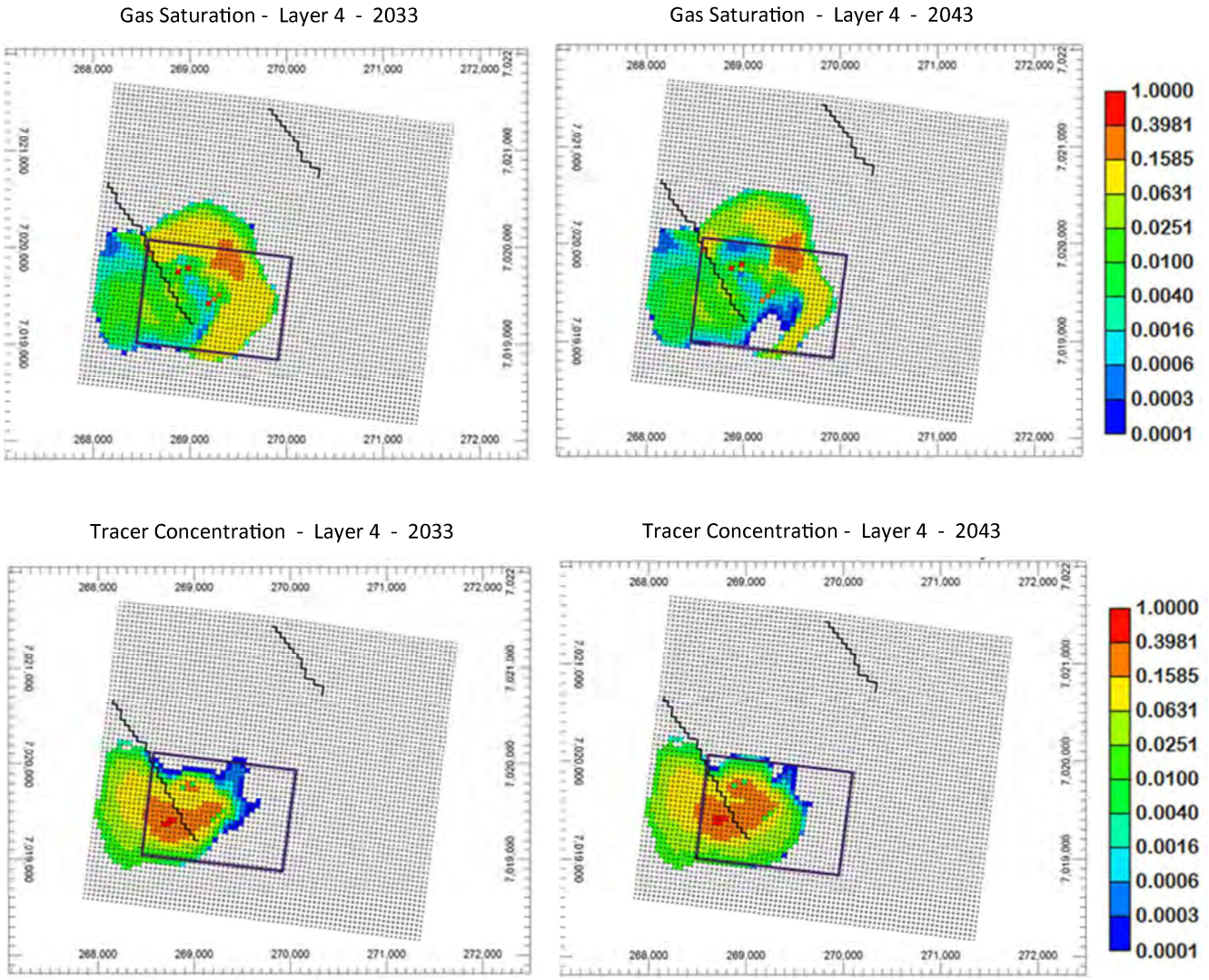


Figure 16. Gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the current Arrow development case

With Arrow Development of PL253/493

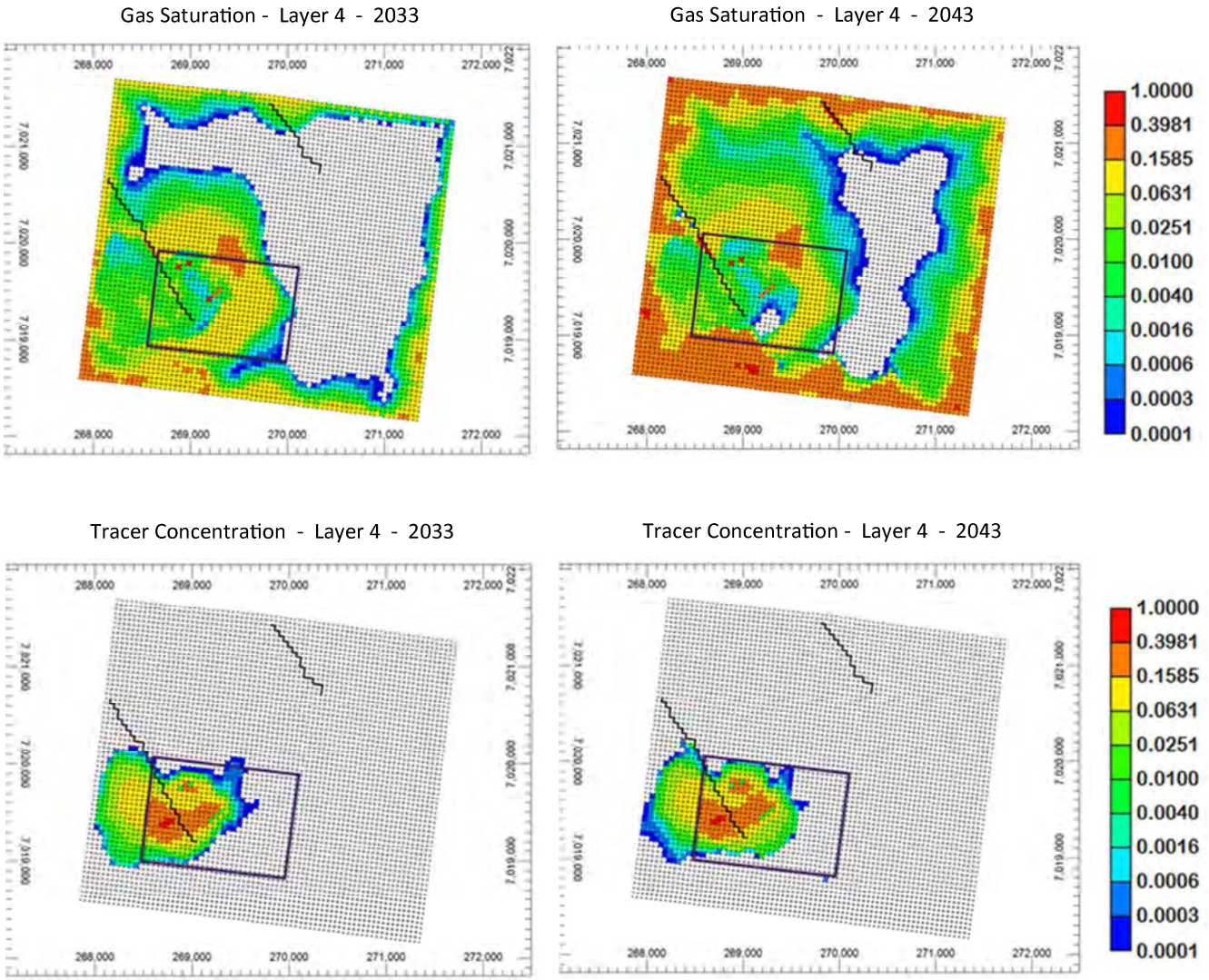


Figure 17. Gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the proposed Arrow development case

4.2.3 Scenario 4 – Alternate Permeability Realisation

The maps of coal presence and intrinsic permeability fields are generated stochastically. This scenario explores other realisations of coal and permeability, using the same statistical properties, i.e. mean and standard deviation. Figure 18 shows the resulting permeability field for Scenario 4. This permeability field was passed through the workflow presented in Figure 7 to ensure it conforms to the soft calibration criteria with 30 – 40 m of head decline in 2019. Both production scenarios were then simulated with the new permeability field.

2013-2019

The area of gas saturation and tracer concentration are slightly different for Scenario 4, shown in Figure 19, compared to the Scenario 1 Base Case (Figure 8). Between 2013 and 2019 gas saturation decreases significantly with a corresponding increases in tracer concentration which indicates gas adsorption in the 6 years post-UCG. The overall plume size is similar to the base case.

Beyond 2019

Figure 20 presents gas saturation and tracer concentration in 2043 for both production scenarios. The plots show effectively no different between the current and proposed Arrow developments. For this scenario the neither Arrow development plans cause changes to saturation or any gas movement.

4.2.4 Scenario 5 – Higher Permeability

Coal permeability influences gas movement and it can also change the volumes of gas adsorbed due to pressure propagation through the model. The mean intrinsic coal permeability for the Base Case Scenario 1 is 10mD, within the range of the observations around the Linc site. This scenario assesses the sensitivity of predictions of gas movement to higher permeability values. A new permeability field shown in Figure 21 was generated with the mean value of 50mD, 5 times higher than the Base Case, with the same standard deviation was generated. This permeability field was then simulated and tested through the same workflow as before (Figure 7).

Higher permeability permits UCG related pressure declines can propagate further. Additionally gas on site may move more easily, under buoyancy or viscous forces related to pressure gradients from Arrow developments.

Figure 22 shows gas saturation and tracer concentration in year 2043 (end of the simulation) for both Arrow development cases. Comparing these figures with those for the Scenario 1 Base Case shows the size and location of the plume difference (Figures 9, 10). However, the predicted effect of the proposed Arrow development is hard to discern with some slight changes in gas saturation, but no real change in the location of gas.

For both current and proposed Arrow cases, gas saturation and tracer concentration are more uniform within the plume comparing to the previous cases. This is due to the higher average permeability (connectivity) within this model, especially in the Linc site.

4.2.5 Scenario 6 – Enhanced Permeability around Gasifiers

Increased permeability, particularly immediately overlying a UCG cavity, is a known risk of UCG operations (Sury et al. 2004). At the Linc site this may have increased vertical permeability with fracturing upward into the lower Springbok formation, above the gasifiers. This scenario considers increased vertical permeability between the gasifiers and the Springbok, compared to the Base Case, at locations shown in Figure 23.

The vertical permeability is enhanced above the location of the gasifiers and is extended laterally by 50m. The permeability in this area is increased to the same values as in the underlying model cells in Layer 4, representing the Macalister A Seam.

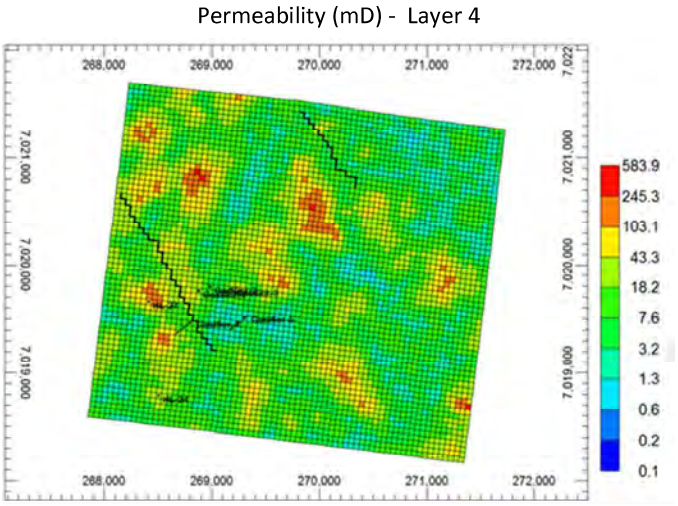


Figure 18. A new permeability distribution for layer 4 (Macalister Seam A)

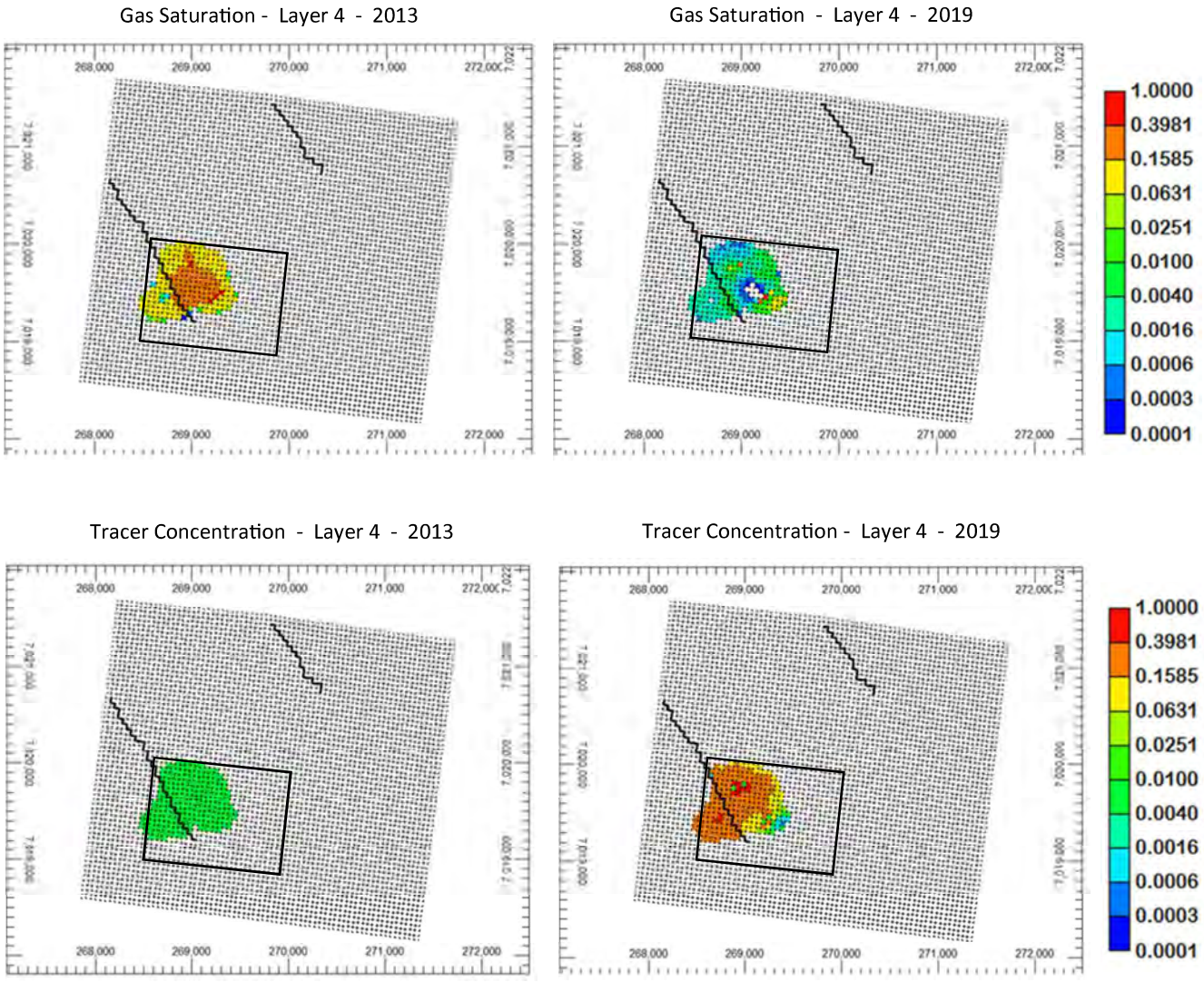


Figure 19. Gas saturation, and tracer concentration of Macalister seam A in 2013 and 2019

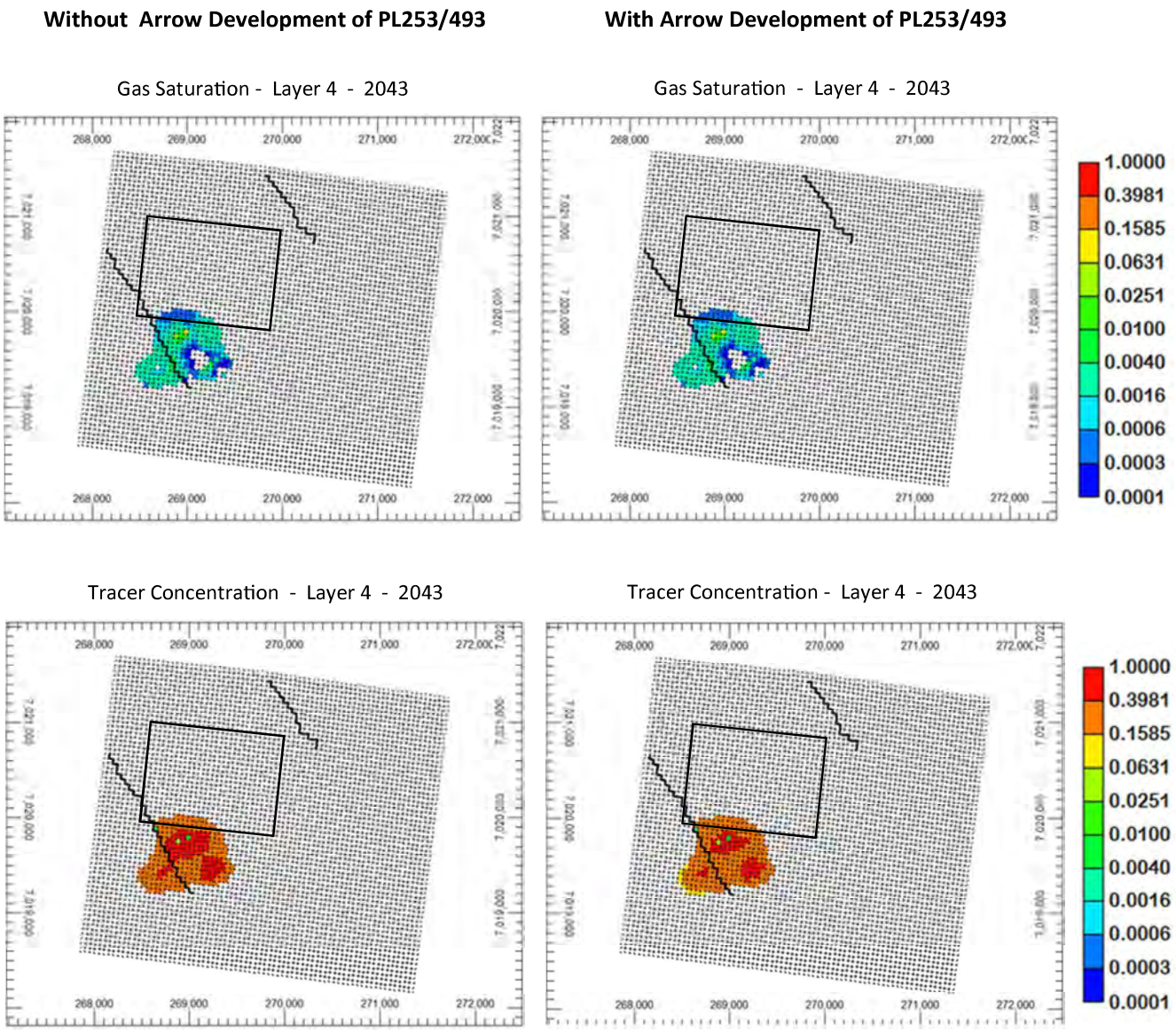


Figure 20. Gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for different Arrow development cases

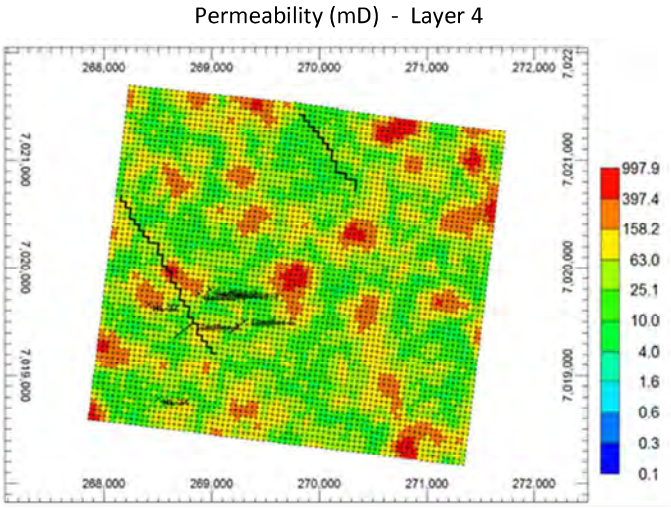
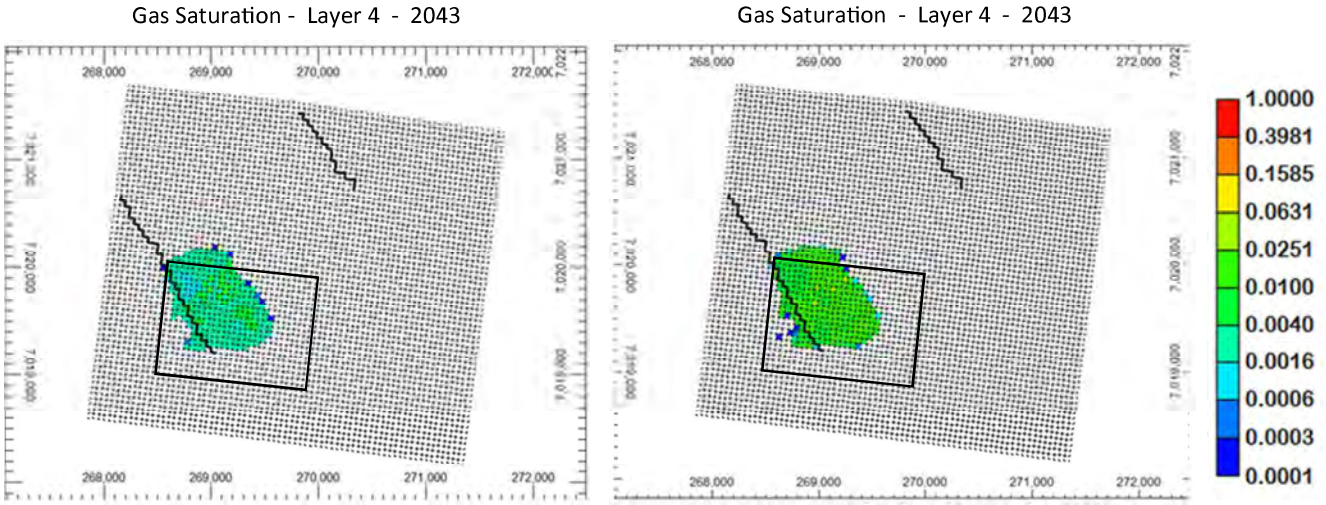


Figure 21. The permeability map of layer 4 (Macalister seam A) with mean of 50mD

Without Arrow Development of PL253/493 | **With Arrow Development of PL253/493**



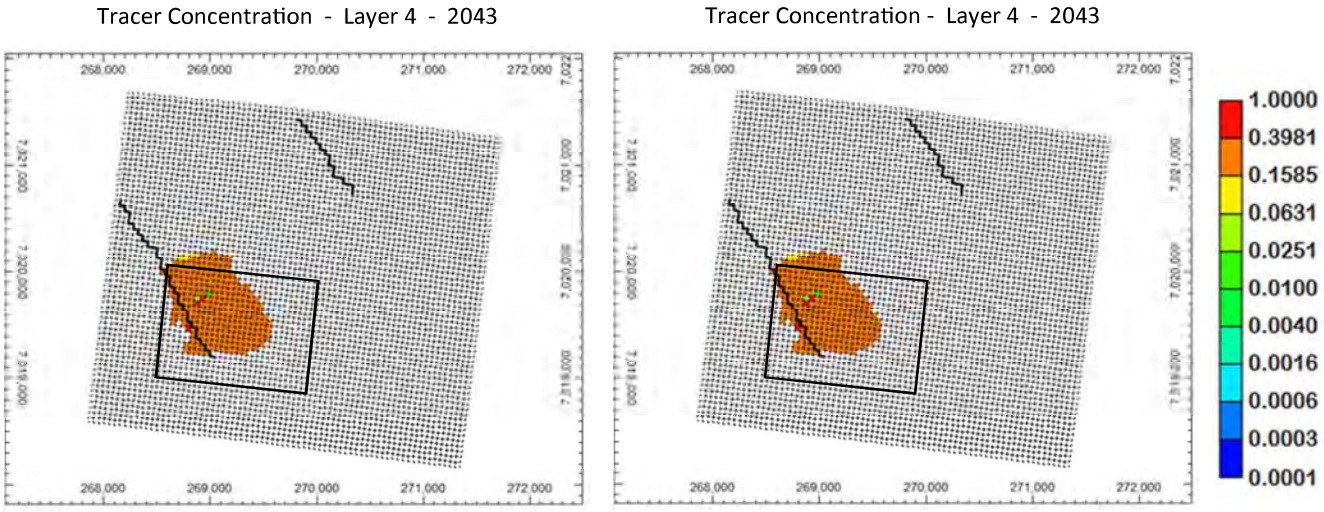


Figure 22. Gas saturation, and tracer concentration of Macalister seam A in 2043 for different Arrow development cases, with higher permeability (Figure 17)

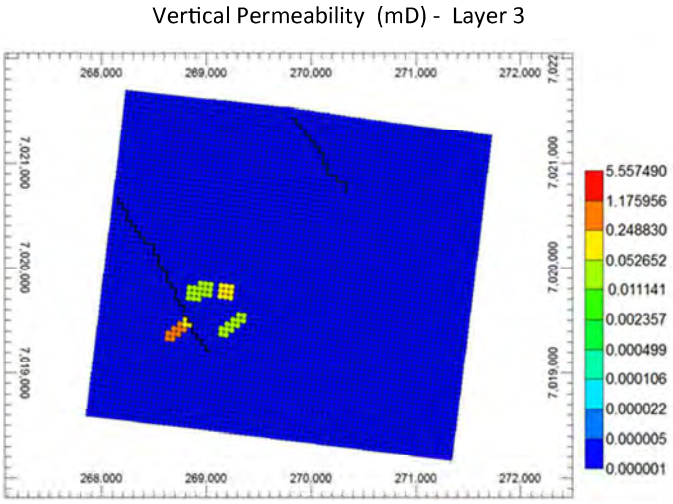
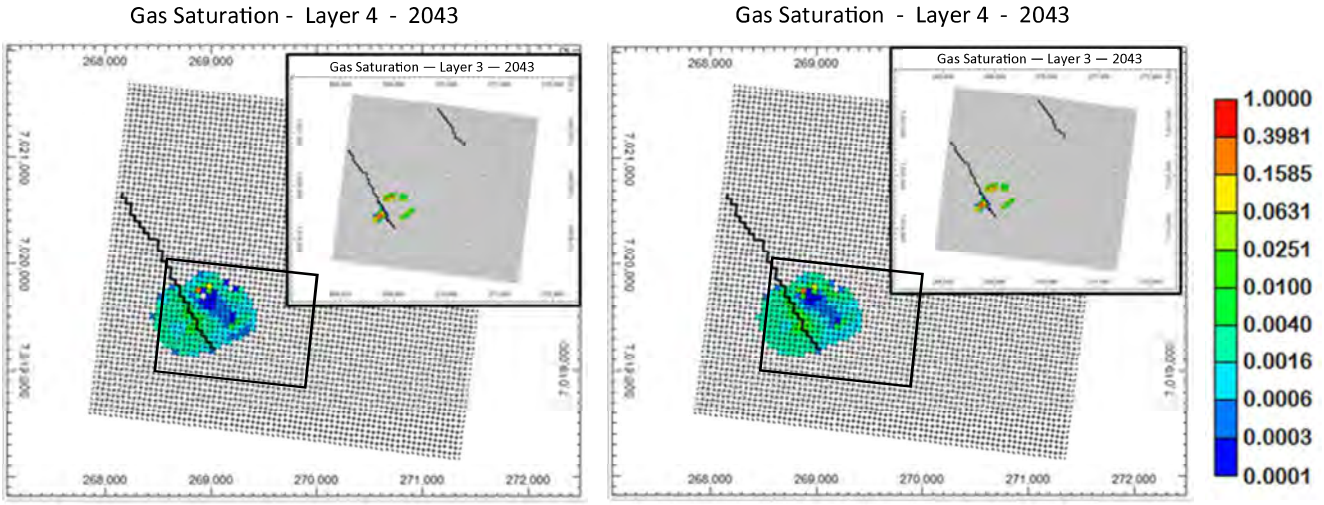


Figure 23. Increased vertical permeability in lower Springbok (layer 3), above the gasifiers

Without Arrow Development of PL253/493 | **With Arrow Development of PL253/493**



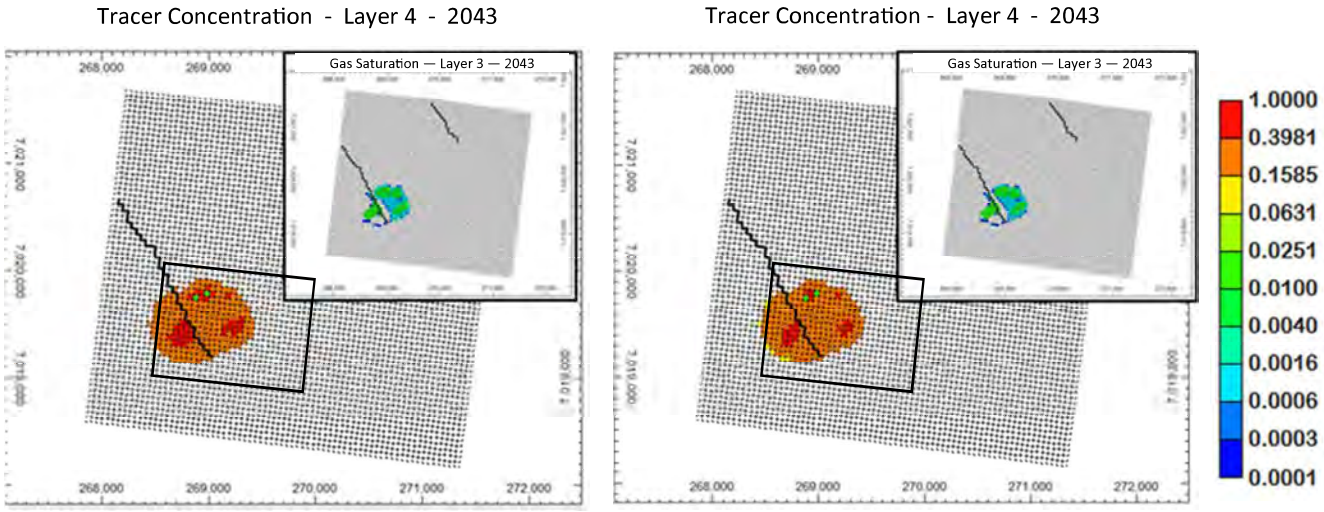


Figure 24. Gas saturation, and tracer concentration of Macalister seam A and lower Springbok (layer 3) in 2043 for different Arrow development cases

Figure 24 presents gas saturations and tracer concentrations in 2043 for the two development cases for both Layer 3 and Layer 4. Differences between the plots are hard to discern and are very similar to the results of the base case with no fracture in Layers 3 (Figures 9, 10). This indicates that increased vertical permeability at the gasifiers is unlikely to lead to migration of gas within the coals with or without further Arrow development.

4.2.6 Scenario 7 – Better Connectivity Through Interburden

In the Base Case and other scenarios the vertical permeability of the interburden is 0.000001 mD. The future development case with Arrow production in PL253/493 has wells producing from Wambo coals within the model domain from 2027 (Table 1). This scenario explores the influence of production from the Wambo coals under the condition of higher interburden permeability. For this the vertical permeability of the model Layer 7, the interburden between the Wambo (Layer 8) and Macalister B Seam (Layer 6) is set 100 times higher than other interburden layers as shown in Figure 25.

Comparing gas saturation and tracer concentration in Layers 4 (Seam A) and 6 (Seam B) for both Arrow development cases (Figure 26) shows a very minor sensitivity of the results to vertical permeability of the interburden layer (Layer 7). Gas saturation in Layer 6 remains very low.

The results show that with greater connectivity between the Macalister and Wambo seams, and future production by Arrow, there is no appreciable change in future gas movement at the former Linc site.

4.2.7 Scenario 8 – High Capillary Pressure in Interburden

In the Base Case and other scenarios capillary pressure has been set at zero. Zero capillary pressure means that this mechanism that may impede gas migration is inactive. The zero capillary pressure assumption may be valid in naturally fractured coal. However, in non-coal it is unlikely that capillary pressure is zero, especially for low permeability rocks.

This scenario tests whether capillary pressure could influence gas generation or movement with a relatively high capillary pressure curve, shown in Figure 27, assigned to non-coal cells in the model. A capillary threshold pressure of 50 kPa means gas cannot enter where water is placed unless subject to a great than 50 kPa pressure difference. Coal capillary pressure is assumed to remain at zero, due to natural fracturing causing coal permeability.

The results of the simulation are shown in Figure 28 with the results of the base case with capillary pressure (Pc) equal to zero (Figures 9-10) next to each figure. They show that capillary pressure has almost no effect on gas generation and movement, and that no gas movement occurs as a result of the proposed Arrow development plan.

4.2.8 Scenario 9 – Increased Pressure Gradient

Scenario 1 to 8 are all based on AGE's predictions of future depressurisation due to Arrow Development. This Scenario explores the sensitivity of future gas movement to the hydraulic gradient across the former Linc site using boundary conditions with double the drawdown at the south east corner of the model (i.e. towards the nearest Arrow wells completed in the Macalister) compare to that predicted by AGE. Whilst this is considered unlikely, the results provide an indication of how sensitive predictions of gas movement around the Linc site are to increases in hydraulic gradient across the site.

Figure 29 shows the groundwater heads, gas saturation and tracer concentrations for this high hydraulic gradient scenario. This scenario considers Arrow development in PL253/493, and comparison should be made with the Base Case results, shown in Figures 9 and 10. The results show the gas plume to be effectively immobile, despite a total head difference of 26 m across the model by 2043.

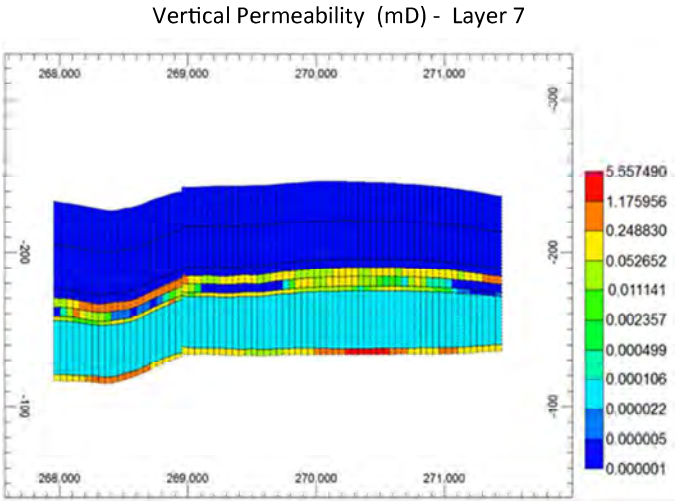
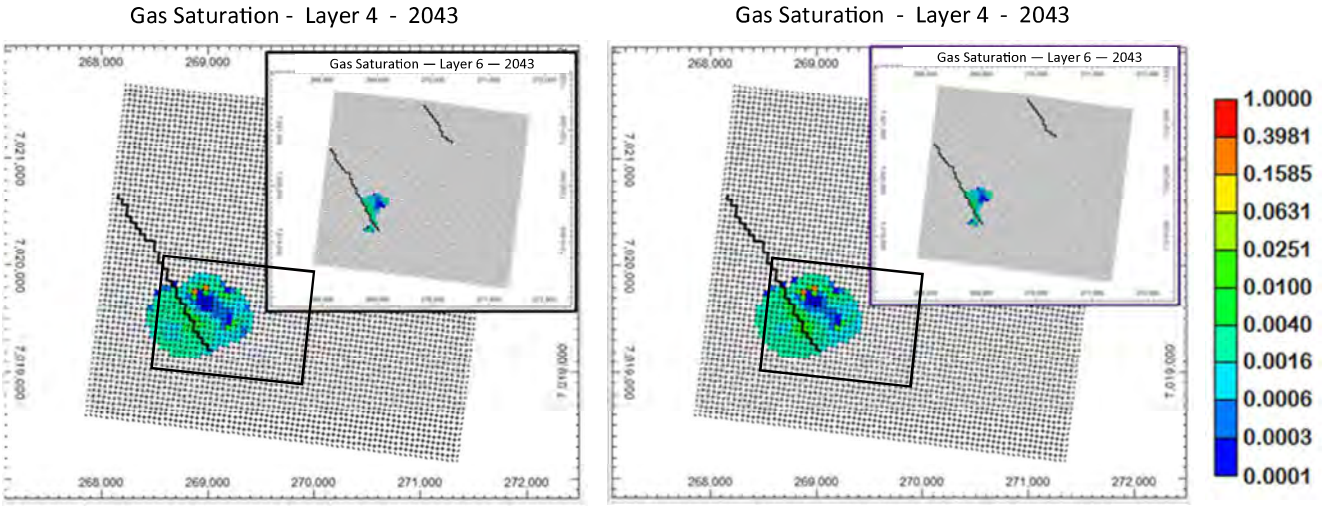


Figure 25. Vertical permeability of coal and interburden layers in a cross section of the model

Current Arrow Development

Proposed Arrow Development



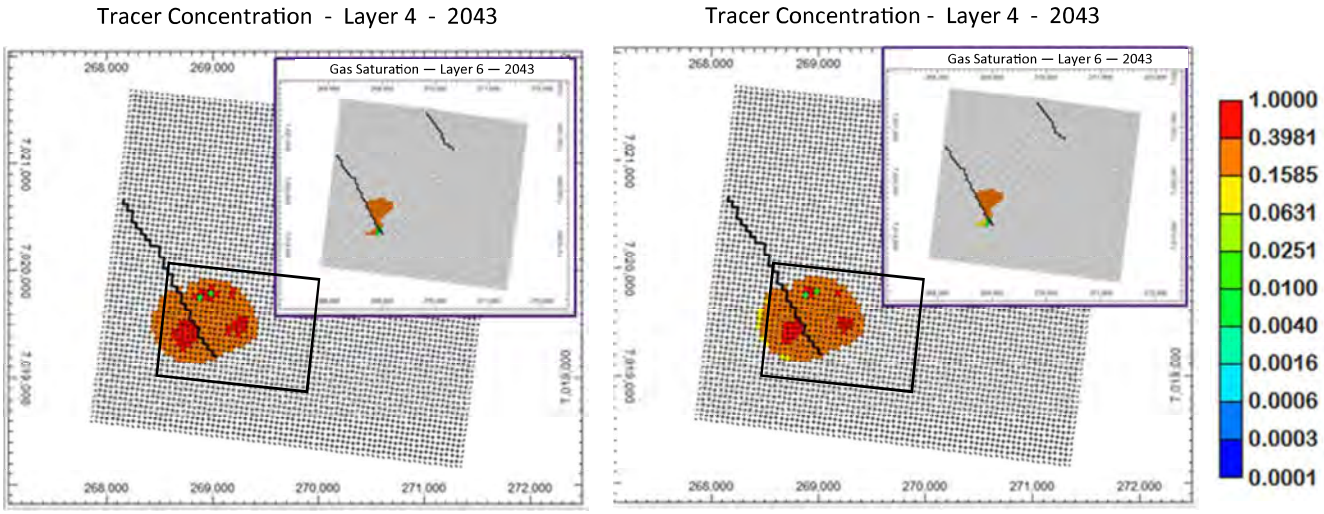


Figure 26. Gas saturation, and tracer concentration of Macalister seams A and B (layers 4 and 6) in 2043 for different Arrow development cases

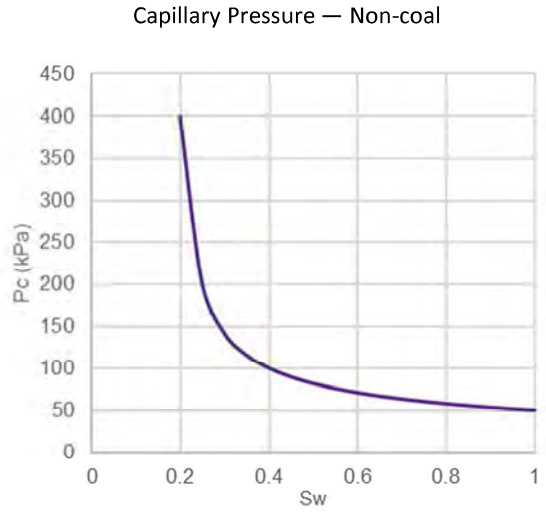


Figure 27. Capillary pressure curve for non-coal

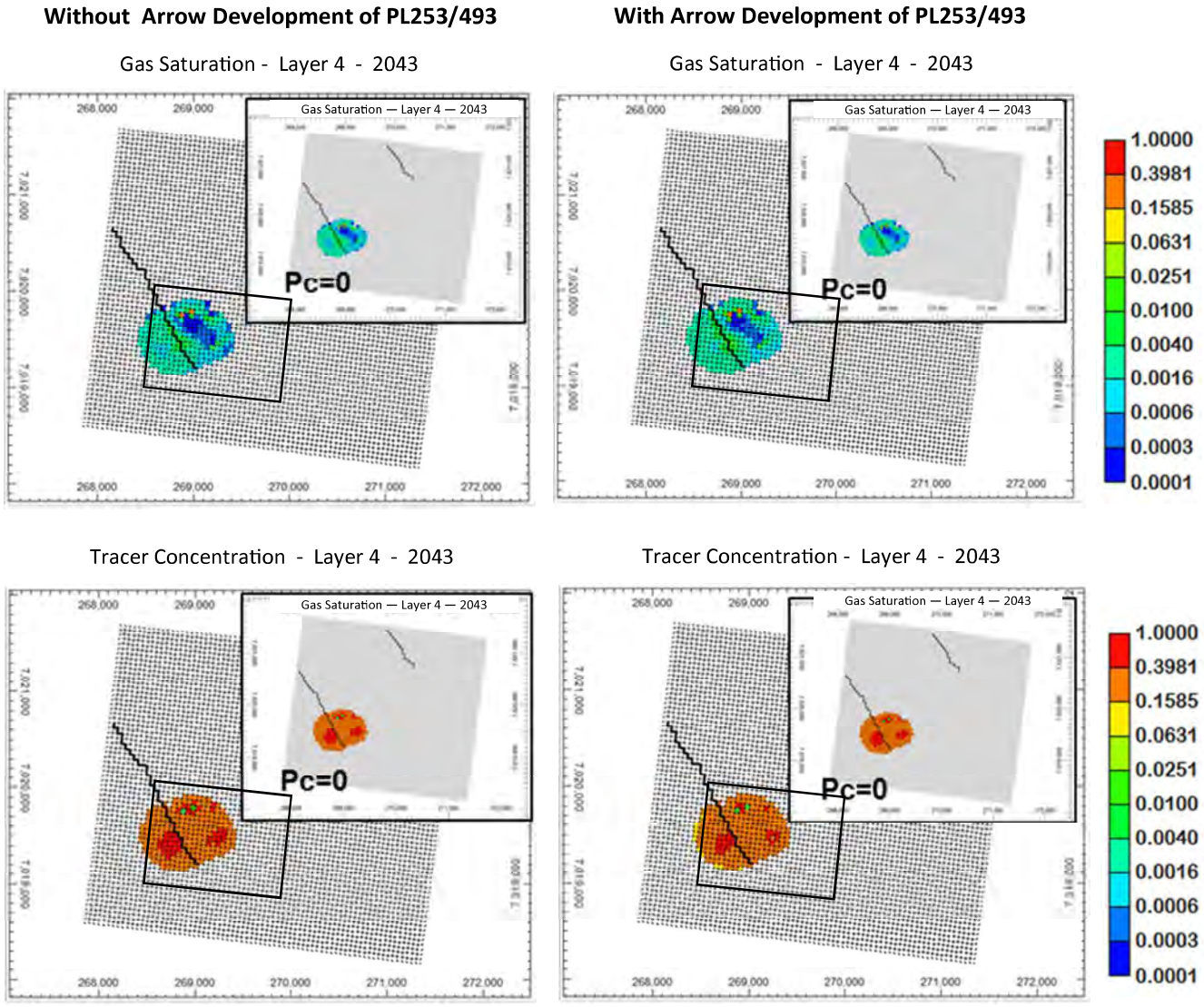


Figure 28. Gas saturation, and tracer concentration of Macalister seams A in 2043 for different Arrow development cases. The base case (Pc=0) results are also added into each figure.

With Arrow Development of PL253/493

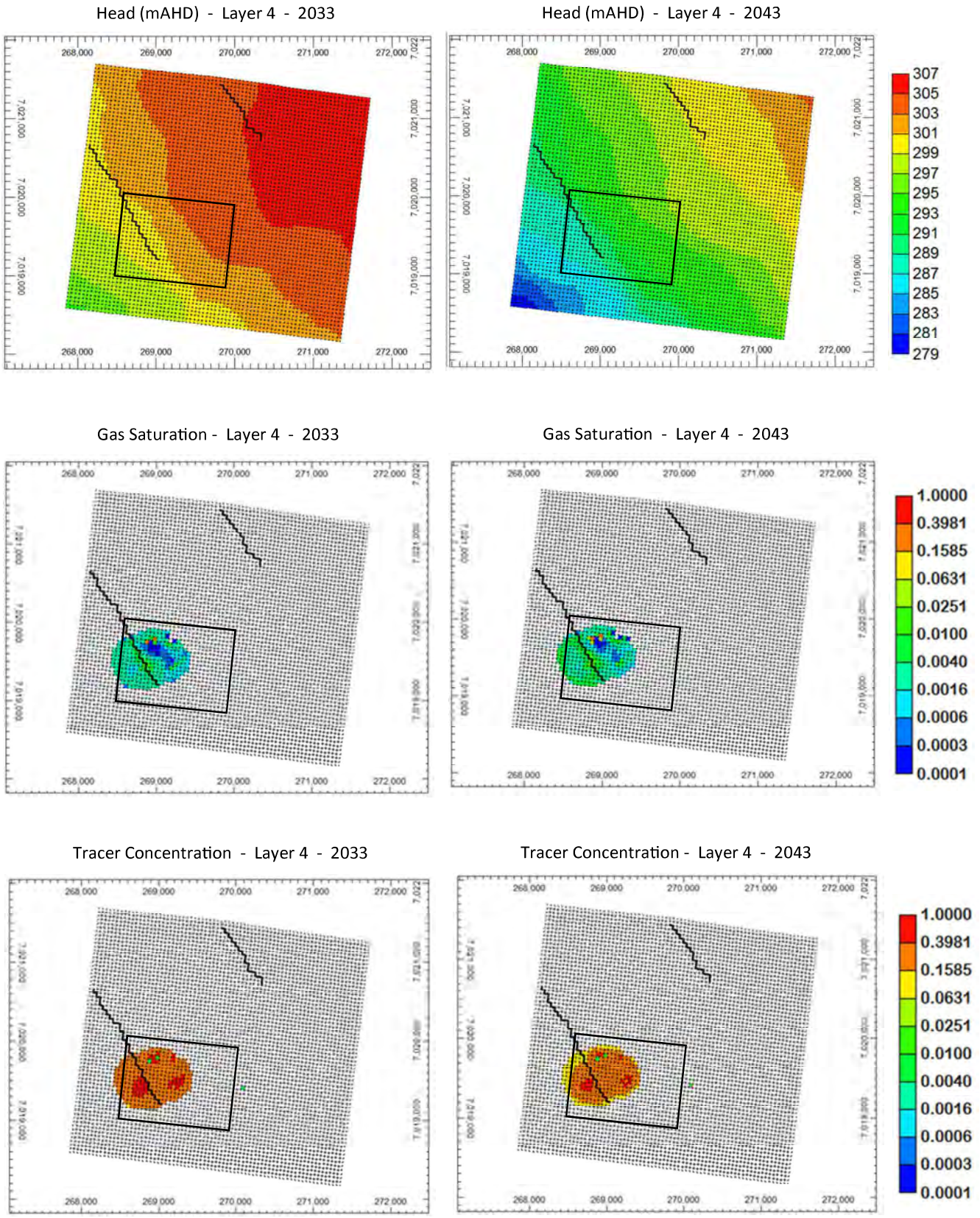


Figure 29. Water head, gas saturation, and tracer concentration of Macalister seam A in 2033 and 2043 for the case with increasing head gradient

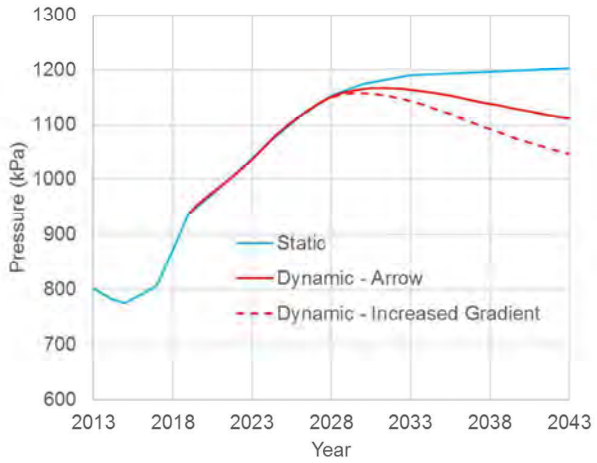
Time series of groundwater heads, gas saturation and tracer concentrations at grid cell 23,23,4, located in between the gasifiers are shown in Figure 30. They shows that the high hydraulic gradient almost doubles the drawdown at the Linc Site compared to AGE predictions. Gas saturation slightly increases while tracer concentration decreases, indicating gas desorption in this area after 2028. The gas saturation remains very low.

4.2.9 Scenario 10 – Macalister topology

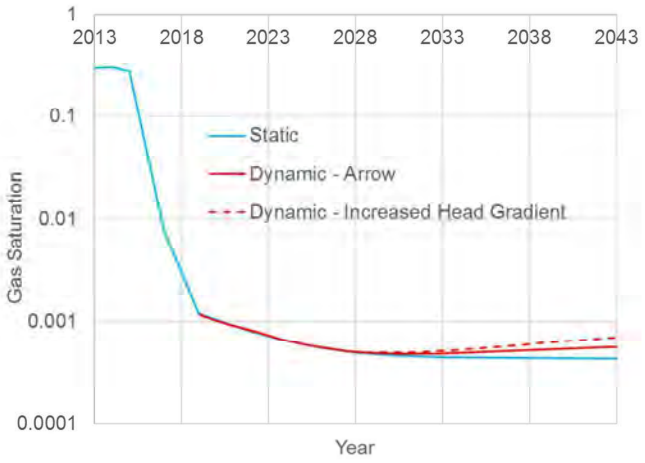
The 3D form and gradient (dip) of the top of the Macalister A Seam will control the degree that gas buoyance drives migration. The top Macalister horizon defined by Arrow from well completion reports and seismic has a steep slope around the faults, Figure 31 (top-left). This may represent a structural trap to gas movement and have limited predicted migration in Scenarios 1 to 9. This scenario considers a smoothed top to the Macalister A Seam, such that small high points where gas may become trapped, are removed. Two smoothed geometries are shown in Figure 31.

These two geometries are simulated using the increased pressure gradient applied in Scenario 9. Plots on the right hand side of Figure 31 show the predicted gas saturations in 2043. The results remain effectively identical to all others; Arrow's proposed development of PL253/493 is predicted to have negligible impact on horizontal gas movement at the Linc site.

(a) Pressure at Grid 23,23,4



(b) Gas saturation at Grid 23,23,4



(c) Tracer concentration at Grid 23,23,4

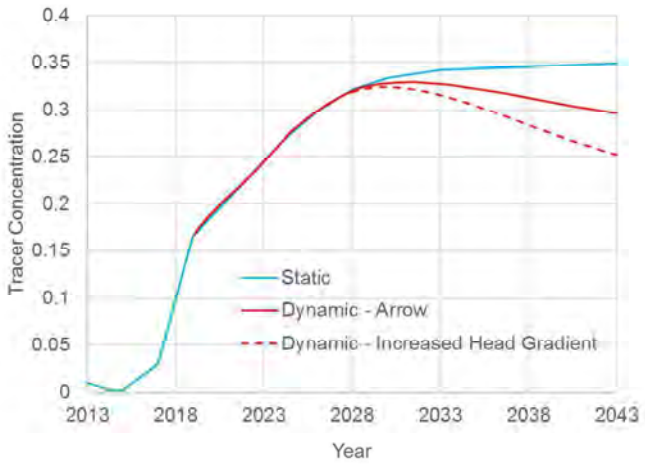
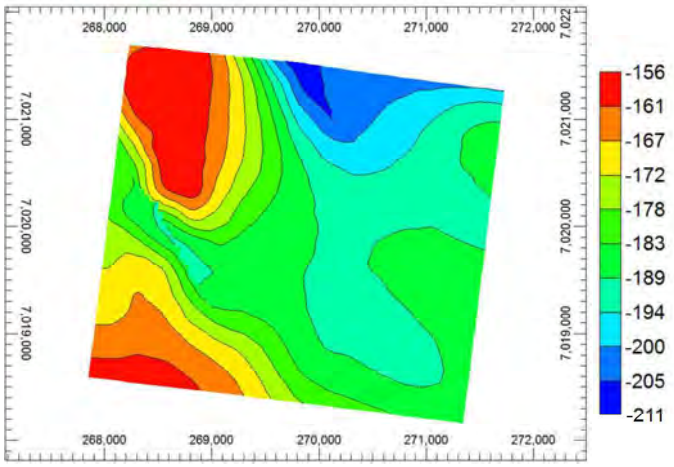


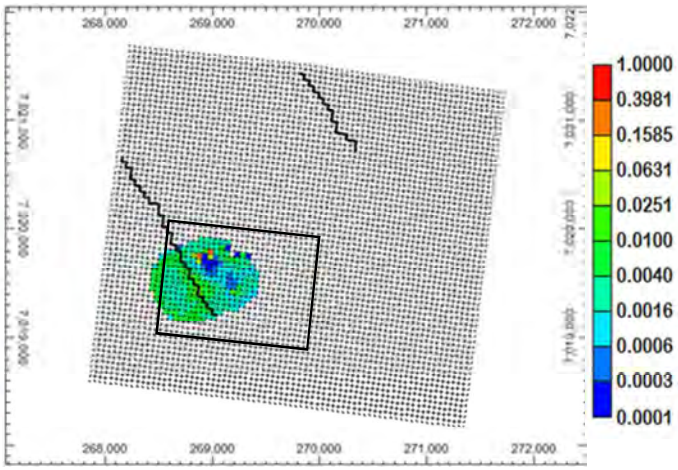
Figure 30. Pressure (a), gas saturation (b), and tracer concentration (c) at grid 23,23,4 for the base case and extreme case (synthetic dynamic boundary condition).

Increasing Head Gradient—Extreme Case

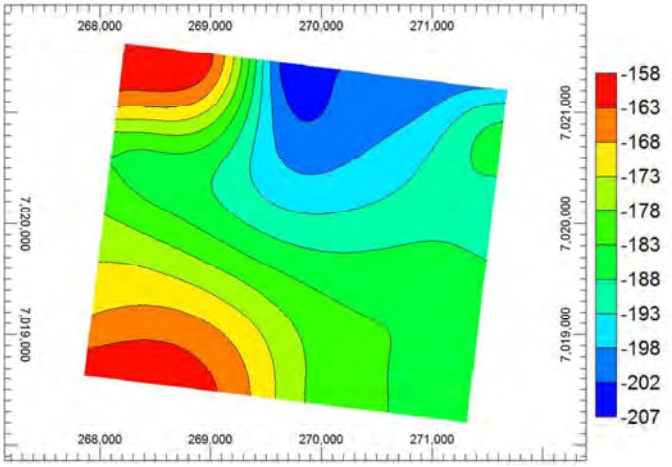
Topology - Layer 4 - Base Case



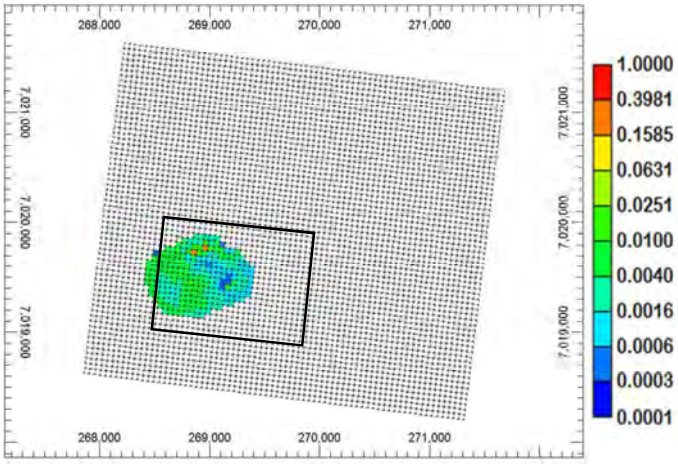
Gas Saturation - Layer 4 - 2043



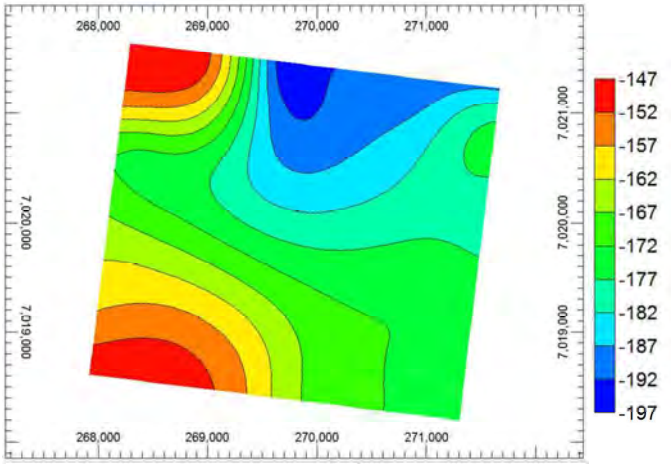
Topology - Layer 4 - Amended 1



Gas Saturation - Layer 4 - 2043



Topology - Layer 4 - Amended 2



Gas Saturation - Layer 4 - 2043

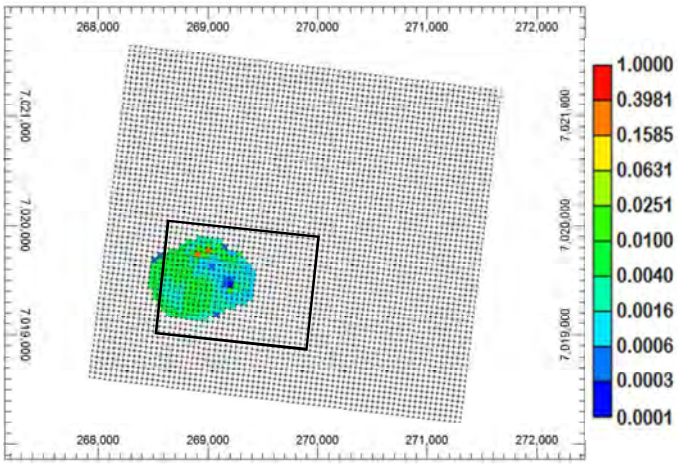


Figure 31. Topology and gas saturation in layer 4 (seam A)

5. Summary, Discussion and Conclusions

5.1 Summary

Multi-phase numerical simulations have been developed of the former Linc Energy site that include approximation of gasification activities to generate subsurface free gas and then simulate its evolution and movement to 2019 and then into development cases out to 2043 with and without Arrow development of PL253/493. For predictive/forward models, boundary conditions that replicate pressure heads simulated by larger scale groundwater modelling (AGE, 2020) were applied around the model perimeter and base. Two versions of these boundary conditions represent the difference between two main scenarios of current development with no further Arrow production in PL253/493, and with Arrow development. An inert tracer was added to the free gas phase in the model to allow "contaminant" gases remaining after gasification to be identified.

The sensitivity of multiple parameters that control gas movement was tested. This included models with enhanced permeability (horizontally, and vertically into the Springbok), transmissive or sealing faults, higher saturation (adsorbed gas content) of the coal, and models with an enhanced pressure gradient across the model.

Results from the Base Case and 9 further sensitivity scenarios suggest that Arrow's proposed development of PL253/493 unlikely to alter the behaviour of residual gases that remain around the former Linc Energy site. Groundwater movement is predicted to be inward toward the site for a further 5 to 15 years as pressures recover. After this time, groundwater movement is predicted to be influenced by Arrow development (AGE 2020). With low residual gas saturations at this time, there is likely to be little influence of gas on groundwater flow.

5.2 Discussion

Section 3.1 acknowledges that the historical information available to this project regarding the Linc site is not exhaustive. For example, ASX documentation indicates that substantial additional drilling was completed by Linc Energy and we believe that further monitoring information also exists for the site. We are also aware of media reports of UCG gases in soils that may indicate the presence of vertical pathways, and the conviction of Linc Energy in 2018. Detailed site information of geology, coal connectivity, gasifier sizes and operational history, groundwater pressures and levels and gas concentrations were not available for this study.

The scope of the sensitivity analysis was in part designed to address this, by considering different coal distributions and permeability fields. Scenarios also consider high gas saturation of coals, enhanced permeabilities and vertical connectivity and the influence of capillary pressure. Further scenarios included alternative static geological models with a smoothed Macalister A Seam top and much higher than predicted hydraulic gradients across the former Linc site due to the proposed Arrow development. Despite all these alternative scenarios, no substantial gas migration of gases present in 2013 from the site was predicted. The results of the base case and all sensitivity analyses suggest Arrow's development of PL253/493 is unlikely materially alter the locations and concentrations of UCG residual gases at the former Linc Energy site.

This result can be understood by considering the physical processes that occur around the site. Initially, the area around the gasifiers is depleted compared to the surrounding area with an inward pressure gradient mostly towards the gasifiers. Actual flow is at very low rates, due to a combination of the low intrinsic permeability of the rock, and the low relative permeability to water or gas. This behaviour is consistent with the site observations in 2019, which indicate the site remains depleted (pressures had not recovered in the six years since gasification operations ended). Buoyancy does cause some gas movement in the models; however, this is limited by the low permeability, or low relative permeability, around the site. Note that conceptually gasifiers would be 100% gas saturated at the end of gasification whilst coals in the far field, at sufficient distance from gasification, remain 100% water saturated. Between these end members, coal cleats

will be partially saturated with both gas and water, and the relative permeability to each fluid may act to impede flow.

The gradual flow of water inward towards the gasifiers leads to pressure increasing, and as this happens free gas will be compressed and within coal cleats will be adsorbed into the coal matrix becoming trapped. This is the opposite of the behaviour seen in Coal Seam Gas operations, where pressures are reduced (by dewatering) to cause desorption and release trapped gas. This adsorption leads to the apparent increase in tracer concentration in the simulations as methane adsorbs, and the non-adsorbing tracer remains in the free gas phase.

This means that, whether the Arrow development of PL253/493 is included in the models or not, the majority of residual gas in the models becomes trapped, either by adsorption, or due to small structures (traps) within the structure of the Macalister A seam. Simulation results indicate that free gas that is not trapped by these mechanisms is still unlikely to move (again due to low permeability, or low relative permeability), even if subjected to the increased pressure (or head) gradient predicted to occur due to Arrow's development.

The result of very minor future gas migration horizontally, with or without Arrow development, may appear counter intuitive when considered in the Surat Basin context of gassy groundwater bores, bubbles in rivers and recent coal exploration hole fluxes. But in the context of CSG development the results may be more in line with expectation. The major CSG projects typically have permitting for many thousands of production wells, with typical initial spacings of 750 m. Infill drilling frequently reduces this to 350 to 400 m to improve access to connected coals. To rapidly produce gas, wells are typically dewatered with bottom hole pressures 200 to 300 m lower than hydrostatic. Effective gas production requires gas migration to wells needing high pressure gradients, and close well spacing. The pressure gradients acting at the former Linc site, with or without further Arrow development, are insufficient to promote horizontal gas migration.

This work has concentrated on the horizontal pathway for gas migration from the Linc site, within the coal seams. The vertical pathway, upward into the Springbok, has been briefly explored in Scenario 6. We understand there are concerns that vertical permeability on site may have been enhanced by effective hydraulic fracturing of coals and over burden. If such enhance vertical permeability exists, it may enhance migration of gases vertically toward the surface. Gas movement via this vertical pathway will be driven through the saturated zone by buoyance, and will not be influenced by relatively minor pressure changes associated with Arrow's proposed development.

5.3 Conclusions

The aims of the project were to address the following questions and points:

1. "What is the fate of 'free gas' and water pressures at the former Linc UCG site on PL253 under two scenarios:
    a. Current development with no further Arrow production in PL253/493;
    b. Proposed development with Arrow production in PL253/493.
2. What is the uncertainty in the prediction of the fate of 'free gas' and water pressures in these scenarios.
3. Undertake a dual phase model that incorporates groundwater and gas movement that will demonstrate how gas movement may influence groundwater movement. Model gas movement, including up dip movement (Condamine bubbles), given that gas is more actively moving due to fracturing."

From the data available and modelling work reported here the following conclusions are drawn and answers provided:

- The work undertaken has shown a low likelihood that Arrow Energy's proposed future Field Development plan will alter the movement of residual gases present around the former Linc Energy site.

- The main fate of free gas is re-adsorption within coal seams. Groundwater pressures are predicted to continue to recover, taking a further 5 to 15 years to approach pre-production levels. (i.e. groundwater will flow towards the gasifiers for another 5 to 15 years).
- Uncertainty of the predictions has been assessed by sensitivity analysis that considers a range of values for uncertain parameters and boundary conditions. The sensitivity analysis results show low uncertainty for these scenarios, suggesting a degree of confidence in the main result of minimal additional gas migration. However, there may be other factors acting at site unaccounted for in this work that may still promote gas movement. One such mechanism is via enhanced permeability pathways, particularly vertically toward surface.
- Arrow development is predicted to cause some minor depressurisation across the site (AGE, 2020). Depending on coal properties and gas saturation, this could induce minor future desorption of methane gas and if this occurred, the movement of this gas would be expected to be limited by the relatively poor flow properties around the site.
- In summary, dual phase modelling of water and gas has been completed and no significant gas movement is predicted in the base case or in the sensitivity scenarios considered.

6. Assumptions

The modelling work presented makes the following assumptions:

- UCG operations are approximated as producing CSG wells in order to create subsurface gas rather than UCG processes, with the wells operational for a continuous 6 year period rather than over Linc's operational period of 1999 to 2013. The objective of the 6 year production period is to create a significant plume of subsurface gas for future predictions, and this approximation is not thought to affect the predictive ability of the models.
- All combustion, phase changes and thermal effects are ignored. The model assumes isothermal conditions and other than alterations to porosity in cells at gasifier locations, no other modifications are made to coal properties. As predictions consider a period more than 7 years post combustion, this approximation is considered reasonable.
- The gas migration modelling uses a static geological model from Arrow with inferred faults that is based on regional understanding and from the Arrow wells drilled around the site. Scenario 10 considers different static geometries.
- Changes in pressure due to future Arrow development are taken directly from AGE (2020) model predictions. Note that the sensitivity of predictions to pressure gradient changes across the site is explored.
- The modelling assumes that all gas on site is methane or the 1% concentration of inert tracer. Combustion gases including H_2, CO and CO_2 and injected gases (N_2 and O_2 in air) are ignored. With most combustion gases extracted via production wells, and desorption of methane due to pressure reductions, this is considered a reasonable approximation. It is supported by the soil vapour monitoring showing high methane concentrations on site.
- The model grid at 50 x 50 m is limited in resolution. It is not capable of resolving smaller scale changes in geology.
- The DES request (see Section 1.1) makes reference to gas actively moving due to fracturing. Information regarding the causes or results of fracturing at site were not available to this study. Scenario 6 considers enhanced vertical permeability into the Springbok Sandstone and showed some vertical migration of gas.

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