Appendix A – CSG Water Management Plan

Plan

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Appendix A - CSG Water Management Plan

Surat Gas Project

CSG Water Management Plan

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1. Introduction

1.1 Location and Project Description

This Coal Seam Gas Water Management Plan (CWMP) is for Arrow Energy Pty Ltd.'s (Arrow) Surat Gas Project (SGP). The project development area is located approximately 160 km west of Brisbane in Queensland's Surat Basin and extends from the township of Wandoan in the north towards Millmerran in the south, in an arc through Dalby (Figure 1-1). The towns of Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, and Miles are located in or adjacent to the project development area.

The SGP will be a phased development over the approximate 40 year life of the project. Within the Surat Basin Arrow operates existing domestic gas facilities referred to as the Dalby Expansion Project (DXP). The SGP will utilise existing DXP water assets (e.g. dams and water treatment plants), and will also provide water to existing QGC operated assets. Over the life of the project, new assets will be developed by drilling wells and constructing associated infrastructure to transport both gas and water.

The project development area comprises Petroleum leases (PLs) 194, 198, 230, 238, 252, 258, 260, 185, 253, 304, 305, 491, 492, 493, 494, 1039, 1040, 1041, 1042, 1043, 1044 and ATP 676.

1.2 Purpose

The purpose of this CWMP is to:

- Address the requirements of section 126 of the EP Act as required for a site specific EA application (in this instance a site specific amendment application) ;[1]
- Address Arrow's commitment under the Surat Gas Project Environmental Impact Statement (EIS) to produce a CWMP; and
- Describe how SGP's CSG water will be managed in a way that protects and maintains environmental values whilst balancing social and economic considerations.

This CWMP has been prepared in accordance with the following Queensland Government regulatory guidance documents:

- The *Environmental Protection Act 1994* (Qld) (EP Act) – specifically Section 126 (1) and 126 (2); and
- The Department of Environment and Heritage Protection *Coal Seam Gas Water Management Policy*[2] – specifically its prioritisation hierarchy for managing and using CSG water and for managing saline waste.

Figure 1-1 Surat Gas Project Development Area

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[1] Section 126 requirements for each project EA are provided as part of each site specific EA application.

[2] Queensland Department of Environment and Heritage Protection (2012*), Coal Seam Gas Water Management Policy*.

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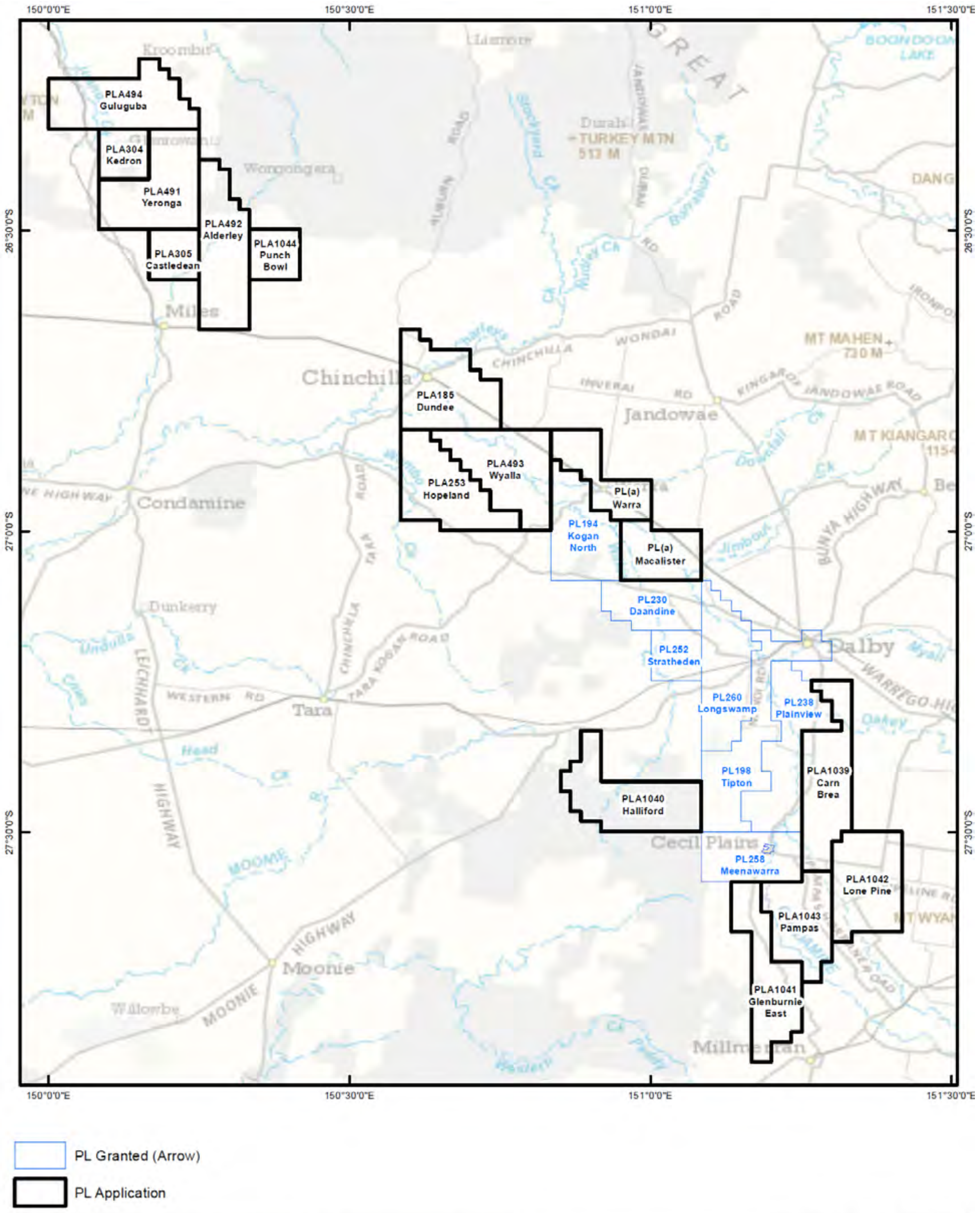

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Source:
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Coordinate System: GCS GDA 1994

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Surat Gas Project Tenures

Date: 9/04/2018

1.3 Scope

The scope of this CWMP includes:

- Characterisation of CSG water and the existing environment;
- Description of current and proposed CSG water management including the use, treatment, storage and beneficial use of water; and
- Description of procedures, controls and monitoring programs that minimise risk of CSG water management causing environmental harm.

The strategies for managing CSG water described in this CWMP align with Arrow Energy's broader vision for CSG water management in the Surat basin, as outlined in its Surat Gas Project CSG Water Management Strategy[3].

1.4 Conformance Table

Table 1-1 lists specific CWMP regulatory requirements specified under Section 126 of the EP Act, and identifies the relevant sections of the CWMP which address each specific requirement.

Table 1-1 EP Act Conformance Table

Requirement Under Section 126 of the EP Act	Relevant Section of CWMP
The quantity of CSG water the applicant reasonably expects will be generated in connection with carrying out each relevant activity.	Section 3.1
The flow rate at which the applicant reasonable expects CSG water will be generated.	Section 3.1
The quality of the water, including changes in the water quality that the applicant reasonably expects will happen while each relevant activity is carried out.	Section 3.2
The proposed management of CSG water including use, treatment, storage or disposal.	Section 4 and 5
The measurable criteria (the management criteria) against which the applicant will monitor and assess the effectiveness of water management including: • The quantity and quality of the water used, treated, stored or disposed of; • Protection of environmental values affected by each relevant activity; and the disposal of waste, including, for example, salt.	Section 6
The action proposed to be taken if any of the management criteria are not complied with, to ensure the criteria will be able to be satisfied in the future.	Section 6

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[3] Arrow Energy (2017), *Surat Gas Project CSG Water Management Strategy*, Rev: 0, Doc No: ORG-ARW-ENV-STR-00001.

1.5 Project Approvals

Table 1-2 lists the status of Arrow Energy's CSG water management approvals applicable to the scope of this CWMP.

Table 1-2 Arrow Energy's CSG Water Management Approvals in the Surat Basin

Responsible Department	Area of Regulation	Requirement of Regulation	Status
Department of Environment and Science	CSG activities including CSG water management	Environmental Authorities (EAs)	Approved - Dalby Expansion Project EA (EPPG00972513) for PLs194, 198, 230, 238, 252, 258 and 260.
			Approved - EA North for PLs 304, 305, 491, 492, 494, and 1044.
			Approved - EA South PLs 185, 253, 493, 1039, 1040, 1041, 1042, and 1043.
			Approved - EA Kogan – for PLs 1052 and 1053
			Approved - EA Hopeland for PL 253.
			Approved – EA Kenya Pipelines and Brine Dams PPL 2034
		CWMP	Finalised May 2018 to support EA applications and updated June 2020 to support the Hopeland EA amendment application

1.6 DES CSG Water Management Policy

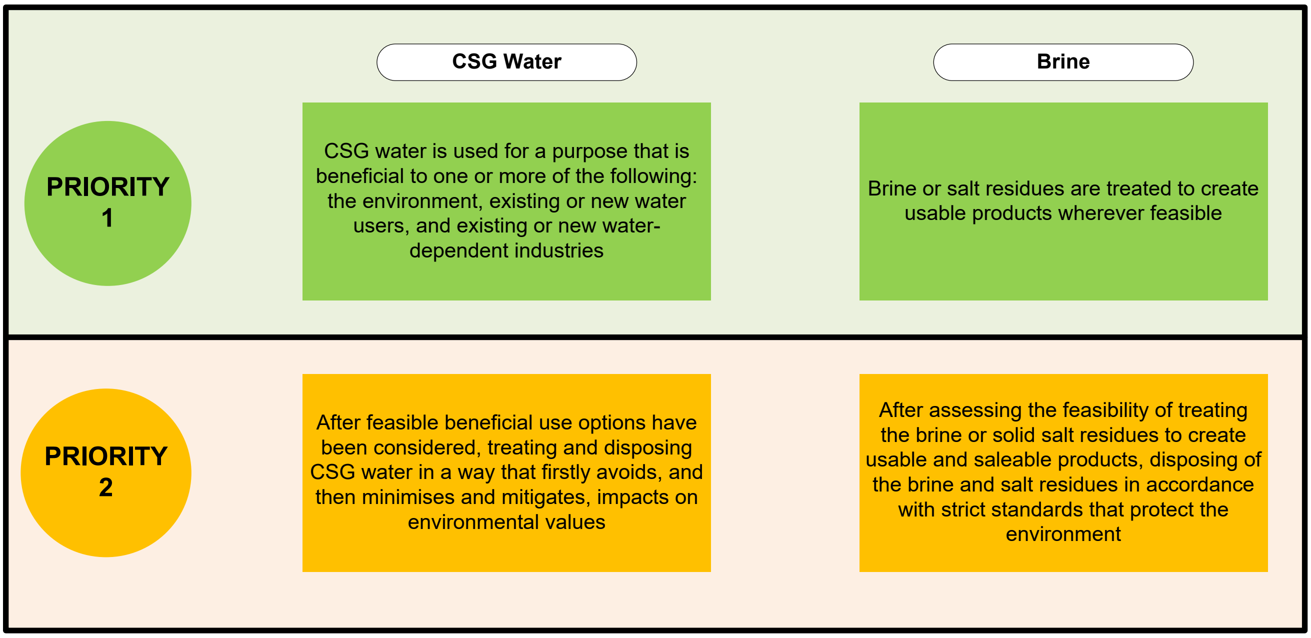
The *CSG Water Management Policy* (DEHP, 2012) outlines the Queensland Government's position on the management of CSG water and guides CSG operators to consider the feasibility of using such water to meet the obligations of the EP Act as part of developing their CSG water management strategies and plans.

The policy aims to encourage the beneficial use of CSG water in a way that protects the environment and that maximises its productive use as a valuable resource. To achieve this, the policy outlines prioritisation hierarchies for managing and using CSG water, and for managing saline waste.

The policy focuses on the management and use of CSG water under the EP Act, and does not change obligations the *Water Act 2000* (Water Act), including 'making good' any relevant impacts that may result from a CSG operation on water bores. Such measures executed under the Water Act may require the provision of water to mitigate impacts.

Arrow has adopted the DES prioritisation hierarchy as its starting point for determining the options for management of CSG water and brine. DES's prioritisation hierarchies for

CSG water and brine are presented in Figure 1-2. In accordance with the Policy, Arrow evaluates potential management options for water and brine against the prioritisation hierarchy, and implements Priority 1 options wherever feasible. Where Priority 1 options are not feasible, Priority 2 options are implemented. In determining the feasibility of options, factors that may be considered include technical and economic aspects in assessing identified options.



	CSG Water	Brine
PRIORITY 1	CSG water is used for a purpose that is beneficial to one or more of the following: the environment, existing or new water users, and existing or new water-dependent industries	Brine or salt residues are treated to create usable products wherever feasible
PRIORITY 2	After feasible beneficial use options have been considered, treating and disposing CSG water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values	After assessing the feasibility of treating the brine or solid salt residues to create usable and saleable products, disposing of the brine and salt residues in accordance with strict standards that protect the environment

Figure 1-2 **DES Prioritisation Hierarchies for CSG Water and Brine Management**

2. Existing Environment

2.1 Climate

The Darling Downs has a warm climate typical of subtropical regions with mean temperatures in the project development area ranging from a mean monthly minimum of 3.6 in winter months (June to August) to a mean monthly maximum of 35°C in summer months (December to February).

The majority of rain falls between November and February. The average annual rainfall varies across the region and ranges from an average of 20 to 40 mm a month in winter, to 70 to 100 mm a month in summer. Around 20 thunderstorm days per year occur in the region, often involving strong winds, heavy rainfall and flooding.

2.2 Surface Water

The regional surface water environment is represented by four drainage basins, all of which intersect the SGP development area: Condamine-Culgoa Basin (Condamine River and Balonne River), Fitzroy Basin (Dawson River), Border Rivers Basin (Weir and Macintyre rivers and Macintyre Brook), and Moonie Basin (Moonie River). The Condamine-Culgoa, Border Rivers, and Moonie basins form part of the Murray-Darling drainage division, while the Fitzroy Basin is part of the North-East Coast drainage division.

Basins can be divided into sub-basins, with six sub-basins in the project development area: Balonne River, Condamine River, Macintyre Brook, Macintyre and Weir rivers, Moonie River and Dawson River. The Condamine is the predominant sub-basin within the project development area, accounting for over 50% of the total area.

The location or origin of each drainage basin is as follows:

- The Condamine-Culgoa Basin forms the northern headwaters of the Murray-Darling river system;
- The Border Rivers Basin, comprising the Weir and Macintyre rivers, lies mostly within Queensland. Macintyre Brook is a major tributary of the Macintyre River, which eventually joins the Weir River near Talwood, Queensland;
- The Moonie Basin contains the Moonie River, a tributary of the Barwon River forming part of the Murray-Darling Basin; and
- The Fitzroy Basin is located in central eastern Queensland and contains the Dawson River sub-basin. The Fitzroy River is formed by the confluence of the Dawson and MacKenzie rivers and then flows into the Coral Sea north of Rockhampton.

The project area is characterised by an extensive network of watercourses that are largely ephemeral, with varying geomorphic stream types that provide geomorphic diversity and contribute to habitat diversity. Rivers and creeks are generally intermittent, with surface waters in many streams receding to disconnected pools and dry beds during the dry season.

Potential water uses within catchments that include the SGP are:

- Agricultural (crop production and stock watering)
- Pastoral;
- Urban;
- Power generation;
- Mining; and
- Recreation.

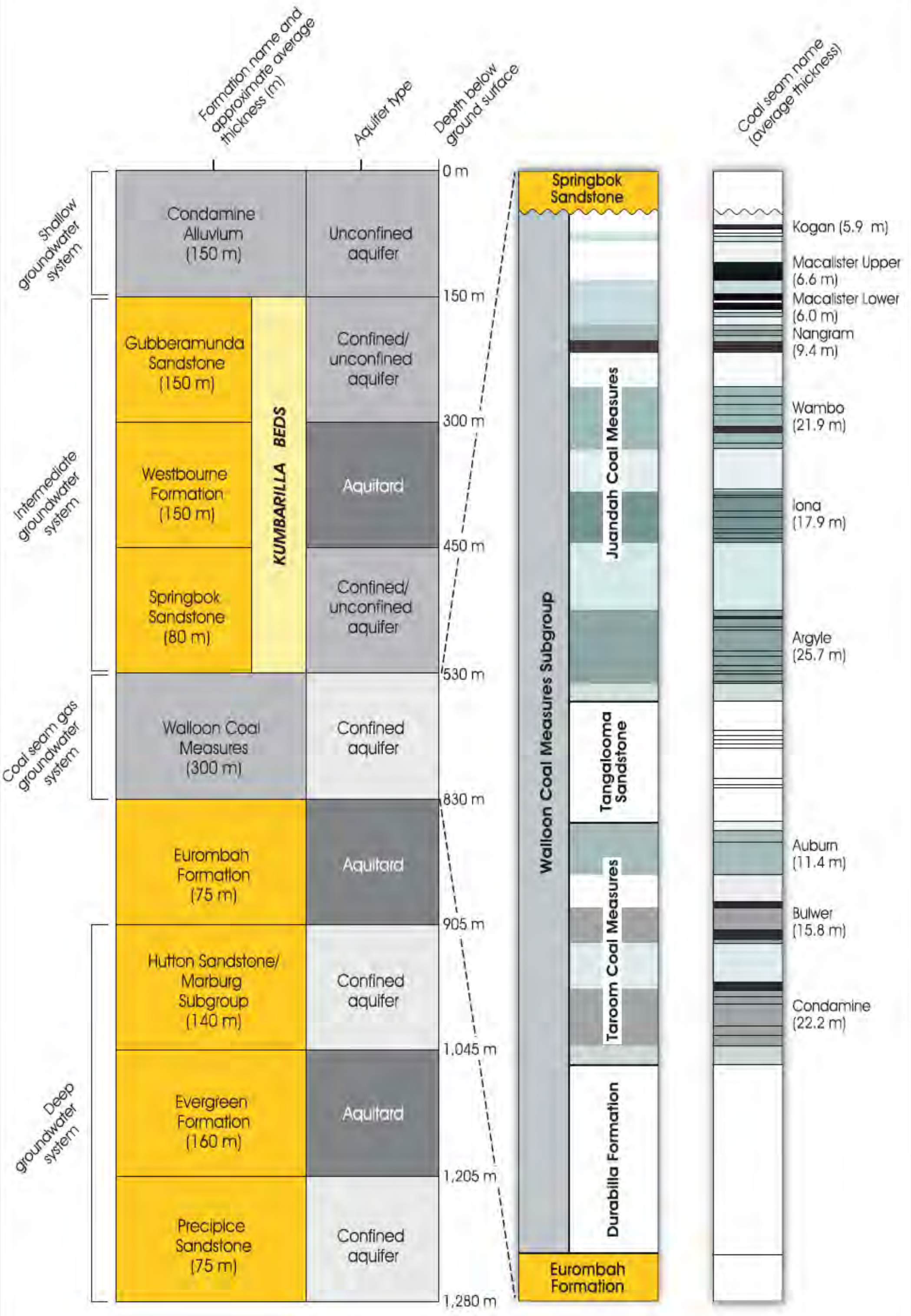
2.3 Groundwater

The geology of the Surat Basin is presented in Figure 2-1, and reflects approximately 200 million years of sedimentation producing a sedimentary sequence with up to a 2,500 m maximum depth. Geology underlying the project area consists of a sequence of interbedded aquifers and aquitards and is situated on the eastern section of the Great Artesian Basin (GAB) and the western margin of the Clarence-Moreton Basin.

The following groundwater systems have been identified in the vicinity of the project area (listed in order of increasing depth):

- Shallow groundwater system – Condamine Alluvium;
- Intermediate groundwater system – Gubberamunda Sandstone, Westbourne Formation and Springbok Sandstone;
- Coal seam gas groundwater system – Walloon Coal Measures; and
- Deep groundwater system – Hutton Sandstone, Evergreen Formation and Precipice Sandstone.

Figure 2-1 SGP Groundwater Geology



Source: Data form Arrow Energy
Scott et al (2004)

2.4 Terrain, Geology and Soils

2.4.1 Terrain

Topography of the SGP area is characterised by gently undulating land formed by fluvial deposition and erosion processes. Rock outcrops are present where resistance to erosion and channel scour has occurred. The underlying geology and geomorphic conditions have influenced the landscape and the area is characterised by the Great Dividing Range highlands, the Kumbarilla Ridge uplands and four drainage basins, the Condamine-Culgoa, Fitzroy, Border Rivers and Moonie.

2.4.2 Geology

Gas reserves within the SGP project area are primarily contained within the Walloon Coal Measures. The Walloon Coal Measures were formed during the Middle Jurassic period and are characterised by carbonaceous mudstone, siltstone, minor sandstone and coal. The geology of the Walloon Coal Measures is presented above in Figure 2-1 and comprises the following formations:

- Juandah Formation;
- Tangalooma Sandstone;
- Taroom Coal Measures; and
- Euromah Formation.

Only the Juandah Formation and Taroom Coal Measures are targeted for CSG production for the SGP.

2.4.3 Soils

Soil types across the SGP area have been classified under the Australian Soil Classification System and divided into seven broad types:

- Gilgai Clays - Occurring on flat to gently undulating terrain.
- Cracking Clays - Widespread across the Project area.
- Uniform Non-cracking Clays - Occurring on gently undulating plains and rises, and upper slopes of hills.
- Texture Contrast Soils - Sharp textural contrast between surface and subsoil horizons of low agricultural value.
- Uniform Loams and Clays - Loams found along upper slopes whereas clay occur on lower slopes.
- Sands and Sandy Loams - Consists of alluvial and residual sands found on plains.
- Skeletal, Rocky or Gravelly Soils - Occur adjacent to rocky outcrops.

2.4.4 Land Use

The SGP is located within the Darling Downs, which is an important agricultural area. The land use in the area is strongly related to the different soil types and topography. Soils within the project development area are dominated by heavy clays, which form rich agricultural soil around the Condamine River. These soils are characterised by self-mulching, cracking clays with a deep profile. At higher elevations, shallow, gravelly soils are present.

Soil erosion is evident in areas where brigalow woodland has been extensively cleared. Agricultural land use within the project development area ranges from concentrated agriculture on the Condamine River floodplain, where many paddocks have been laser-levelled to achieve effective flood irrigation, through to cattle grazing in more marginal areas located to the north and west. Limited agricultural activity exists in areas of higher elevation and within state forests.

Current agricultural activities in the greater Darling Downs region include:

- Dryland broadacre farming;
- Irrigated broadacre farming;
- Horticulture;
- Fruit;
- Vineyards;
- Livestock industries; and
- Timber production.

3. CSG Water Characteristics

This section presents forecast CSG water production data and expected water quality.

3.1 CSG Water Quantity

CSG is the name given to naturally occurring gas trapped in underground coal seams by water and ground pressure. The gas lines the open fractures between the coal (called cleats) and the inside of the pores within the coal (the matrix). Coal seams store both gas and water. When the water pressure is reduced, the gas is released. In the production process, the water pressure is reduced when a well is drilled into a coal seam and the water is gradually pumped out of the seam. This allows the gas to flow to the surface via the well. CSG water production volumes and qualities vary considerably with location, well-spacing and coal seam depth. Water production forecasts fluctuate over time as a product of progressively commissioning and decommissioning wells to meet Gas Sale Agreements. For these reasons, forecasts for the timing, volumes and quality of CSG water production are updated on a monthly basis. Production forecasting involves the following steps:

1. Developing key assumptions such as expansion areas, gas sales targets and gas usage for production activities;

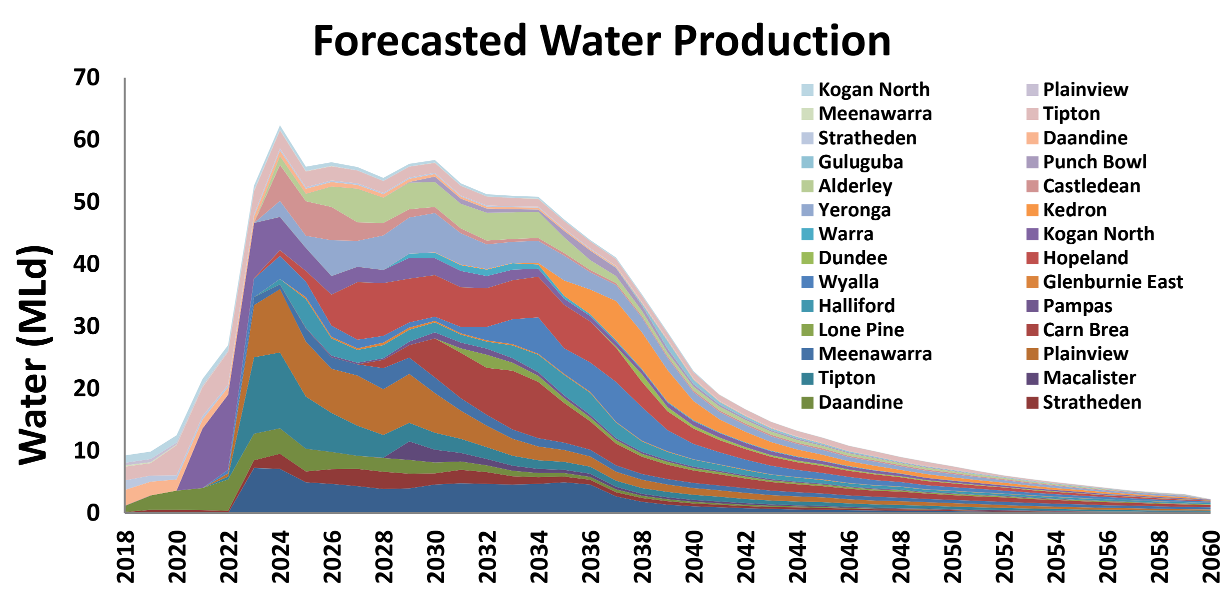
2. Simulating the required production rates using a reservoir engineering model;

3. Developing and maintaining well program based on forecast timing; and

4. Reviewing model performance against actual production data and history matching.

Figure 3-1 presents the CSG water production forecast for the SGP. The forecast indicates that approximately 400 GL of water will be produced over the life of the project. Water production starting in 2018 was the continuation of production in the existing DXP EA development areas, with production from new areas commencing in 2021. Water production peaks at a flow rate of approximately 62 ML/day achieved in 2024. Water production will diminish from the peak until project completion in approximately 2060.

Figure 3-1 SGP Forecasted Water Production



3.2 CSG Water Quality Characteristics

3.2.1 CSG Water at the Well

The SGP targets the Walloon Coal Measures. CSG water quality in these formations varies from slightly brackish to brackish. The water typically has the following characteristics:

- pH of approximately 8 to 9;
- Salinity in the range of 5,000 to 13,000 µS/cm (i.e. brackish);
- Suspended solids that will usually settle out over time;
- Trace metals and low levels of nutrients.

Table 3-1 presents a summary of expected water quality for wells across the SGP development area.

Table 3-1 SGP Expected Water Quality[4]

Parameter	LOR	Units	10%	Median	90%
Alkalinity					
Bicarbonate Alkalinity as CaCO3	1	mg/L	389.8	815.5	1387.0
Carbonate Alkalinity as CaCO3	1	mg/L	< 1	27.5	119.7
Hydroxide Alkalinity as CaCO3	1	mg/L	< 1	< 1	< 1
Total Alkalinity as CaCO3	1	mg/L	392.6	872	1440.0
Major Anions					
Bromide	0.02	mg/L	3.6	4.99	10.6
Chloride	1	mg/L	1040.0	1705	4231.0
Fluoride	0.1	mg/L	1.0	1.8	2.6
Silicon	0.05	mg/L	7.5	8.2	9.5
Sulfate as SO4 2-	1	mg/L	< 1	< 1	2.0
Sulfide as S2-	0.1	mg/L	< 0.1	< 0.1	< 0.1
Major Cations					
Calcium	1	mg/L	4.0	9	39.7
Magnesium	1	mg/L	2.0	3	13.0
Potassium	1	mg/L	5.0	7	13.0
Sodium	1	mg/L	1233.0	1630	2720.0
Major Ions					
Ionic Balance	0.01	meq/L	21.5	106.72	191.9
Total Anions	0.01	meq/L	85.9	171.1	256.3
Total Cations	0.01	meq/L	86.2	171.4	256.6
Metals (Dissolved)					
Aluminium	5	µg/L	< 5	< 5	12.8
Arsenic	0.2	µg/L	< 0.2	< 0.2	0.6
Barium	0.5	µg/L	603.4	1100	4212.0
Beryllium	0.1	µg/L	< 0.1	< 0.1	< 0.1
Boron	5	µg/L	235.6	340	590.0
Cadmium	0.05	µg/L	< 0.05	< 0.05	0.1
Chromium	0.2	µg/L	< 0.2	< 0.2	2.4
Cobalt	0.1	µg/L	< 0.1	< 0.1	< 0.1
Copper	0.5	µg/L	< 0.5	< 0.5	2.0
Ferric Iron	0.05	mg/L	< 0.05	< 0.05	0.2
Ferrous Iron	0.05	mg/L	< 0.05	< 0.05	0.5
Hexavalent Chromium	0.01	mg/L	< 0.01	< 0.01	< 0.01
Lead	0.1	µg/L	< 0.1	< 0.1	< 0.1
Manganese	0.5	µg/L	2.0	9	45.0
Mercury	0.0001	mg/L	< 0.0001	< 0.0001	< 0.0001
Molybdenum	0.1	µg/L	< 0.1	< 0.1	2.0

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[4] The information presented in this table is aggregated data from production sampling at Arrow's Dalby Expansion Project and exploration sampling across ATP tenures proposed for conversion to PLs as part of the SGP. A < value indicates observations below the limit of reporting.

Nickel	0.5	µg/L	< 0.5	< 0.5	1.0
Selenium	0.2	µg/L	< 0.2	< 0.2	0.2
Strontium	1	µg/L	1036.0	1920	9234.0
Trivalent Chromium	0.01	mg/L	< 0.01	< 0.01	< 0.01
Vanadium	0.2	µg/L	< 0.2	< 0.2	10.0
Zinc	1	µg/L	< 1	< 1	16.0
Metals (Total)					
Aluminium	5	µg/L	20.0	640	4244.0
Arsenic	0.2	µg/L	< 0.2	< 0.2	2.0
Barium	0.5	µg/L	717.2	1250	4510.0
Beryllium	0.1	µg/L	< 0.1	< 0.1	< 0.1
Boron	5	µg/L	250.0	360	580.0
Cadmium	0.05	µg/L	< 0.05	< 0.05	0.2
Chromium	0.2	µg/L	< 0.2	2	9.4
Cobalt	0.1	µg/L	< 0.1	< 0.1	3.0
Copper	0.5	µg/L	0.5	3	18.0
Lead	0.1	µg/L	< 0.1	1.4	8.0
Manganese	0.5	µg/L	8.0	31	118.4
Mercury	0.0001	mg/L	< 0.0001	< 0.0001	< 0.0001
Molybdenum	0.1	µg/L	< 0.1	< 0.1	0.4
Nickel	0.5	µg/L	< 0.5	1	6.0
Selenium	0.2	µg/L	< 0.2	< 0.2	0.2
Strontium	1	µg/L	1136.0	2110	9496.0
Vanadium	0.2	µg/L	< 0.2	< 0.2	1.4
Zinc	1	µg/L	< 1	13	65.4
Nutrients					
Ammonia as N	0.01	mg/L	0.8	1.13	1.7
Nitrate as N	0.01	mg/L	< 0.01	0.01	0.1
Nitrite + Nitrate as N	0.01	mg/L	< 0.01	0.01	0.1
Nitrite as N	0.01	mg/L	< 0.01	< 0.01	< 0.01
Reactive Phosphorus as P	0.01	mg/L	< 0.01	0.01	0.0
Total Kjeldahl Nitrogen as N	0.1	mg/L	0.9	1.3	1.8
Total Nitrogen as N	0.1	mg/L	0.9	1.3	1.8
Total Phosphorus as P	0.01	mg/L	0.0	0.06	0.2
Organic Carbon					
Dissolved Organic Carbon	1	mg/L	< 1	6	14.1
Total Organic Carbon	1	mg/L	< 1	13	35.1
Physico-Chemical					
Electrical Conductivity @ 25°C	1	µS/cm	5640.0	7070	13060.0
pH Value	0.01	pH Unit	8.1	8.385	8.6
Suspended Solids (SS)	5	mg/L	11.9	100.5	520.5
Total Dissolved Solids @180°C	5	mg/L	3190.0	4215	7546.0
Turbidity	0.1	NTU	6.1	50	401.8
Silica					

Reactive Silica	0.1	mg/L	14.1	15.9	19.2
Silica	0.1	mg/L	15.7	17.4	20.4

3.3 Arrow Energy CSG Water and Salt Management Strategy

Arrow is committed to managing CSG water in a way that maximises beneficial use and that minimises environmental impact. To demonstrate this, Arrow has developed a Surat Gas Project Water Management Strategy[5] to ensure that the SGP manages water and salt consistently and within the Queensland Government regulatory framework. The strategy is supported by a series of plans and procedural documents to ensure that the following objectives are achieved:

- Communicate corporate policy and principles for the management of CSG water and salt;
- Align with the regulatory framework that applies to the:
    - Gathering, treatment, storage, distribution, beneficial use and disposal of CSG water and salt;
    - Monitoring and management of groundwater and predicted impacts to groundwater level changes in quality;
- Facilitate management of CSG water and salt in a way that maximises beneficial use and minimises the potential for environmental impacts; and
- Establish a framework for development of aquifer, surface water and infrastructure groundwater monitoring programs.

3.3.1 Water and Salt Management Options

Arrow CSG Water and Salt Management Strategy aligns with the DES CSG Water Management Policy as defined in Section 1.6.

To ensure that the most sustainable CSG water management portfolio is implemented, Arrow evaluates all strategy management options using a systematic and transparent multi-criteria assessment (MCA) process (refer Figure 3-2). The performance of each identified option is assessed against a set of weighted criteria and options selected as either “preferred”, “reserved” or “not preferred” based on the weighted score derived from the MCA[6].

Preferred options are prioritised for investment whilst reserved options continue to be evaluated through targeted feasibility studies. Non-preferred options are put on hold. To ensure that Arrow’s approach to CSG water utilisation remains reflective of the latest information, MCAs may be updated on a periodic basis.

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[5] Arrow Energy (2017), *Surat Gas Project CSG Water Management Strategy*, Rev: 0, Doc No: ORG-ARW-ENV-STR-00001.

[6] Safety is a core value of Arrow Energy and all activities and processes require safety to be at the forefront of assessment. Therefore, safety is not incorporated into the MCA.

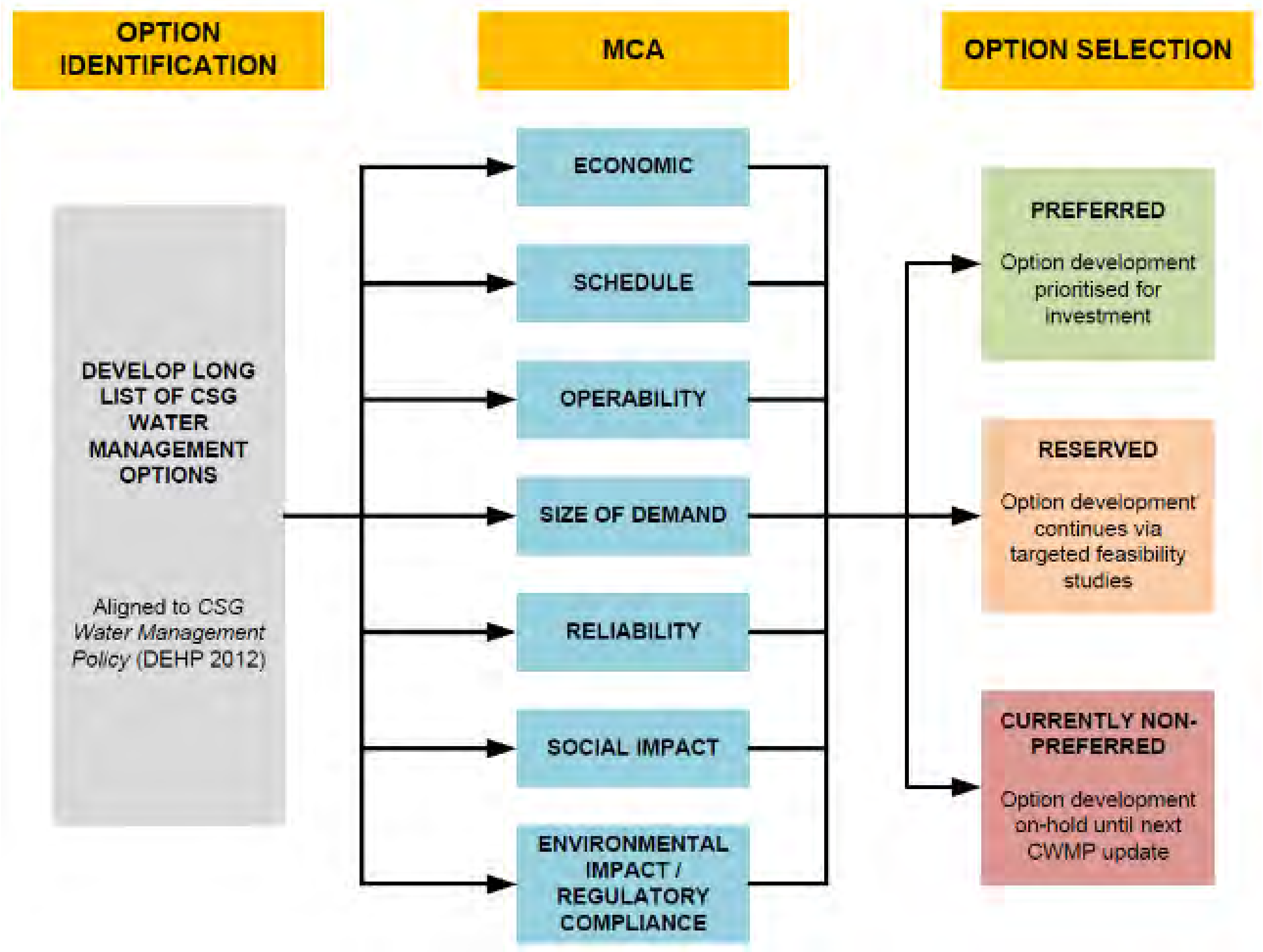


Figure 3-2 Option Selection and MCA Framework

3.4 Water management options

This section presents the water management options considered for the SGP. Saline waste management is discussed in Section 3.5.

Implementation of the preferred CSG water management options will result in the distribution of CSG water to a range of beneficial uses. Currently identified options are described below.

3.4.1 Agricultural uses

Irrigation is the predominant water use within the SGP development area. Options exist to provide water to existing irrigators, to replace other water sources used for irrigation (including through substitution of their existing groundwater allocations), or to supply water to new irrigation projects.

Key considerations for providing CSG water to end users for irrigation include:

- The ability of end users to take large volumes of water regularly and reliably;
- The location of end users in relation to the water treatment facility (due to the cost of transporting water over large distances);
- The approvals framework;

- The extent to which the user is going to become reliant on water supplied by Arrow; and
- The appropriateness of the supply given the short term nature of CSG water availability.

The water and implications of its use will be the responsibility of the end users. Arrow retains no control over how the water is used beyond the transfer point.

Where practical, Arrow's preferred management option for CSG water is beneficial use through substitution of existing groundwater allocations in the operating area. Substitution of allocations has the advantage that it constitutes both a beneficial means of managing produced CSG water, and a means of offsetting the potential impacts of Arrow's CSG production to bore owners with groundwater allocations.

Currently, there is no regulatory basis to facilitate substitution. Therefore, Arrow would develop a commercial scheme to support the supply of treated CSG water to groundwater users who hold allocations. Under this scheme end users would receive and utilise water supplied by Arrow in lieu of their groundwater allocations.

Arrow has committed to offsetting its component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown, as a result of CSG water extraction from the Walloon Coal Measures. This can be achieved through a beneficial use network that will distribute water to groundwater users within specified areas of the Condamine Alluvium to mitigate the modelled likely flux impact by substitution of their allocations. These users, or other existing users, could be offered excess water in addition to the substitution requirements to manage peaks in the water production profile.

3.4.2 Other agricultural uses

Other potential agricultural beneficial uses include provision of water for livestock watering purposes (including feedlots) or for aquaculture.

3.4.3 Discharge

Discharge of treated CSG water to watercourses is a reserved option in the event that other beneficial uses of CSG water are temporarily unavailable.

3.4.4 Urban uses

Urban supply remains a potential CSG water end use, but is subject to further negotiation and a suitable supply arrangement that economically satisfies regulatory requirements.

3.4.5 New uses

Over the course of the SGP, water demands across areas in which Arrow operates will vary and it is anticipated that new opportunities for use of treated and untreated water may emerge.

Whilst Arrow may choose to evaluate any such opportunities in accordance with the adopted selection methodology (refer Section 3.3.1), supply to new users is not a preferred water management option. This is because the CSG water supply will only be available for a reasonably short period of time, and the development of new water reliant uses may result in potential legacy issues when CSG water is no longer available.

3.4.6 Aquifer injection

Aquifer injection, either for re-pressurisation or as a means for CSG water management, is not currently proposed for the SGP due to the potential risks and the lack of an appropriate regulatory system.

3.4.7 Ocean outfall

Disposal of CSG water to the sea via an ocean outfall pipeline is recognised as a technically feasible option, but currently non-preferred due to environmental and community concerns, and potential schedule impact.

3.4.8 Alignment of Arrow and DES priorities

A summary of the CSG water management options is presented in Table 3-2 which aligns Arrows preferred and non-preferred options with the DES prioritisation hierarchy.

Table 3-2 CSG water management – alignment of Arrow and DES priorities

Arrow priority	Option	Comments	DES Priority
Preferred	Arrow operational supply	Dust suppression, construction, potable, etc.	Priority 1
	Substitution of allocations	Beneficial use to existing abstractors (virtual injection)	Priority 1
	Industrial supply to existing users	Non-Arrow use, where established	Priority 1
Reserved	Discharge to watercourse	Subject to Environmental Authority conditions	Priority 2
	Urban water supply	Subject to negotiation and approvals	Priority 1
Non-preferred	MAR	Managed aquifer recharge	Priority 1
	Industrial supply to new users	Non-Arrow use, where established	Priority 1
	Ocean outfall	Non-preferred due to environmental and community concerns, and potential schedule impact	Priority 2
	Deep aquifer injection	Currently no identified target aquifer	Priority 2

3.5 Brine and salt management options

Water treatment processes that include desalination, such as reverse osmosis, produce a brine stream by-product.

Assuming an average salt concentration of 4,500 mg/L for CSG water in the Surat Basin, treatment of CSG water via reverse osmosis (to ~500 mg/L TDS) will generate in the order of 4 tonnes of salt per megalitre of treated water. Raw water feed concentrations vary across tenements and may also change over time within a given CSG field. Brine stream concentrations will therefore change accordingly.

Specific measures are required to manage the storage and use (or disposal) of brine. A range of brine management options are identified, and described in the following sections.

3.5.1 Salt recovery

The concentrated brine by-product of desalinated water from the Surat Basin coal measures is comprised primarily of sodium chloride, sodium carbonate and sodium bicarbonate salts. A range of options for salt recovery are under consideration for the SGP.

i. Non-selective salt recovery and landfill

Non-selective recovery can be undertaken in purpose designed, lined solar evaporation ponds, through other thermal processes, or using mechanical crystallisers. The mixed salt product recovered has little or no commercial value, therefore landfill of the solid product is required, either in third-party landfills, or through encapsulation of the solid salts in purpose designed cells.

ii. Selective salt recovery

SSR requires the selective crystallisation of salts from RO brine to provide separate end product streams – typically sodium chloride, sodium carbonate and sodium bicarbonate, enabling commercial opportunity for sale of the product. A waste salt by-product is also produced that is dependent on the chemical characteristics of the brine processed at the salt recovery facility.

SSR is currently a reserved option because work to date has demonstrated that the recovered salt product has only modest value and the market is fully supplied by existing low cost producers. Furthermore, the process is energy intensive and substantial transport distances to market would present issues of safety and cost. The combined energy and transport requirements would also result in high emissions intensity for the final product.

3.5.2 Brine injection

Brine injection requires identification of a target formation with permeability and parameters sufficient to enable injection and storage, and where the water quality is such that injection of the brine will not impact the environmental values of the groundwater system.

To date, suitable aquifers have not been identified within Arrow's Surat tenements, and brine injection is a non-preferred management option.

3.5.3 Ocean outfall

As for water, disposal of brine to the sea via an ocean outfall pipeline is recognised as a technically feasible option, but is currently non-preferred.

3.5.4 Alignment of Arrow and DES Priorities

A summary of the brine and salt management options is presented in Table 3-3 which aligns Arrows preferred and non-preferred options with the DES prioritisation hierarchy.

Table 3-3 Saline waste management – alignment of Arrow and DES priorities

Arrow priority	Option	Comments	DEHP Priority
Preferred	Non-selective salt recovery and landfill encapsulation	Solid product landfill in purpose designed regulated waste facilities	Priority 2
Reserved	Selective salt recovery	Currently uneconomic, unable to demonstrate a commercial market, has high emissions intensity and greater safety risk.	Priority 1
Non-preferred	Brine injection	Currently no identified target aquifer	Priority 2
	Ocean outfall	Non-preferred due to community concerns, and potential schedule impact	Priority 2

4. SGP Coal Seam Water Management Network

4.1 SGP Water Management

As stated in Section 1, the SGP will utilise existing DXP gas and water assets (e.g. water treatment plants), but will also provide both gas and water to existing QGC assets. SGP water management will comprise six main process components:

1. CSG production wells and associated water gathering system;
2. Water transfer pipeline(s);
3. Aggregation dam(s);
4. Water Treatment Plants (WTP);
5. Treated water dam(s) and associated beneficial use offtakes; and
6. Brine dam(s).

Figure 4-1 provides a conceptual diagram of this process. Figure 4-2 provides an overview of the proposed SGP water management network.

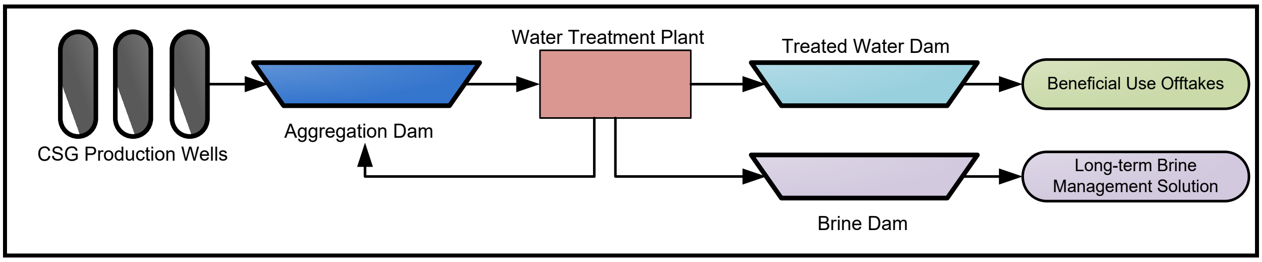
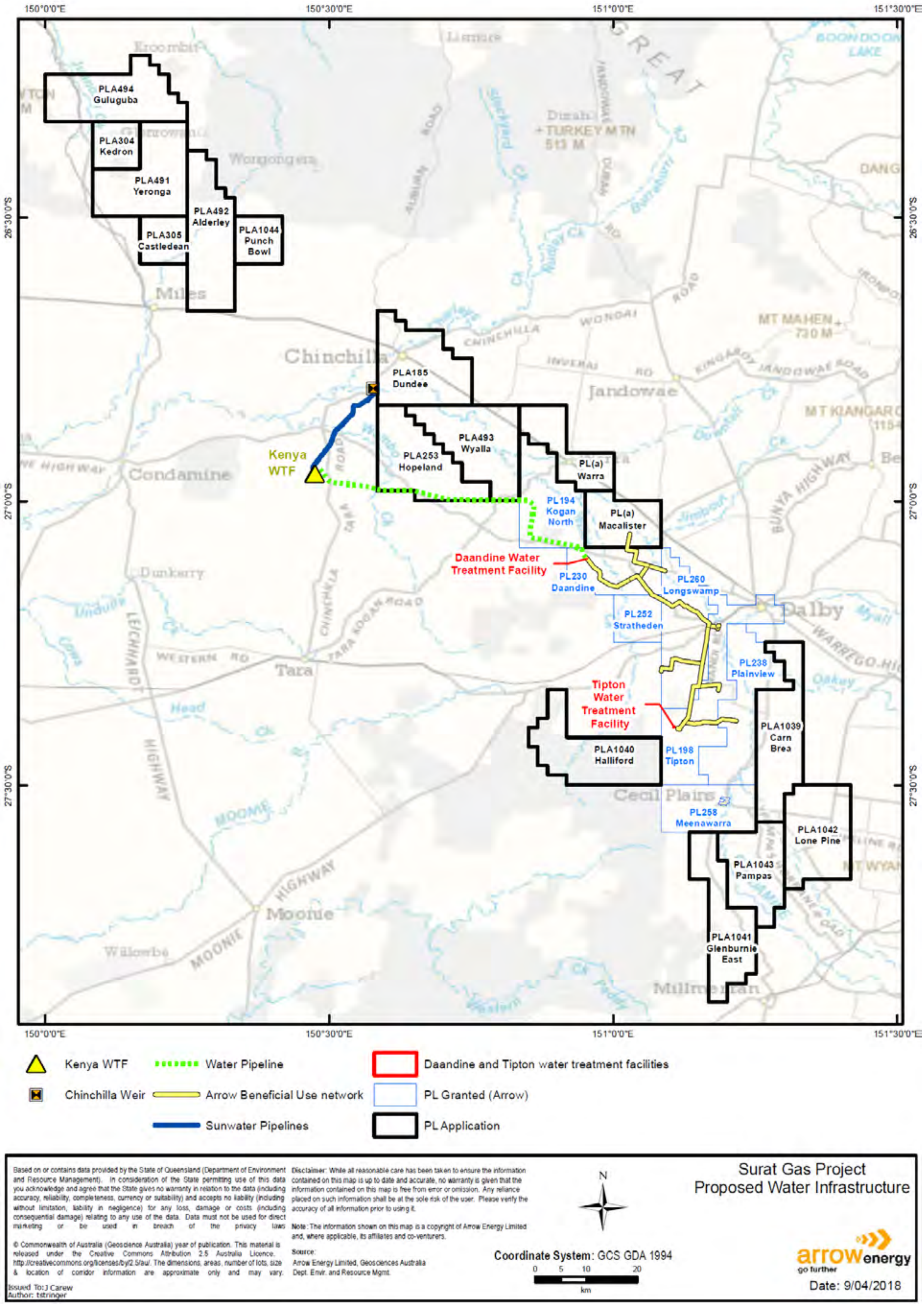


Figure 4-1 Conceptual Diagram of CSG Water Management



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Issued To: J Carew
Author: tstringer

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Source:
Arrow Energy Limited, Geosciences Australia
Dept. Envir. and Resource Mgmt.

Figure 4-2 Proposed SGP CSG Water Management Network

4.1.1 Gathering System and Storage

CSG water is gathered via a network of buried HDPE low pressure pipes to a series of aggregation dams. Arrow Energy defines its dams as follows:

- **Aggregation Dams** – contain CSG water from gathering network. Aggregation dams provide a buffer to address variations in CSG water production and water treatment capacity.
- **Treated Water Dams** – contain treated CSG water. Treated water dams provide a buffer between treatment plant output and beneficial use demand.
- **Central Gas Processing Facility (CGPF) and WTP Utility Dams** – contain waste lubricants and chemicals used in treatment and compression systems.
- **Brine Dams** – contain brine produced from the reverse osmosis water treatment process.

DES requires that consequence categories of dams are assessed. The DEHP 2013 *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures*[7] provides guidance on the assessment process. Arrow has implemented the assessment procedure outlined in the manual.

4.1.2 CSG Water Treatment

Arrow Energy currently treats CSG water through a process of MF and RO. QGC uses similar technologies at its Kenya water treatment facility. MF is a microporous membrane separation process with selectivity on the basis of the size of the particle. Most MF membranes are screen filters with the feed inlet pressure serving as the driving force for filtration. The membranes allow the removal of turbidity, bacteria, cysts and particulates from the water to sizes of 0.1 to 3 µm. Following MF, water is treated using RO to remove dissolved salts. RO is significantly more complex than MF and involves the separation of salts from solution through a semi–permeable, microporous membrane under elevated hydrostatic pressure creating a permeate stream of treated CSG water and a brine waste stream containing concentrated salts.

4.1.3 Brine Management

Water treatment processes that include desalination, such as reverse osmosis, produce a brine stream by-product. The resulting brine will be stored in purpose built brine storage dams until such time as Arrow selects a brine management solution. A range of brine management options have been identified and are described above in Section 3.4.

Both Arrow and QGC WTPs include (or have planned) technologies to minimise the brine stream and thereby reduce the number of required brine storage dams. The Kenya facility already has thermal brine concentrators to produce a highly concentrated brine stream whilst the Arrow facilities plan to utilise membrane concentration technology to further concentrate the brine stream.

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[7] Queensland Department of Environment and Heritage Protection, *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures,* DEHP, Queensland, Australia (ESR/2016/1934).

4.1.4 Beneficial Use

As detailed above in section 3.4, the preferred DES CSG water management strategy is beneficial use. Across the SGP, the most substantial beneficial use option is irrigation. Other major beneficial use options include supply to industrial users (power stations or coal mines) and intensive livestock (feedlots, piggeries). Selection of beneficial use options requires careful consideration of the predicted water volumes, stakeholder requirements and Arrow's approval obligations.

Arrow's preferred management option for CSG water is beneficial use through substitution of existing Condamine Alluvium groundwater allocations. Under this scheme end users would receive and utilise water supplied by Arrow in lieu of their groundwater allocations. Arrow has committed to offsetting its component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of CSG water extraction from the Walloon Coal Measures and is conditioned to do so under its Federal environmental approval.

A beneficial use network (BUN) will be constructed to distribute treated water to groundwater users within specified areas of the Condamine Alluvium. Users connected to the network will receive water from the Tipton and Daandine facilities as well as a proportion of Arrow's water treated at the QGC Kenya facility. Water from the Kenya facility will be provided back to the Arrow BUN via pipeline. The proposed BUN and associated water pipelines are presented above in Figure 4-2. Any remaining treated water from Kenya will be supplied to the existing SunWater beneficial use scheme which connects Kenya to the Chinchilla weir.

It is expected that treated water distributed by Arrow will be supplied under conditions in the relevant EA or by using the relevant End of Waste Code. Treated water specifications from all of the water treatment facilities will meet the requirements of these approvals.

A small portion of produced water may selectively be used by Arrow for construction purposes or dust suppression, or may be supplied for industrial uses (e.g. coal mines or power stations) or stock watering.

4.2 Arrow Daandine Water Management Network

As discussed in section 4.1, the SGP will integrate with Arrow's existing facilities at both Daandine and Tipton. The Daandine water management network connects Daandine, Kogan North and Stratheden fields to a WTP at Daandine. Figure 4-3 schematically illustrates Daandine water management network infrastructure.

4.2.1 Dams

The Daandine water management network includes six (6) dams. Five dams are located within the Daandine field, and a sixth dam is located at Kogan North. The Kogan North dam enables aggregation and transfer of CSG water to the Daandine WTP for treatment. Table 4-1 lists dam storage characteristics.

Table 4-1 Daandine Water Management Network Storages

Dam Description	Volume at Mandatory Reporting Level (ML)	Volume at Spillway (ML)	Volume at Design Storage Allowance (ML)
Daandine Aggregation Dam	1,239	1,458	1,166
Daandine Feed Water	418	458	392
Daandine Treated Water	208	238	199
Daandine Brine	1,096	1,184	1,045
Daandine Utility	31	48	26
Kogan North	299	427	261

Note: DSA and MRL volumes have been updated to reflect the 2017 Annual Dam Inspections (AECOM, 2017).

4.2.2 Water Treatment Plant

In December 2009, Arrow Energy constructed and commissioned a 12 ML/d water treatment plant (WTP) at Daandine, to facilitate beneficial use and align Arrow's operation with the *CSG Water Management Policy* (DEHP, 2012).

For a description of the water treatment process refer to section 4.1.2. For characterisation of treated CSG water quality refer to section 3.

4.2.3 Beneficial Use

A number of beneficial use offtakes have been developed as part of the Daandine water management network. Table 4-2 identifies currently operating offtakes and peak daily usage. Additional offtakes will be added when the SGP enters the development phase. These offtakes will form part of the proposed Arrow BUN.

Table 4-2 Current Daandine Third Party Water Off-takes

Beneficial Use Offtake	Peak daily usage (ML/day)	DEHP Hierarchy Priority
Irrigation	8*	Priority 1
Power Station	1.5	Priority 1
Power Station	1	Priority 1
Arrow Projects (construction and operational uses)	1	Priority 1
Feedlot	1	Priority 1

Note: Irrigation offtake rate has no minimum or maximum under the existing agreement. Supply rates are limited to pumping and pipeline infrastructure at 8ML/day.

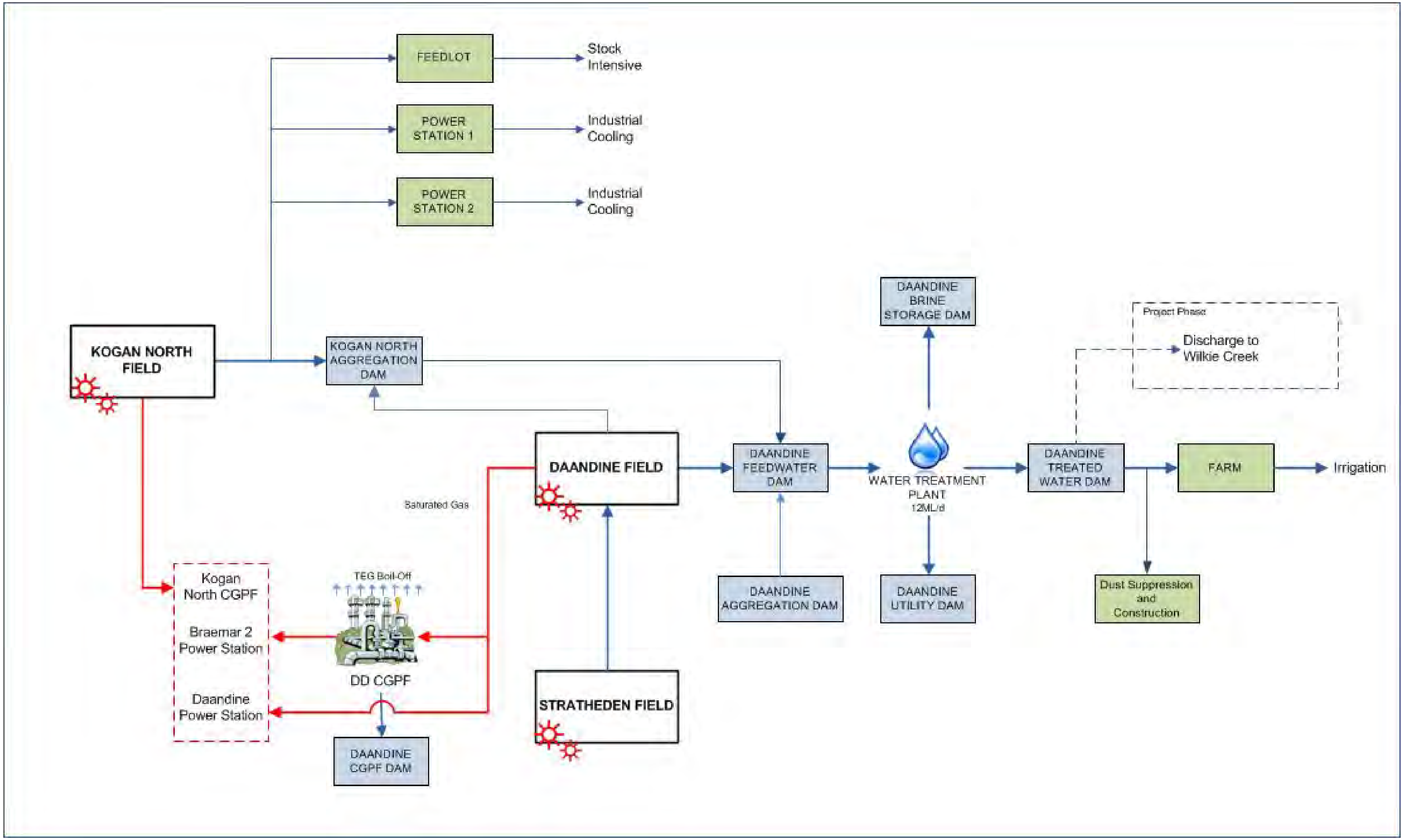

Figure 4-3 Schematic diagram of the Daandine Water Management Network

4.2.4 Brine Management

Brine at Daandine is currently stored in a dam compliant with the DEHP 2013 *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures*[8] and the DXP EA conditions. Arrow is currently pursuing brine management options in line with its Surat CSG Water and Salt Management Strategy (refer Section 3.5). A long term brine management solution has not been selected at this stage.

4.2.5 Contingency Discharge

Arrow is currently licensed under the DXP EA to release treated CSG water to Wilkie Creek. Arrow is committed to maximising beneficial use of its CSG water prior to disposal methods and thus discharge to Wilkie Creek is held as a contingency measure to adapt to seasonal fluctuation in irrigation demand or to preserve dam integrity during excessive rainfall. The infrastructure required to facilitate discharge to Wilkie Creek has not yet been constructed.

4.3 Arrow Tipton Water Management Network

Figure 4-4 illustrates the existing Tipton water management network.

4.3.1 Dams

Refer to Section 4.1.1 for a description of the gathering network and conditions pertaining to dams. Arrow operates six (6) dams at Tipton. Table 4-3 provides dam storage characteristics for Tipton.

Table 4-3 Tipton Storage Characteristics

Dam Description	Volume at Spillway (ML)	Volume at Mandatory Reporting Level (ML)	Volume at Design Storage Allowance (ML)
Tipton Aggregation Dam 1	1,443	1,240	1,096
Tipton Aggregation Dam 2	2,046	1,728	1,781
Feedwater Dam	422	388	357
Treated Water Dam	422	404	367
Brine Dam	1,141	989	879
Utility Dam	61	57	41

Note: DSA and MRL volumes have been updated to reflect the 2017 Annual Dam Inspections (AECOM, 2017).

4.3.2 Water Treatment Plant

In April 2013, Arrow Energy commissioned a 12 ML/d WTP at Tipton to facilitate beneficial use and align Arrow's operations with the updated CSG water management policy (DEHP, 2012). For a description of the water treatment process refer to Section 4.1.2. For characterisation of treated CSG water quality refer to Section 4.2.

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[8] Queensland Department of Environment and Heritage Protection, *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures,* DEHP, Queensland, Australia (ESR/2016/1933).

4.3.3 Beneficial Use

Table 4-4 outlines the beneficial use offtakes from Tipton. The only current offtake is supply to a feedlot. Additional offtakes will be added when the SGP enters the development phase. These offtakes will form part of the proposed Arrow BUN.

Table 4-4 Tipton Third Party Water Offtakes

Beneficial Use Offtake	Maximum Possible Volume (ML/day)	DEHP Hierarchy Priority
Feedlot	Min = 1.75, Max = 4	Priority 1

Plan

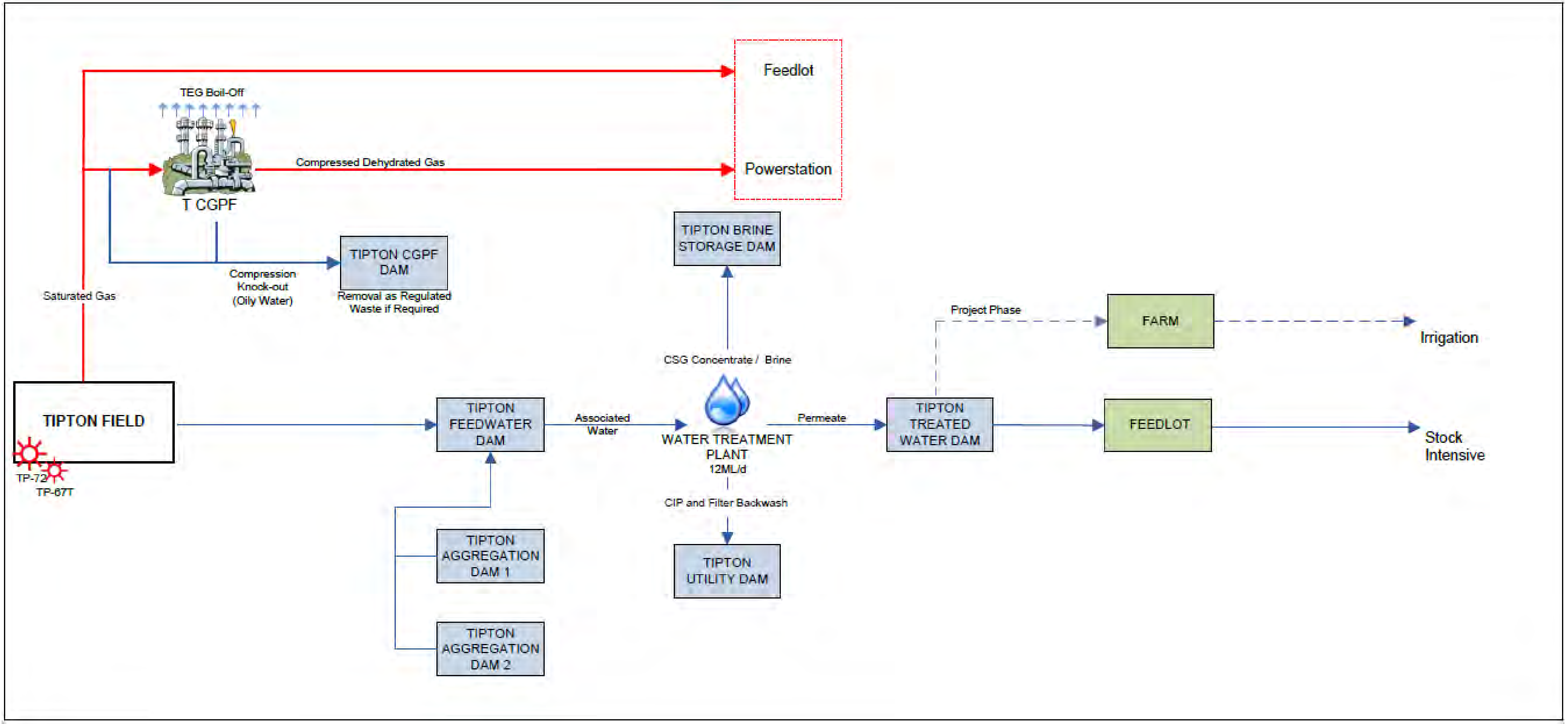

Figure 4-4 Schematic diagram of the Tipton Water Management Network

4.3.4 Brine Management

Brine at Tipton is currently stored in a dam compliant with the DEHP 2013 Manual for Assessing Consequence Categories and Hydraulic Performance of Structures and the DXP EA conditions. Arrow is currently pursuing brine management options in line with its Surat CSG Water and Salt Management Strategy (refer Section 3.5). A long term brine management solution has not been selected at this stage.

5. RISK MANAGEMENT

Arrow implements a standardised approach to risk management enabling risks to be ranked and prioritised across all operations. Arrow's approach to risk management seeks to:

- Identify and understand risks inherent to the business; and
- Apply adequate risk response by:
    - Decreasing the likelihood and consequence of adverse effects;
    - Increasing the likelihood and impact of positive effects;
    - Implementing effective controls;
    - Setting boundaries for risk acceptance;
    - Focusing assurance activities towards the highest areas of risk.

5.1 SGP Risk Assessment

An assessment of the risks related to CSG water management for the SGP was completed in March 2018. The risk assessment used the Arrow Energy framework[9]. Table 5-1 summarises the most pertinent CSG water management risks for the DXP, alongside mitigation measures that will control all risks to acceptable levels.

The risk assessment shows that:

- Most risks are ranked as Low considering existing management controls;
- Risks related to the failure of the WTP to achieve desired design water quality, the failure to secure off-take agreements and the failure to deliver a long term brine management solution ranked as Medium;
- For risks which ranked as Medium, the residual risk ranking is Low after consideration of risk response measures.

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[9] Arrow Energy, 2018 *Arrow Energy Risk Management Procedure, Appendix 1 - Risk Assessment Matrix*, Version 5.0, Doc No: ORG-ARW-RMT-PRO-00001.

Table 5-1 Summary of Risk Assessment

Hazard / Threat	Consequences	Existing Controls	Current Risk Ranking	Risk Response	Residual Risk Ranking
Dam Break – collapse of the structure due to any possible cause	Dam break has the potential to cause: harm to humans; harm to the environment; general economic loss or property damage; and non-compliance with EA conditions.	Dams are designed and operated in accordance with Queensland regulation. Monitoring and maintenance is undertaken in accordance with Dam Operating Plans. Annual dam inspections conducted. Weekly operator inspections of dam levels.	LOW *Aggregation Dam* LOW *Treated Water Dam* LOW *Brine Dam*	Implementation of emergency procedures as defined in the Dam Operating Plans.	LOW *Aggregation Dam* LOW *Treated Water Dam* LOW *Brine Dam*
Failure to contain – seepage - significant changes to Groundwater from seepage	Seepage has the potential to cause: harm to humans; harm to the environment; general economic loss or property damage; and non-compliance with EA conditions.	Dams are designed and operated in accordance with Queensland regulation. Regular monitoring of groundwater quality in the immediate vicinity of regulated dams as per the Groundwater Monitoring Program. Seepage controls such as HDPE liners and collection systems are in place where required by Queensland regulation. Brine management dams include capability to capture any seepage that may pass through HDPE lining. Monitoring and maintenance undertaken in accordance with Dam Operating Plans.	LOW *Aggregation Dam* LOW *Treated Water Dam* LOW *Brine Dam*	Implementation of emergency procedures as defined in the Dam Operating Plans.	LOW *Aggregation Dam* LOW *Treated Water Dam* LOW *Brine Dam*
Failure to Contain – overtopping – releases due to overtopping of the structure	Overtopping has the potential to cause: harm to humans; harm to the environment; general economic loss or property damage; and	Dams are designed and operated in accordance with Queensland regulation. Operation of storages in accordance with dam operating plans and EA conditions. Adherence to DSA and MRL operating rules.	LOW	Construct contingency release infrastructure. Implementation of emergency procedures (including emergency discharge strategy) as defined in the Dam Operating Plans.	LOW

Hazard / Threat	Consequences	Existing Controls	Current Risk Ranking	Risk Response	Residual Risk Ranking
	non-compliance with EA conditions.	Water production forecasting and water balance modelling. Emergency spillways on dams.			
Failure of water treatment plant to achieve required water quality	Plant failure has the potential to cause: an inability to use treated CSG water for intended beneficial use options; and non-compliance with EA conditions.	Upstream buffer storage to allow for temporary system shut down to resolve potential issues. Automated monitoring within the WTP system to allow for early detection and mitigation of issues. Automated water quality sampling in permeate dam prior to beneficial use. Ability to retreat water from permeate dam if there are significant exceedances.	LOW	Further in-field blending to address potential exceedances. Water treatment plant upgrades (including pre and post treatment systems) or replacements to achieve water quality objectives. Option to turn down / shut in wells if upstream storage becomes limiting.	LOW
Failure to secure water off-takes	Insufficient off-takes have the potential to require disposal of CSG water instead of beneficial use.	CSG water utilisation portfolio to be maintained with sufficient capacity (above upper bound water production curves) to address this risk. Market analysis and identification of off-take opportunities.	LOW	Ability to provide excess capacity into existing SunWater beneficial use pipeline to Chinchilla weir.	LOW
Failure to deliver long-term brine management solution.	No long-term brine management solution has the potential to: require additional brine storage construction when existing capacity is exhausted; and increase operational footprint and create additional impact on environmental receptors.	Brine feasibility studies to identify a long term brine management solution (refer Section 3.5). Construction of additional brine storage dams.	MODERATE[10]	Full evaluation of multiple options in order to ensure long term management approach will be in place.	LOW

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[10] Risk ranks as moderate due to costs associated with disposal at a third-party waste facility.

6. MANAGEMENT CRITERIA

6.1 Measurable Criteria

Arrow Energy has defined Measurable Criteria for the SGP in accordance with Section 126 (1) of the *EP Act 1994*. To ensure criteria are targeted towards those CSG water management activities and elements that require greatest control, they have been developed from the outcomes of the risk assessment described in Section 5. The Measurable Criteria will be used to monitor and assess the effectiveness of CSG water management across a range of indicators and will be reported in the annual return.

Table 6-1 presents the measurable criteria required to satisfy the requirements of the EP Act. The criteria will be re-evaluated if required as a result of changes in the way which Arrow manages CSG water.

Table 6-1 Measurable Criteria

Management Component	Objectives	Environmental Value Protected	Controls	Measurable Criteria
Transmission of CSG water via pipelines	Effective containment of water throughout transmission activities from well to beneficial use / disposal.	Surface and groundwater quality. Soil quality (including structural and chemical properties).	Regular monitoring and maintenance in accordance with asset integrity and maintenance plan. Process safety in design and controls.	No reportable unplanned releases of CSG water.
Storage of CSG water in regulated dams	Effective containment of CSG water in dams. Regulated dams operated and maintained in accordance with approvals.	Surface and groundwater quality. Soil quality (including structural and chemical properties).	Annual dam integrity inspections. Groundwater monitoring program. Scheduled maintenance of infrastructure and facilities. Dam operating plans. Water balance modelling to develop operating philosophy and strategy.	Water level below DSA at Nov-1.[11] No breaches of MRL. Annual inspections completed. No unplanned releases.
Beneficial Use	Maximise beneficial use of CSG water. Ensure that supplied beneficial use water is in accordance with approvals.	Surface and groundwater quality. Soil quality (including structural and chemical properties).	Regular monitoring of the qualities and quantities of water suppled for beneficial use. Scheduled maintenance of infrastructure and facilities. CSG Water and Salt Management Strategy.	Water supply agreements in place. Water quality for beneficial use meets approval conditions.
Management of salt and brine	Management of salt in accordance with the regulatory framework.	Land use capability, having regard to economic considerations. Surface and ground water quality. Soil quality (including structural and chemical properties).	Continual assessment of feasible options for beneficial use and/or disposal of salt in accordance with the CSG Water Management Policy 2012. Containment of salt and brine in fit for purpose storage infrastructure operated and maintained in accordance with approvals.	Water level below DSA at Nov 1. No breaches of MRL. Annual inspections completed. No reportable unplanned releases.

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[11] If the dam is a regulated structure as per the failure to contain overtopping scenario in the *Queensland Department of Environment and Heritage Protection, Manual for Assessing Consequence Categories and Hydraulic Performance of Structures,* DEHP, Queensland, Australia (ESR/2016/1933).

6.2 Response Procedures

Should any of the Measurable Criteria in Table 6-1 not be met, the following response procedure will be implemented:

- Where relevant, reporting of incident in line with DES requirements;
- Evaluation (including root cause analysis) of the underlying cause of the criteria not being met;
- Review of relevant procedures, protocols and management plans and make changes where required;
- Implementation of corrective actions to address underlying cause. This, for example, could include:
    - Engineering solutions;
    - Amendments to operating procedures; and/or
    - Change to management process.

6.3 Arrow Operating Procedures

Arrow Energy commits its staff to the adoption of a series of procedures that control important elements of CSG water management. These procedures include:

- 99-H-PR-0010 (5) Incident Reporting Recording and Investigation Procedure;
- ORG-ARW-HSM-PRO-00016 (8) Chemical Management Procedure;
- ORG-ARW-HSM-PRO-00066 (4) Waste Management Procedure; and
- ORG-ARW-HSM-PRO-00073 (7) Land Rehabilitation Procedure.

Each of Arrow Energy's procedures is reviewed regularly in order to ensure that all operating factors are considered, and that procedures continue to reflect latest understanding.

7. MONITORING

7.1 Environmental Monitoring

7.1.1 Surface Water

Contingency discharge of treated CSG water to watercourses is a potential option in the event that other beneficial uses of CSG water are temporarily unavailable. Prior to the release of treated CSG water to a watercourse, Arrow will develop a Receiving Environment Monitoring Plan (REMP) to monitor, identify and describe any adverse impacts to surface water environmental values, water quality, and flows due to authorised releases. The REMP will be developed in accordance with granted EA conditions. Arrow does not currently have any installed watercourse release infrastructure.

7.1.2 Groundwater

The Groundwater Monitoring Program will provide for the early detection of significant risks and changes in groundwater quality and levels as a result of activities authorised under the SGP EAs.

The Groundwater Monitoring Program will be based on the current program at Arrow’s DXP and may include:

- regular monitoring of groundwater quality in the immediate vicinity of regulated dams;
- monitoring of background sites;
- monitoring of dam water quality;
- establishment of site-specific environmental values for the shallow groundwater system;
- development of site-specific trigger values;
- ongoing monitoring of groundwater to identify environmental impacts; and
- implementation of management actions in the event of environmental impact.

Monitoring groundwater quality at dam sites requires installation of monitoring bores in close proximity to dams. The exact location of these bores is guided by geotechnical investigations to identify the direction in which in groundwater impact is likely to travel. Background sites are also installed at distances of 500m to 1,500m (where access allows) both up and down gradient of the dams.

Site-specific trigger levels are developed by considering the background groundwater quality, established trigger levels (such as ANZECC water quality criteria), and the potential impacts of seepage from regulated dams. Ongoing monitoring is then used to identify whether, and to what extent, environmental impacts, with reference to the aforementioned criteria, are occurring. Where unacceptable impacts have occurred, management actions are initiated to remedy these.

7.2 Monitoring of CSG Water Management Dams

In accordance with dam operating plans, Arrow Energy will conduct the following monitoring:

- Weekly monitoring:
    - Dam water levels monitored against MRL and DSA;
    - Visual inspections to consider integrity issues; and
    - Visual inspections for algae, surface slicks or fauna interaction.
- Monthly Monitoring:
    - Visual structural inspection for early identification of integrity issues; and
    - Identification of any changes to the dam service/contents.
- Biannual monitoring:
    - Groundwater impact monitoring for physico-chemical parameters.
- Annual monitoring:
    - Each regulated dam will be inspected by a suitably qualified and experienced person with an Annual Inspection Report prepared and certified; and
    - An assessment of the DSA will be undertaken on or before 1 November each year.

8. REPORTING

8.1 Annual Return

In accordance with the requirements of the SGP EAs, Arrow Energy will complete and submit an Annual Return which will include an evaluation of the effectiveness of the management of CSG water under the criteria described in Section 126(1)(e) of the EP Act.

8.2 Annual Inspection Report

Arrow Energy will provide to DES upon request a copy of the Annual Inspection Report for each of its regulated structures. This will be certified by a suitably qualified and experienced person and will include any recommended actions to ensure the integrity of inspected dam.

8.3 Annual Monitoring Report

An Annual Monitoring Report summarising monitoring results over the previous 12 month period will be prepared and made available to DES upon request. All monitoring results will be retained for no less than five years.

8.4 Incident Reporting

If any contaminant levels are identified as having caused, or have the potential to cause environmental harm, this will be reported to DES in accordance with EP Act and EA requirements.

9. REFERENCES

ANZECC & ARMCANZ 2000, Australian and New Zealand guidelines for fresh and marine water quality, ANZECC & AMCANZ, Australia.

Arrow Energy, 2018 *Arrow Energy Risk Management Procedure, Appendix 1 - Risk Assessment Matrix*, Version 5.0, Doc No: ORG-ARW-RMT-PRO-00001.

Arrow Energy, 2013 Coal Seam Gas Water Management Plan – Surat Basin, Rev: 0, Doc No: ENV11-133.

Arrow Energy 2017, *Surat Gas Project CSG Water Management Strategy*, Rev: 0, Doc No: ORG-ARW-ENV-STR-00001.

Arrow Energy, 2017 Dalby Expansion Project (DXP) – Dam Operating Plan, Rev: 2, Doc No: 19-W-PL-0001.

Arrow Energy, 2013 Daandine Expansion – Field Development Plan, Rev: 3, Doc No: 05-PE-PL-0002 (3).

Arrow Energy, 2017 Daandine and Kogan North Water Management Review, Rev: 0, Doc No: 05-W-REP-0012.

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Arrow Energy, 2017 Monthly Tipton Water Operations Report, Rev: 0, Doc No: 00-W-REP-0008.

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Appendix B – Section 126 A

Appendix B: Response to Section 126A of the EP Act 1994 – Requirements for site-specific and amendment applications – underground water rights

A number of assessments have been undertaken which relate to the exercise of underground water rights for all of Arrow tenures which include:

- 2019 Surat Cumulative Management Area (CMA) Underground Water Impact Report (UWIR) https://www.business.qld.gov.au/industries/mining-energy-water/resources/environment-water/coal-seam-gas/surat-cma/uwir
- Surat Gas Project (SGP) Environmental Impact Statement (EIS) and Supplementary Report to the EIS (SREIS) https://www.arrowenergy.com.au/environment/project-assessment-eis/surat-gas-project-eis
- Stage 1 and Updated Water Monitoring and Management Plan for the EPBC approval for the Surat Gas Expansion Project (EPBC 2010/5344) https://www.arrowenergy.com.au/environment/environmental-management-plans-and-reports

In addition to this, 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 has also been completed for this EA amendment application, and is provided in Appendix E. Reference should be made to all of these existing assessments with respect to addressing Section 126A. The following information is provided to satisfy the provisions of Section 126A of the EP Act for the exercise of underground water rights for a resource project for this EA Amendment Application.

1) *This section applies to site-specific application, involving the exercise of underground water rights, for-*
   a) *a resource project that includes a resource tenure that is a mineral development licence, mining lease or petroleum lease; or*
   b) *a resource activity for which the relevant tenure is a mineral development licence, mining lease or petroleum lease.*

This EA Amendment Application applies to the exercise of underground water rights. This is described in more detail in Section 4 of this amendment application.

2) *The application must also state the following-*
   a) *any proposed exercise of underground water rights during the period in which resource activities will be carried out under the relevant tenure*

Arrow proposes to exercise underground water rights on Hopeland tenure (PL253) based on the resource activities described in this amendment application.

There are six existing production wells within PL253, forming the Hopeland pilot.

As indicated in Sections 5.1 and 5.2 of this amendment application, a total of 55 new production wells are proposed to be constructed. The CSG water production over the life of the project will be in the order of 10.4 GL, with a peak rate of approximately 11 ML/day in year 1 (2025) and diminishing quickly from this peak in 2026 and continue to diminish through the project.

Arrow provides its water production volumes and forecasts to the Office of Groundwater Impact Assessment (OGIA) for inclusion in the Surat CMA UWIR.

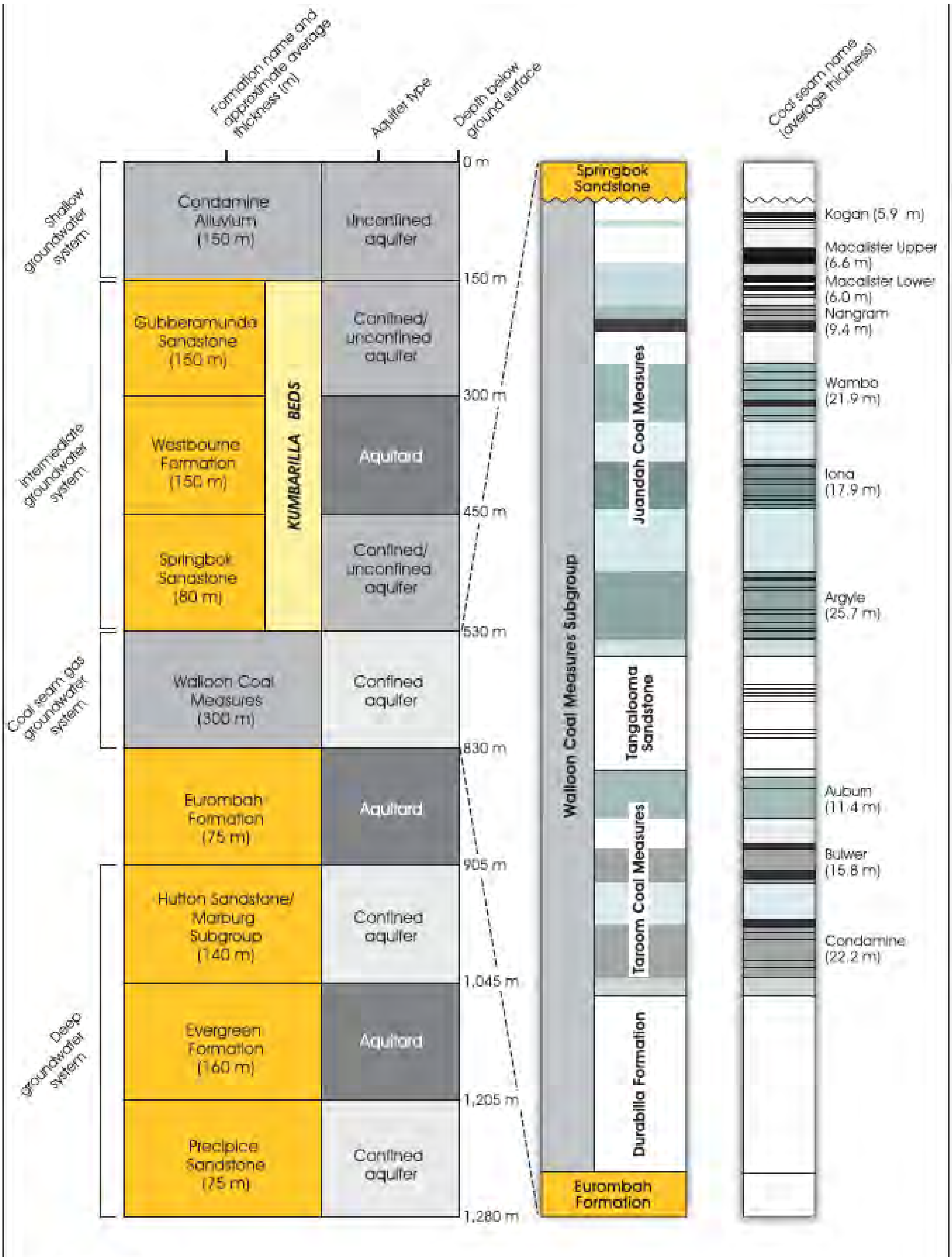
b) the areas in which underground water rights are proposed to be exercised

Underground water rights are proposed to be exercised within the south and east of PL253 and discussed in more detail in **Sections** 4 and 5 of this amendment application. It is noted that well locations may change prior to construction following liaison with landholders and pre-disturbance ecology and cultural heritage field assessments.

c) for each aquifer affected, or likely to be affected, by the exercise of underground water rights

i. a description of the aquifer;

All aquifers that occur within or outside of the tenure are described in detail in the 2019 Surat CMA UWIR as well as the SGP EIS and SREIS. A generalised hydrostratigraphy of this is shown in **Figure 1** below. It should be noted that PL253 is located to the southwest of the Condamine Alluvium (CA) and does not contain the deposits of this formation.



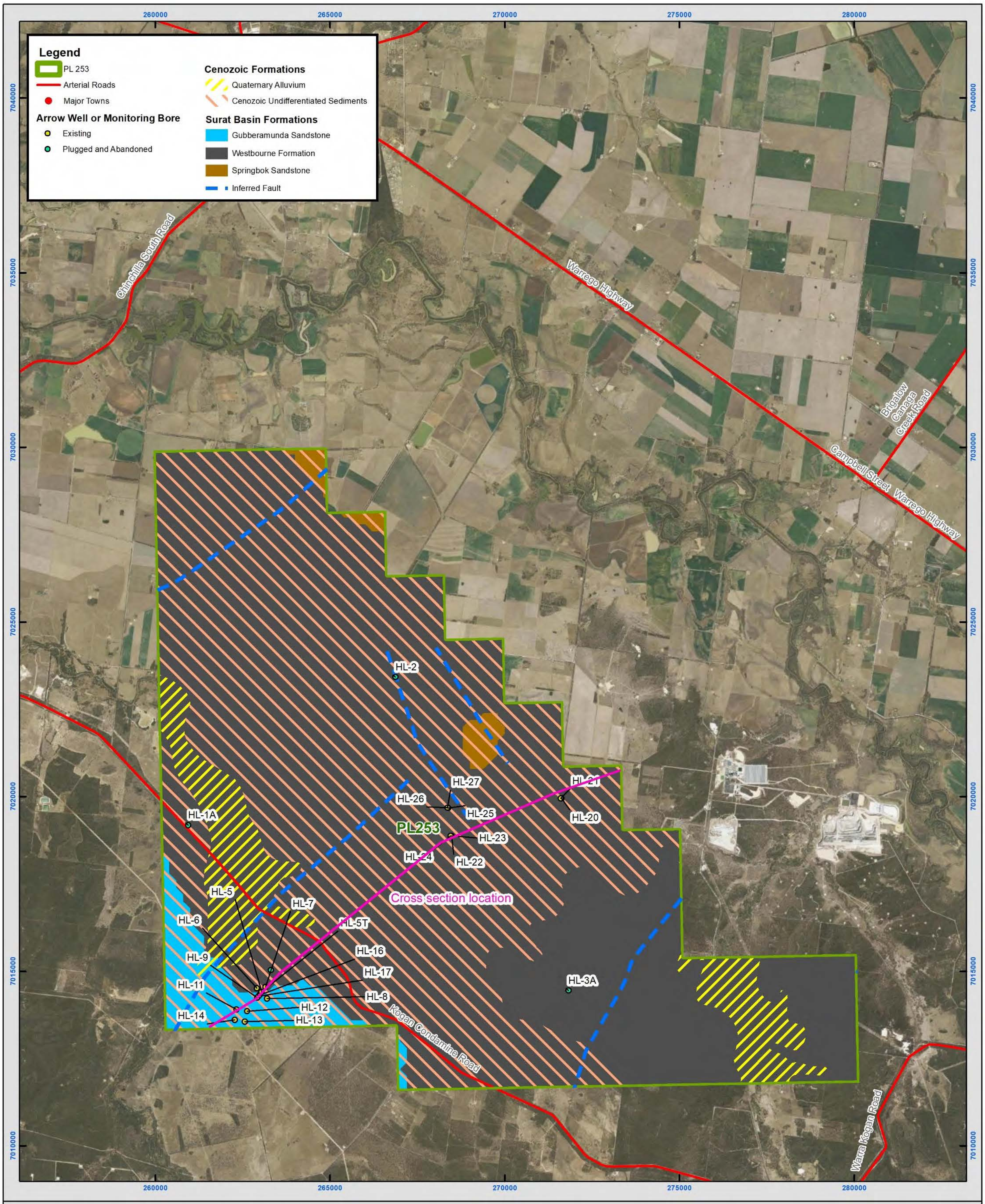
Source: Data from Arrow Energy
Scott et al (2004)

Figure 1 – Hydrostratigraphy of all formations that occur within and adjacent to PL253

PL253 lies within the Surat Basin, a highly heterogeneous mix of alternating layers of sandstones, siltstones, mudstones and coal of Jurassic and Early Cretaceous age which attains a maximum thickness of approximately 1,000 m in the southwest of the PL. The Surat Basin here sits unconformably over basement rocks, whilst generally relatively thin accumulations of unconsolidated Cenozoic sediments overly much of the Surat Basin sediments in the lower relief terrain. The extent of the Cenozoic sediments and underlying Surat Basin formation is shown in **Figure 2**, with a cross-section in **Figure 3**. The Arrow geological model was used to develop the cross section, and incorporates Arrow's geological drilling log data, which details the depth to formation and aquifer top intersected in the bore holes along the section lines. The geological model is developed using Arrow and other drill log data and seismic data collected within PL253 and regionally. The location and orientation of the cross section has been chosen to assist with the visual presentation and interpretation of the underlying geology and aquifer data. The vertical axis scale is exaggerated to assist with the presentation and visualisation of the underlying geology.

There are 14 groundwater monitoring bores maintained by Arrow within PL253. Data from landowner, registered and baselined bores has also been incorporated into these aquifer and water quality discussions.

The Surat Basin is a sub-basin of the Great Artesian Basin (GAB), with the multiple layers of alternating sandstone, siltstone, mudstone and coal forming sequences of aquifers and aquitards. The Surat Basin sediments within the area of PL253 generally dip toward the south west at an angle of 1 to 2 degrees as shown in the cross-section in Figure 3. This dip is consistent with the geological model developed for the Surat CMA UWIR. Arrow monitoring bore Hopeland 17 (RN160699), in the south west of the tenement as shown in Figure 2, was drilled to 1223.16m depth, penetrating the entire Surat Basin sequence within PL253.



Geology and Arrow Wells or Monitoring Bores within PL253

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 14/09/2021
Issued To: Final

0 0.75 1.5 3 4.5 6 Kilometers

Scale: 1:100,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

N

The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

Figure 2 – Geology map and location of Arrow’s Hopeland (HL) wells or monitoring bores

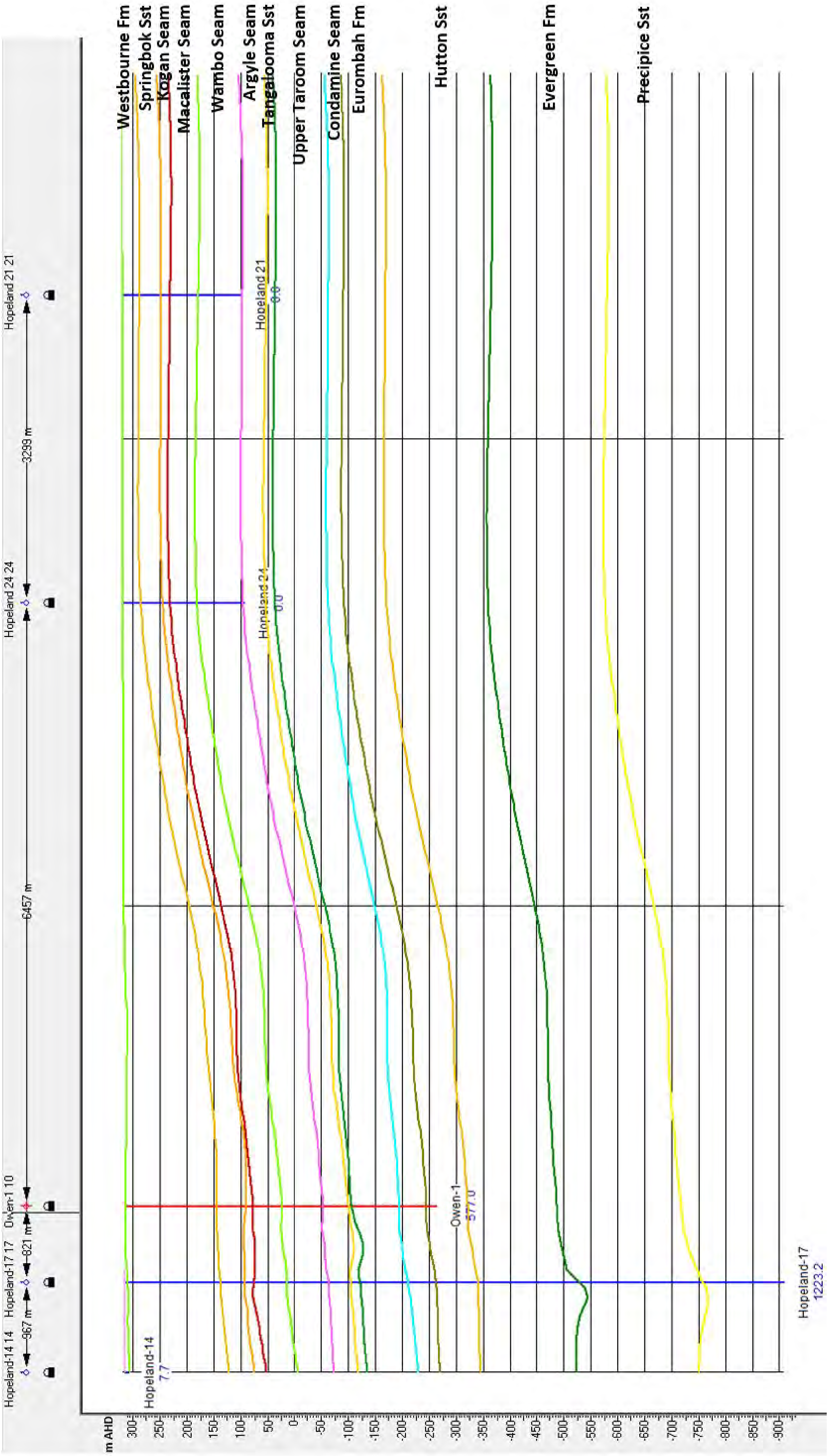


Figure 3 – Geological cross section of PL253

The underlying aquifers for the tenement are described in more detail below. The discussion of the aquifers is based on the following four attributes:

- Aquifer composition
- Aquifer thickness
- Groundwater levels for unconfined aquifers and piezometric data for confined aquifers
- Groundwater quality

The data on aquifer composition and thickness was obtained directly from Arrow Energy's drill logs and data recorded in the Department of Regional Development, Manufacturing and Water (DRDMW) groundwater database (GWDB). These data were supplemented by stratigraphic descriptions contained in the Surat CMA UWIR when drill logs or other stratigraphic data were not available.

Depth to groundwater and aquifer pressure data were obtained for bores where a reliable aquifer attribution could be made, and is sourced from Arrow Energy's groundwater monitoring program and baseline and bore assessment program together with the GWDB. Where sufficient data is available, hydrographs have been developed for each aquifer, plotted as the elevation of the water table (or piezometric surface) in meters Australian Height Datum (mAHD). There are limited data available on the depth to water or the elevation of the piezometric surface from the deeper aquifers (i.e. Hutton Sandstone and Precipice Sandstone).

Data on groundwater quality in the key aquifers has been derived from the following sources:

- Water quality samples from the landholder bores where a baseline or bore assessment has been undertaken by Arrow Energy personnel.
- Seepage Monitoring Program and Groundwater Characterisation Monitoring Program, carried out by Arrow Energy, associated with current Environmental Authority (petroleum activities) no. EA0001401.
- Groundwater samples collected from Arrow Energy's CSG productions wells.
- Additional water quality data captured and stored in the DRDMW GWDB.

Groundwater quality data for monitoring wells within Lot 40 DY85 have been provided to Arrow under confidentiality provisions and therefor are not presented in detail in this report, however the data has been used for development of the groundwater flow model and contaminant fate and transport provided in Appendix E of this EA amendment application to assess potential impacts to these contaminants as a result of the exercise of underground water rights within PL253.

Cenozoic sediments

The topographical relief of the area of PL253 is generally flat, with elevations between 310 (toward the northern and western edges) and 320 mAHD (through the centre), with steeper gradients to the southeast (up to approximately 370 m AHD). The majority of the area drains toward the south and west into Sixteen Mile and Wambo Creeks, while a small portion of the northern area drains to the north into the Condamine River. The elevated terrain in the southeast is bisected by the northerly flowing Kogan Creek.

The Cenozoic sediments consist of floodout and sheet sand with some alluvium, formed as a result of movement of sediments from higher ground in the east to lower ground in the west, toward Wambo Creek and the Condamine River. Drill logs in the area indicate that these Cenozoic sediments attain a maximum thickness of approximately 30 m closer to the creeks, thinning toward the east where it does not exist on the elevated terrain. The sediments comprise sand, red sandy soil, silt and some gravel, and can contain small local unconfined to semi-confined aquifers in the more permeable sediments.

Due to the shallow depth and heterogeneous nature, there are no groundwater bores installed into the Cenozoic sediments within PL253 from which to obtain depth to water level or hydrographs within PL253. Arrow has installed groundwater monitoring bores (Hopeland 11 to 14) to the base of the Cenozoic sediments at a depth of approximately 10 m to monitor for potential seepage from the Hopeland Pilot Dam, however these monitoring bores have remained dry since installation in 2013. There are also no indications of water strikes within these sediments in drill logs within the DRDMW GWDB. However, these sediments are expected to intermittently contain groundwater, particularly in the alluvium associated with the creeks, following rainfall periods sufficient to generate runoff.

Gubberamunda Sandstone

The Late Jurassic to Early Cretaceous-aged Gubberamunda Sandstone is the shallowest of the Surat Basin sedimentary succession that exists within PL253, sub-cropping under the Cenozoic sediments in the southwest of the tenement as shown in Figure 2.

Arrow's geological model indicates that the Gubberamunda Sandstone is up to approximately 10m thick within PL253, however in the area modelled the lithology encountered during drilling of Arrow's Hopeland wells (Hopeland 5 to 9) and monitoring bores (Hopeland 11 to 17) is highly weathered to clay and sand and so is indistinguishable from the Cenozoic sediments. Elsewhere in the Surat Basin the Gubberamunda Sandstone forms a significant aquifer, however in PL253 it is dry due to the shallow depth. The Gubberamunda Sandstone will not be considered further in this Appendix.

Westbourne Formation:

The Late Jurassic-aged Westbourne Formation is a significant aquitard or confining layer in the GAB and locally, consisting primarily of mudstone interbedded with siltstone, with minor fine- to very fine-grained quartzose sandstone and minor coal sequences. Depth and thickness of the formation from drill logs within PL253 are provided in Table 1, with the location of wells provided in Figure 2. The Westbourne Formation conformably underlies the Gubberamunda Sandstone in the southwest of the tenement, with a maximum thickness of approximately 170m. Further up-dip the Westbourne Formation is eroded and thins, unconformably sub-crops under the Cenozoic sediments through most of the tenement and outcrops in the elevated terrain in the east, pinching out in the north.

Table 1 – Drill log data for the Westbourne Formation

Bore ID	Depth From (m)	Depth To (m)	Thickness (m)
Hopeland 1A	10.2	150.8	140.6
Hopeland 2A	19.8	73.0	53.2
Hopeland 3A	0	89.0	89.0
Hopeland 5	5	173.5	168.5
Hopeland 5T	5	173	168
Hopeland 6	4.6	170.7	166.1
Hopeland 7	5	174.6	169.6
Hopeland 8	5	181.6	176.6
Hopeland 9	5	176.3	171.3
Hopeland 16	5.0	49.6*	>49.6
Hopeland 17	5.0	175.3	170.3
Hopeland 24	9.0	43.5	34.5
Hopeland 27	21.0	41.6	20.6

*Drilling ceased mid-way through the Westbourne Formation

As the Westbourne Formation is an aquitard with limited groundwater, 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. The groundwater is contained in thin coal seams interbedded with mudstone at a depth of 43 to 44 mbgl, and the groundwater is subartesian with depth to groundwater of 18.5 to 18.8 mbgl since commencement of monitoring in 2013 as shown in the hydrograph in Figure 4.

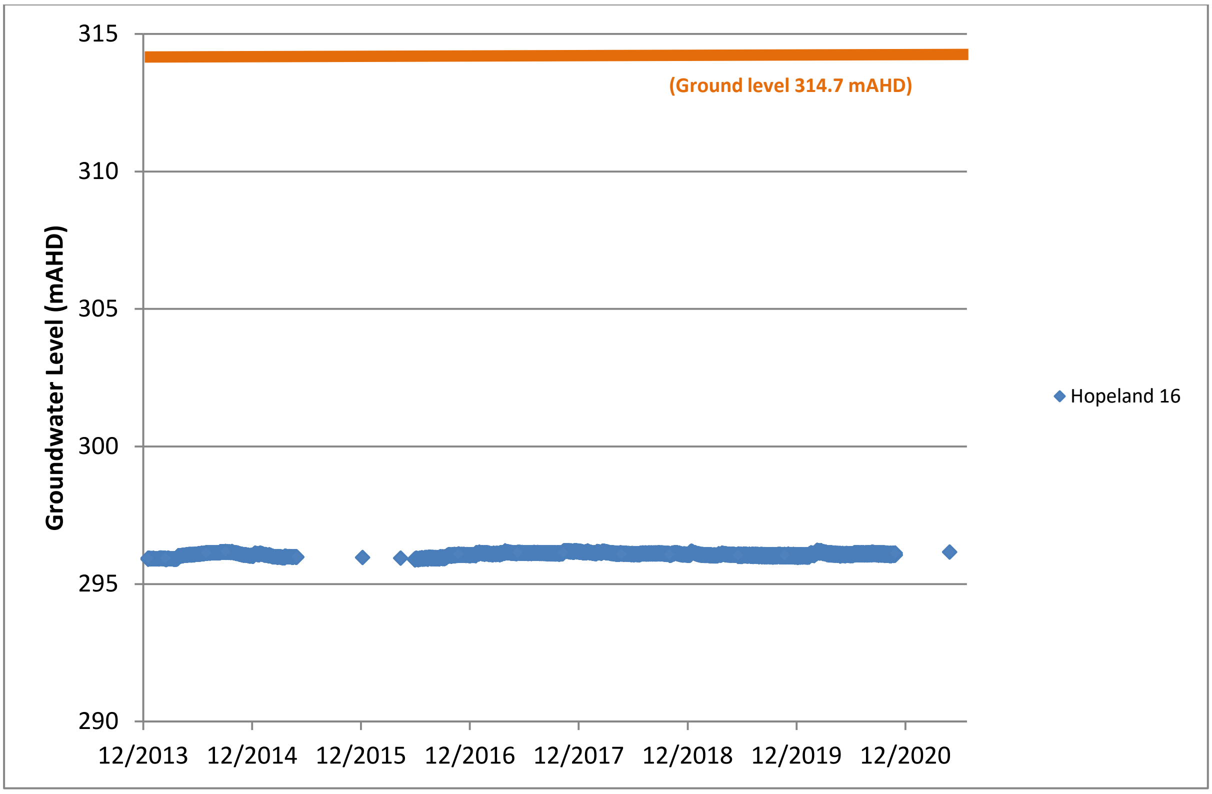


Figure 4 – Hydrograph for Hopeland 16, Westbourne Formation

The groundwater quality data available for the Westbourne Formation, limited to Hopeland 16, indicates that it is slightly acidic, saline and of a sodium-chloride type water with minor calcium and magnesium components, as shown in Attachment A. 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.

Springbok Sandstone:

The Late Jurrasic-aged Springbok Sandstone consists of interbedded fine- to coarse-grained, feldspathic to lithic and often clayey sandstones, siltstones and mudstones. It is considered to be a significant but tight aquifer within the Surat Basin in the 2019 Surat CMA UWIR, with medium to low transmissivity, bore yields that are regionally inconsistent and exhibiting a high degree of heterogeneity. This aquifer system is considered to be a confined aquifer and at many locations, the Springbok Sandstone has a very high content of mudstone and siltstone with very low permeability. This tends to locally isolate groundwater contained in the formation. Regionally, the geological model developed for the 2019 Surat CMA UWIR has recognised that the upper part of the Springbok Sandstone is generally finer grained then the relatively thin but coarser grained and more permeable lower section.

The Springbok Sandstone conformably underlies the Westbourne Formation throughout the tenement apart from in the north where it sub-crops under the Cenozoic sediments where the Westbourne Formation has pinched out. Depth and thickness of the formation from drill logs within PL253 are provided in Table 4, with the location of wells provided in Figure 2. The contact between the Springbok Sandstone and underlying Walloon Coal Measures is unconformable, with the Springbok Sandstone depositing on an undulating erosional surface. The thickness of the Springbok Sandstone is therefore variable throughout the tenement.

Table 4 – Drill log data for the Springbok Sandstone

Bore ID	Depth From (m)	Depth To (m)	Thickness (m)
Hopeland 1A	150.8	180.8	30.0
Hopeland 2A	73.0	98.9	25.9
Hopeland 3A	89.0	140.7	51.7
Hopeland 5	173.5	222.9	49.4
Hopeland 5T	173.0	223.1	50.1
Hopeland 6	170.7	220.1	49.4
Hopeland 7	174.6	220.4	46
Hopeland 8	181.6	221.8	40.2
Hopeland 9	176.3	221.1	44.8
Hopeland 17	175.3	221.0	45.7
Hopeland 21	43.4	77.1	33.7
Hopeland 24	43.5	133.5	90.0
Hopeland 27	41.6	124.8	83.2

A review was undertaken for groundwater level data available on PL253, with the data provided in Table 5. This included data collected from registered water supply bores as shown in Figure 5 and Arrow monitoring bores as shown in Figure 2. Sufficient data is available to generate hydrographs for five of the bores, 33553, 107857,Hopeland 17, Hopeland 22 and Hopeland 25, as provided in Figure 6. Based on this data, groundwater levels in the Springbok Sandstone range from approximately 10 to 30 mbgl (between 290 and 305 mAHD) when unaffected by significant pumping.

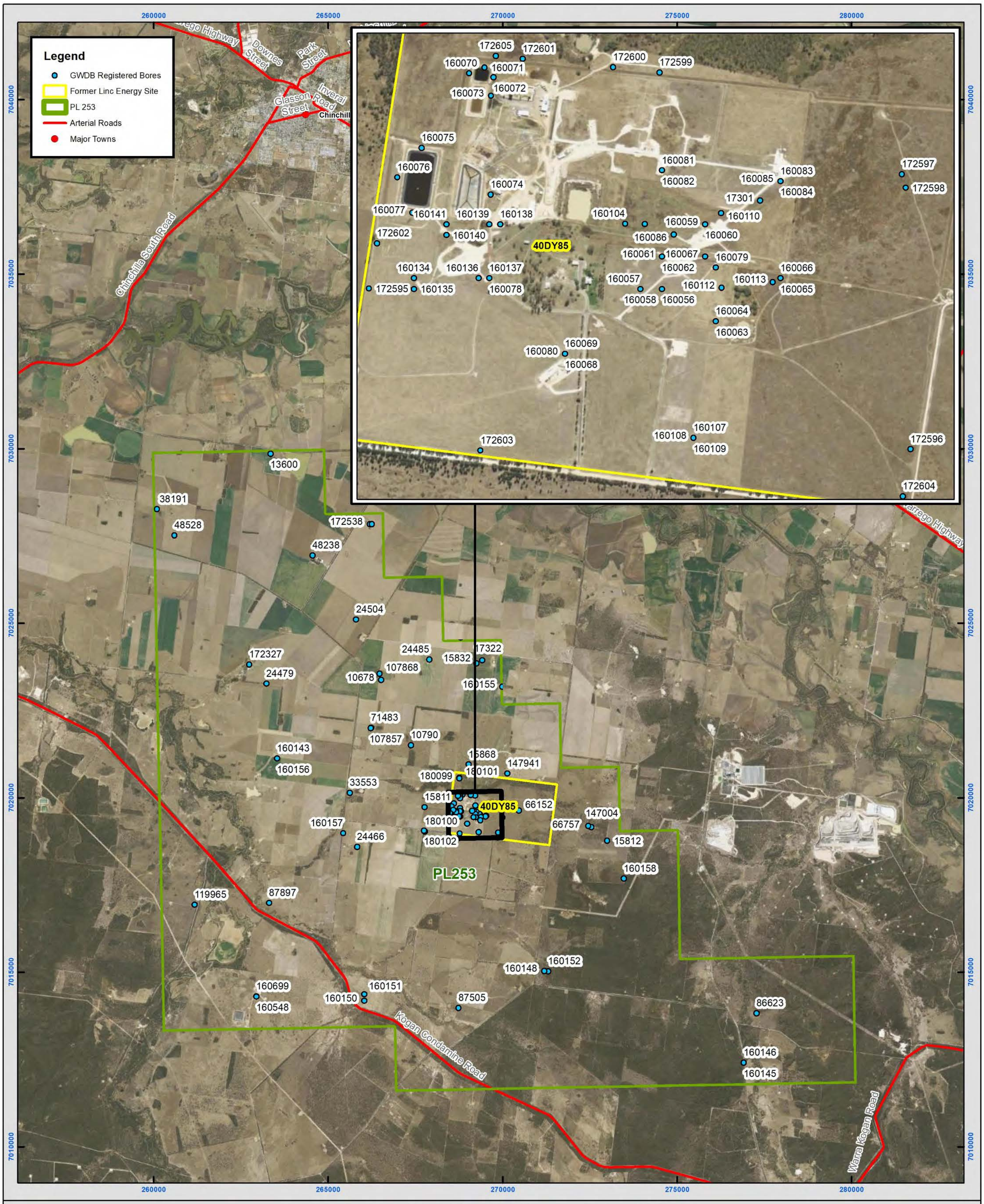
Groundwater levels in the Springbok Sandstone within and immediately adjacent to the former Linc Energy underground coal gasification (UCG) site on Lot 40 DY85 have been affected by operations on that site as indicated by a supressed water level compared to Arrow's adjacent monitoring bores Hopeland 22 and 25. Data supplied by DES indicate that depth to groundwater in the Springbok Sandstone within this site varies from approximately 23 to 118 mbgl (200 to 295 mAHD), although the permeability of the formation is low with water levels still recovering either after monitoring bore installation or with recovery after the UCG operations. The supressed water levels within Lot 40 DY85 indicate that there has been, and potentially still is, connection between the target of the UCG operation (the Macalister seam of the Walloon Coal Measures) and the Springbok Sandstone. Potential connection mechanisms include fracture propagation from the gasifiers up into the Springbok Sandstone, gasifier roof collapse, or failed well integrity in wells or bores on site.

The 2019 Surat CMA UWIR has identified both an Immediate and a Long-term Affected Area (IAA and LAA) for the Springbok Sandstone at PL253 due to exercise of underground water rights.

Table 5 – Groundwater level data for the Springbok Sandstone

Bore ID	Depth to Water (mbgl)	Water Level (mAHD)	Comment
33553	40.8 to 48.9	266.1 to 274.2	Water levels pump affected, hydrograph shown in figure
87505	19.0 to 21.0	297.2 to 299.2	3 water levels, 1991, 2019 and 2020
87897	11.4 to 11.8	299.6 to 299.3	2 water levels in 2019
107857	50.0 to 66.5	269.2 to 252.6	Water levels pump affected, hydrograph shown in figure
147004	31.1 to 31.7	289.3 to 289.8	2 water levels, 2018 and 2020
160145	22.3	298.9	1 water level, 2008
Hopeland 17	0 to 15.1	299.8 to 315.6	Logger data from 2014, hydrograph shown in figure
Hopeland 22	21.3 to 21.5	297.1 to 297.3	Logger data from 2020, hydrograph shown in figure
Hopeland 25	23.5 to 24.6	292.5 to 293.6	Logger data from 2020, hydrograph shown in figure

ARROW ENERGY - SURAT GAS PROJECT



Existing GWDB Registered Bores within PL253

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 14/09/2021
Issued To: Final

0 0.75 1.5 3 4.5 6 Kilometers

Scale: 1:100,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

N

The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

NOT FOR CONSTRUCTION

Figure 5 – Location of registered water bores and monitoring bores listed as existing in the GWDB

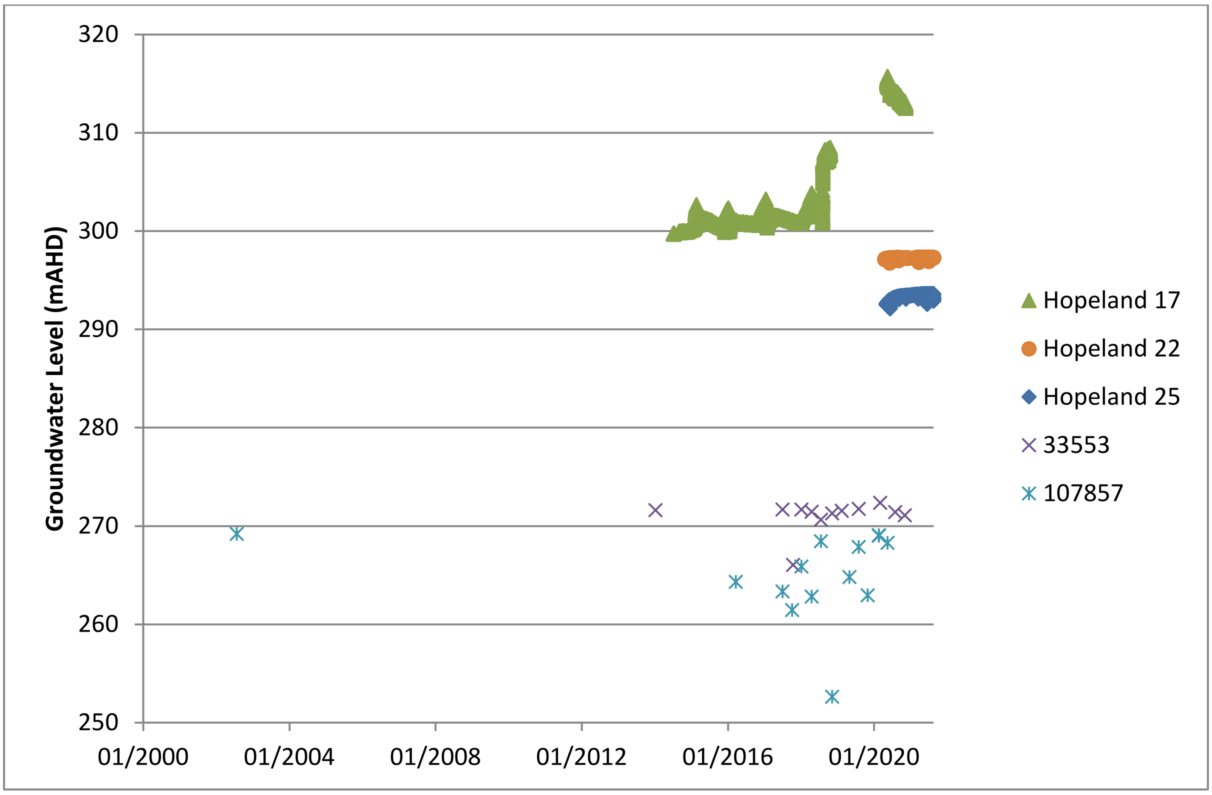


Figure 6 – Hydrograph for Hopeland 17, Hopeland 22, Hopeland 25, 33553 and 107857, Springbok Sandstone

Groundwater quality from seven landholder and two Arrow monitoring bores for the Springbok Sandstone are provided in Attachment A and shown graphically in the Piper diagram in Figure 7. Piper diagrams provide a graphical representation of the chemistry of the groundwater samples using the ratio of major ions. A total of 31 groundwater samples from the 9 bores have been collected over time for the Springbok Sandstone, with the most recent sample for each bore presented in the Piper diagram. Groundwater within this formation is typically near neutral to slightly alkaline, brackish, and of a sodium-chloride type. The median concentrations for TDS and the major ions are: TDS 6,960 mg/L, sodium 2,140 mg/L, calcium 93 mg/L, chloride 3,520 mg/L, and bicarbonate 325 mg/L for the most recent sample from each bore. The median field pH is 7.69.

Within the site of the former Linc Energy UCG operations on Lot 40 DY85, the Springbok Sandstone is contaminated with varying levels of BTEX, phenolic, and polycyclic aromatic hydrocarbon compounds, and the groundwater also tends to be moderately acidic and more saline than that of the Springbok Sandstone regionally. The median concentrations for TDS and the major ions are: TDS 13,400 mg/L, sodium 2,380 mg/L, calcium 566 mg/L, chloride 7,380 mg/L, and bicarbonate 30 mg/L for the 5 monitoring bores, with the most recent sample for each bore presented in the Piper diagram in Figure 7. The median field pH is 5.04. It should be noted that there is evidence of drilling fluids salts (principally potassium chloride) in these groundwater samples, and although improving over time, they may not be fully representative of the groundwater.

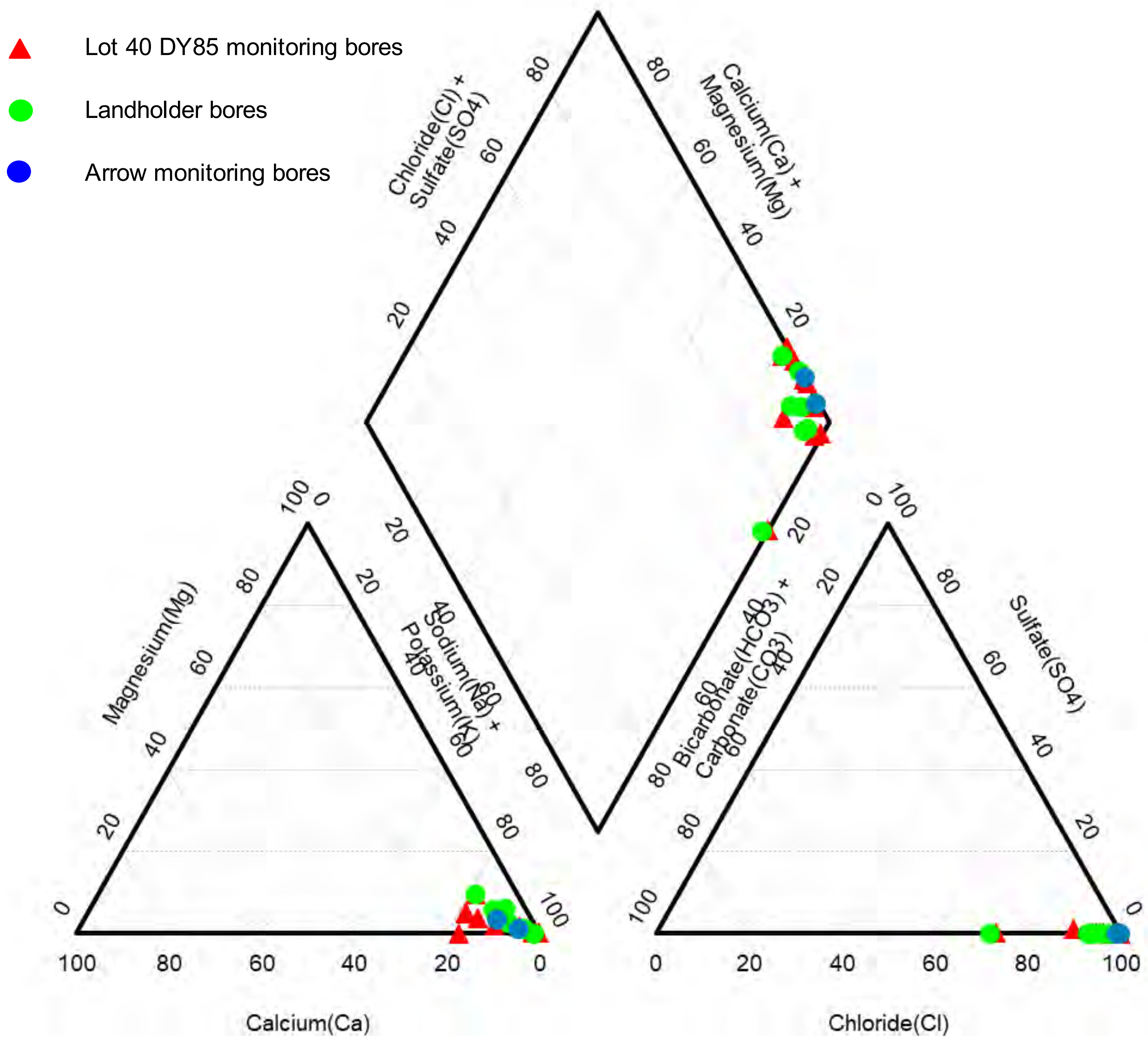


Figure 7 – Piper diagram of groundwater quality data for the Springbok Sandstone within PL253

Walloon Coal Measures

The middle Jurassic-aged Walloon Coal Measures (WCM) are classified as an interbedded aquitard in the 2019 Surat CMA UWIR, with thin, spatially limited water-yielding zones interbedded in an otherwise tight aquitard. The WCM has thin permeable coal seams which sit within a sequence of mainly low permeability mudstones, siltstones and fine- to medium-grained lithic sandstone. The WCM are formally subdivided into the following formations:

- Upper Juandah Coal Measures, further divided into the Kogan and Macalister coal seam packages.
- Lower Juandah Coal Measures, further divided into the Wambo and Argyle coal seam packages.
- Tangalooma Sandstone (fine grained and coal poor).
- Taroom Coal Measures, further divided into the Upper Taroom and Condamine coal seam packages.
- Eurombah or Durabilla Formation (low permeability, coal poor, siltstone, mudstone and massive fine- to medium-grained lithic/feldspathic sandstone aquitard at the base of the WCM).

Depth and thickness of the formation from drill logs within PL253 are provided in **Table 6**, with the location of wells provided in **Figure 2**. The geology of the WCM is complex; layers thicken, thin and are often discontinuous. The coal forms thin, discontinuous seams that generally comprise less than 5 to 10% of the total thickness of the WCM. Each coal seam package is picked on the basis of grouping together cycles of coal seams. The character of each package can vary greatly and it is often difficult to correlate coal seams even over a short distance. Often the most regionally pervasive and reliable correlation markers are the seams of the Macalister and the Condamine packages.

The WCM are unconformably overlain by the Springbok Sandstone, which is incised into the coal measures in places, completely removing the upper coal seam groups in some areas as observed at Hopeland 2.

Table 6 – Drill log data for the WCM

Well Name	Formation	Depth From (m)	Depth To (m)	Thickness (m)	Net Coal (m)	Total WCM Thickness (m)
Hopeland 1A	Kogan	180.8	195.6	14.8	0.3	427.9
	Macalister	195.6	239.5	43.9	5.7	
	Wambo	239.5	316.8	77.3	3.2	
	Argyle	316.8	374.3	57.5	2.9	
	Tangalooma	374.3	386.3	12	0	
	U. Taroom	386.3	468.6	82.3	2.4	
	Condamine	468.6	534.1	65.5	8.2	
	Eurombah	534.1	608.7	74.6	0	
Hopeland 2	Kogan	NA	NA	NA	NA	437.6
	Macalister	98.9	149.8	50.9	7.45	
	Wambo	149.8	249.3	99.5	9.51	
	Argyle	249.3	310.3	61	4.51	
	Tangalooma	310.3	318.1	7.8	0	
	U. Taroom	318.1	429.1	111	8.88	
	Condamine	429.1	451.4	22.3	6.27	
	Eurombah	451.4	536.5	85.1	0.25	
Hopeland 3A	Kogan	140.7	148.3	7.6	0	423.0
	Macalister	148.3	193.1	44.8	7.4	
	Wambo	193.1	283.0	89.9	3.3	
	Argyle	283.0	330.3	47.3	4	
	Tangalooma	330.3	339.8	9.5	0	
	U. Taroom	339.8	445.7	105.9	6.6	
	Condamine	445.7	476	30.3	7.2	
	Eurombah	476	563.7*	>87.78	0.1	
Hopeland 17	Kogan	221.9	240.2	18.3	0	433.2
	Macalister	240.2	299.5	59.3	5.93	
	Wambo	299.5	378.2	78.7	5.05	
	Argyle	378.2	431.4	53.2	3.2	
	Tangalooma	431.4	436	4.6	0.85	
	U. Taroom	436	522.5	86.5	2.53	
	Condamine	522.5	580.7	58.2	5.5	
	Eurombah	580.7	655.1	74.4	0	
Hopeland 21	Kogan	77.1	87.4	10.3	0.3	>148.4*
	Macalister	87.4	142.1	54.3	6.05	
	Wambo	142.1	182.0	39.9	4.63	
	Arglye	182.0	225.4*	>43.4*		
Hopeland 24	Kogan	133.5	136.2	2.7	0.21	>133.2*
	Macalister	136.2	171.5	35.3	8.77	
	Wambo	171.5	266.4*	>94.9*	6.05	
Hopeland 27	Kogan	124.8	128.7	3.9	0.3	>131.5*
	Macalister	128.7	159.2	30.5	9.8	
	Wambo	159.2	256.4*	>97.2*	5.7	

*Drilling ceased mid-way through the WCM

A review was undertaken of groundwater level data for the WCM available within PL253, with a summary of data for bores registered on the GWDB shown in Table 7 and the corresponding hydrographs in Figure 8. Arrow's groundwater monitoring bore Hopeland 17 is located with the existing Hopeland Pilot production wells (Hopeland 5 to 9) as shown in Figure 2, and monitors three discrete coal seams in the WCM. The hydrograph for these monitoring intervals and the water production from the Hopeland Pilot production wells is provided in Figure 9.

At the Hopeland pilot, the multilevel monitoring bore Hopeland 17 monitors three separate sections of the WCM being the Macalister seam package of the Upper Juandah Coal Measures, Argyle seam package of the Lower Juandah Coal Measures, and Upper Taroom seam package of the Taroom Coal Measures, as well as the Springbok Sandstone. Hopeland 17 is located approximately in the middle of the pilot and operation of the pilot production wells, which produce from the full thickness of the WCM, results in drawdown in the units monitored as shown in Figure 9. CSG production wells operate in adjacent tenures as close as 900m to the south of Hopeland 17. The production in these adjacent tenures produces a general downward trend in water pressures in the WCM in Hopeland 17, as seen during the period from the end of 2014 to the middle of 2016 when the pilot was not operational. As the development in the adjacent tenures has progressed, continued drawdown within the WCM has occurred.

Groundwater levels in the Macalister seam package of the WCM within and immediately adjacent to the former Linc Energy underground coal gasification (UCG) site on Lot 40 DY85 have been affected by operations on that site as indicated by a supressed water level and high well head gas pressures. Groundwater levels in Arrow monitoring bores Hopeland 20, 23 and 26 in the Macalister seam package are between 106.5 and 132.3 mbgl, which is 81.1 to 106.5m deeper than those in the paired bores (Hopeland 21, 24 and 27 respectively) monitoring the Wambo seam package as provided in Table 8. Allowing for the wellhead pressures, the potentiometric pressure (combination of water level and gas pressure contained within the well) is approximately 268 and 258 mAHD for the Macalister seam package compared to approximately 294 and 293 mAHD for the Wambo seam package, a difference of 26 to 35m close to the site boundary at the Hopeland 23/24 and 26/27 pairs as shown in Figure 10. Data supplied by DES indicate that depth to groundwater in the WCM within the site varies from approximately 46 to 120 mbgl for the most recent data available, with wellhead pressures of 0 to 703 kPa, giving a potentiometric pressure of approximately 253 to 280 mAHD. These suppressed water levels and pressures in the Macalister seam package relative to the regional groundwater levels and water levels in the deeper coal seams indicates that movement of groundwater is currently toward the former Linc Energy site locally.

These depth to groundwater measurements are highly dependent on which coal seam package of the WCM the bore is screened across, however based on this data, groundwater levels in the WCM range from approximately 25 to 50 mbgl (between 270 and 300 mAHD) when unaffected by significant pumping, CSG production or depressurisation from the former Linc Energy UCG operations.

The 2019 Surat CMA UWIR has identified that all of PL253 is within both the IAA and LAA for the WCM.

Table 7 – Groundwater level data for GWDB registered bores within the Walloon Coal Measures

Bore	Depth to Water (mbgl)	Water Level (mAHD)	Comment
10790	36.5 to 81.6	236.9 to 282.1	Relatively stable water levels, hydrograph shown in figure
15811	42.7 to 48.0	269.0 to 274.3	2 water levels, 1964 and 2003, bore now self-purges
15868	46.5 to 90.8	228.8 to273.1	Water levels pump affected, hydrograph shown in figure
24466	28.3 to 33.0	283.7 to 288.4	Relatively stable water levels, hydrograph shown in figure
24469	45.7 to 47.8	273.4 to 275.5	Relatively stable water levels, hydrograph shown in figure
24475	47.5 to 47.8	273.0 to 273.3	Relatively stable water levels, hydrograph shown in figure
24504	49.5 to 51.4	270.8 to 272.7	Relatively stable water levels, hydrograph shown in figure
38191	32.7 to 44.3	272.4 to 284.1	Water levels pump affected, hydrograph shown in figure
107868	43.0 to 64.4	257.1 to 278.5	Water levels pump affected, hydrograph shown in figure
160158	42.9 to 43.3	293.3 to 293.7	Relatively stable water levels, hydrograph shown in figure

Table 8 – Groundwater level data for monitoring bores in the Walloon Coal Measures close to the former Linc Energy site

Bore	Depth to Water (mbgl)	Water Level (mAHD)	Wellhead Pressure (kPa)	Potentiometric Surface Elevation from Formation Pressure (mAHD)	Comment
Hopeland 20 (Macalister seam)	>115.3 (dry)	<203.9	810 to 846	298.0 to 299.1	Logger data from 2020, hydrograph shown in figure
Hopeland 21 (Wambo seam)	25.4 to 27.5	291.6 to 293.8	4 to 30	294.2 to 295.0	Logger data from 2020, hydrograph shown in figure
Hopeland 23 (Macalister seam)	132.1 to 132.6	185.9 to 186.4	798 to 800	267.5 to 268.4	Logger data from 2020, hydrograph shown in figure
Hopeland 24 (Wambo seam)	24.5 to 26.6	291.9 to 294.0	0 to 20	293.9 to 294.2	Logger data from 2020, hydrograph shown in figure
Hopeland 26 (Macalister seam)	126.4 to 128.2	188.9 to 190.6	658 to 680	257.8 to 258.5	Logger data from 2020, hydrograph shown in figure
Hopeland 27 (Wambo seam)	24.9 to 27.7	289.3 to 292.1	0 to 30	292.2 to 292.7	Logger data from 2020, hydrograph shown in figure

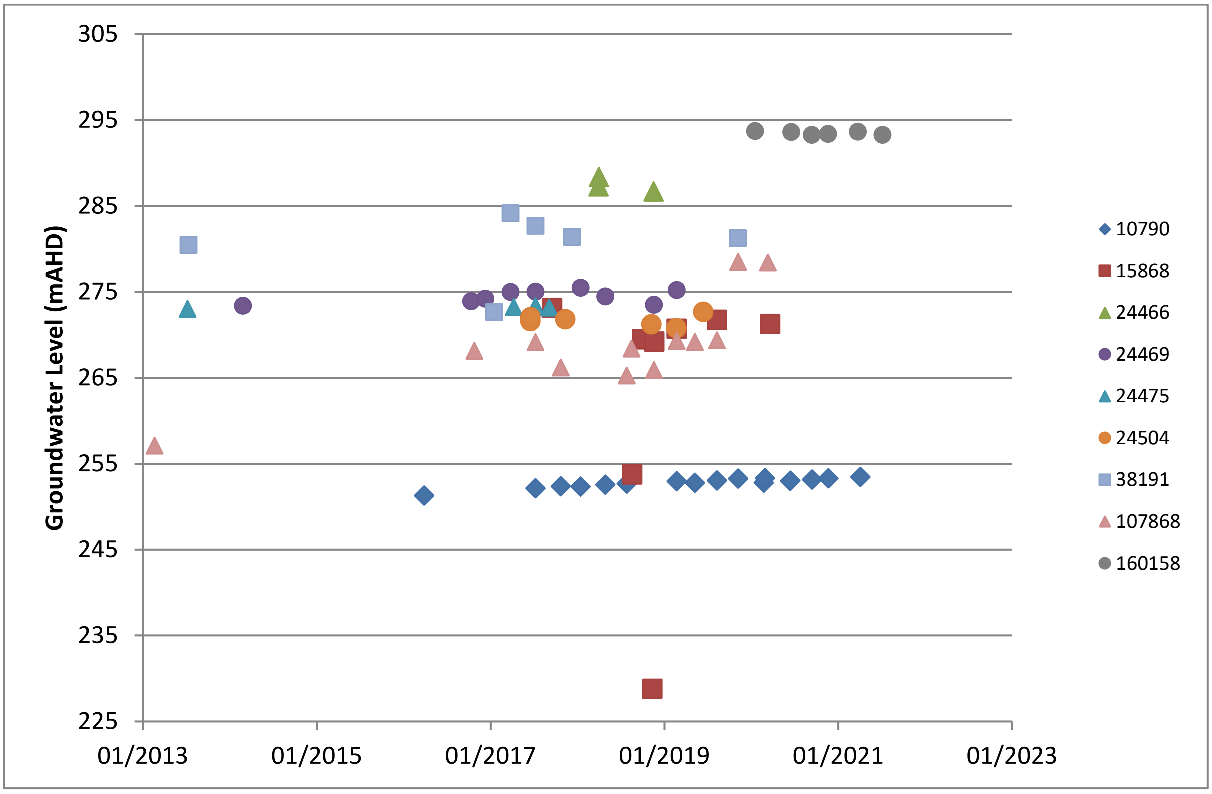


Figure 8 – Hydrographs for registered groundwater bores, Walloon Coal Measures

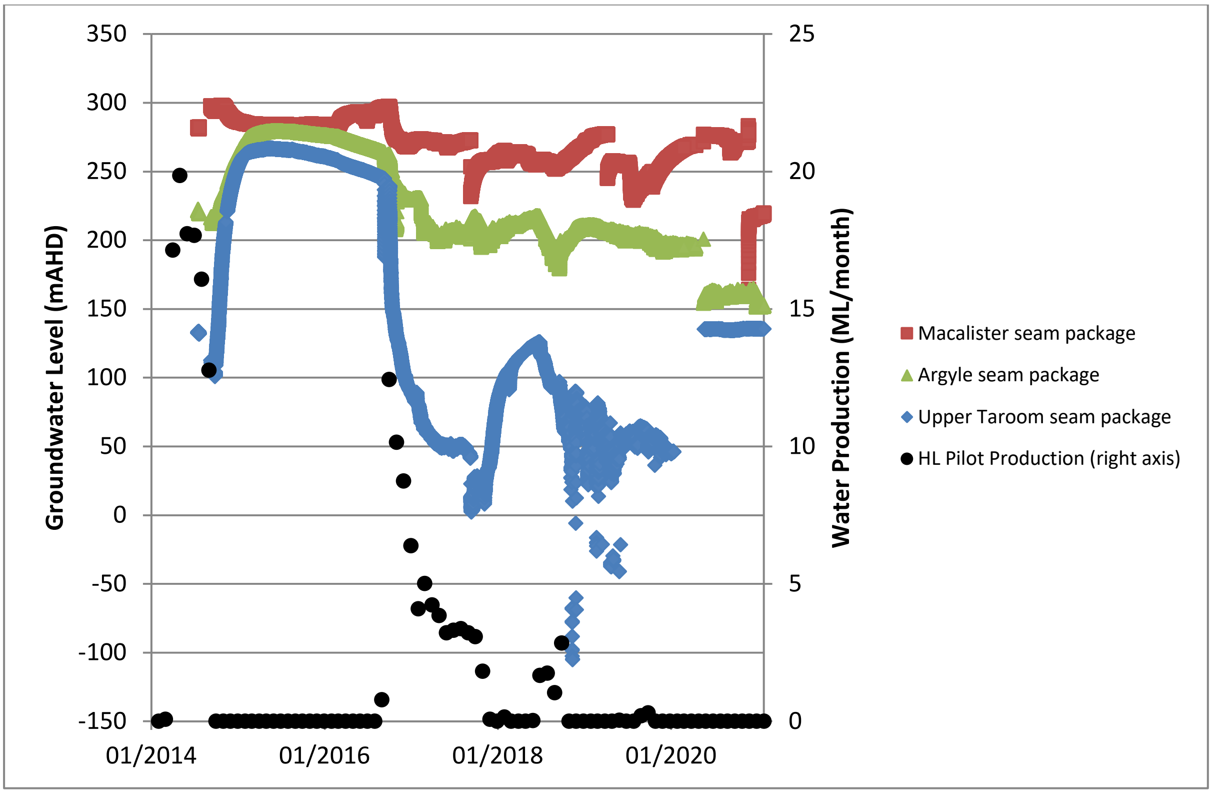


Figure 9 – Hydrographs for discrete seam packages of multilevel monitoring bore Hopeland 17 and monthly water production from the Hopeland Pilot production wells

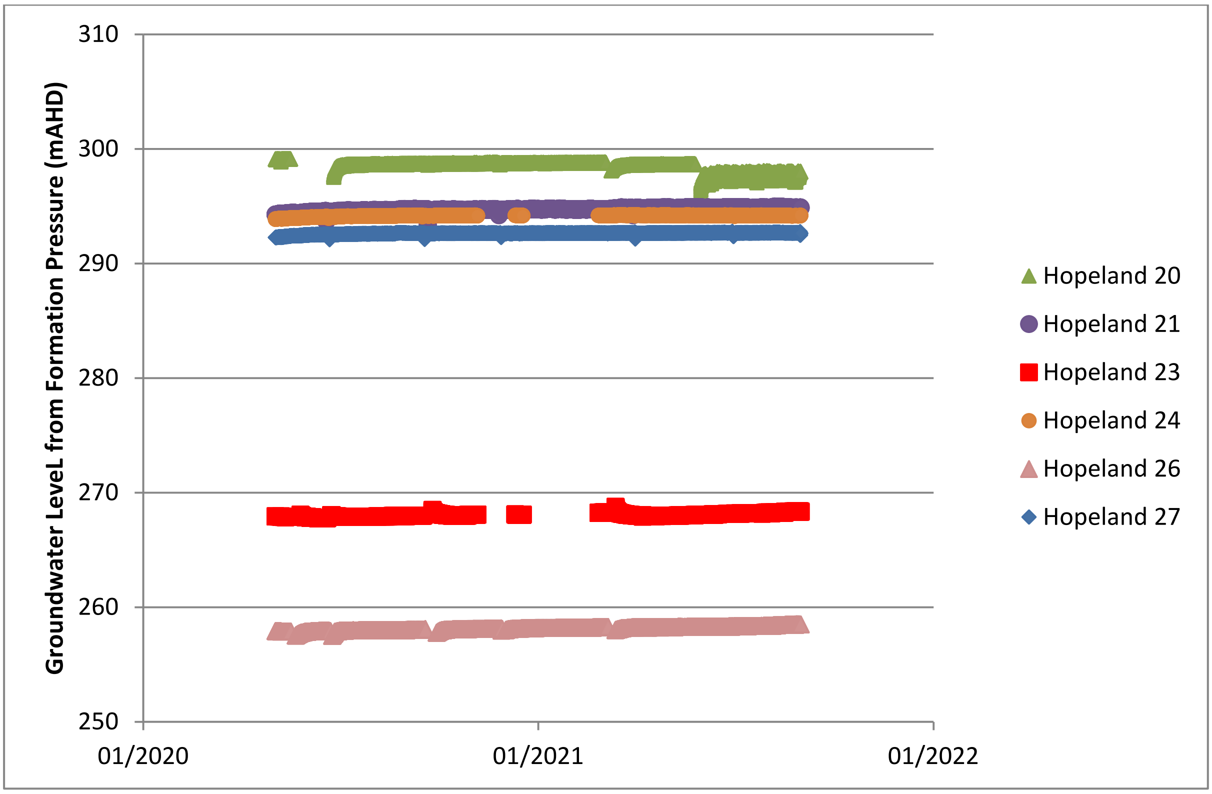


Figure 10 – Hydrographs for registered groundwater bores, Walloon Coal Measures

Groundwater quality from landholder and Arrow monitoring bores for the WCM are provided in **Attachment A** and shown graphically in the Piper diagram in **Figure 11**. Groundwater within this formation is typically moderately alkaline, brackish, and of a sodium chloride-bicarbonate type.

A total of 51 groundwater samples from 27 bores have been analysed for the WCM. The median concentrations for TDS and the major ions are: TDS 2,316 mg/L, sodium 914 mg/L, calcium 6 mg/L, chloride 600 mg/L, and bicarbonate 731 mg/L for the most recent sample from each bore. The median field pH is 8.59.

Within the site of the former Linc Energy UCG operations on Lot 40 DY85, the WCM is contaminated with varying levels of BTEX, phenolic, and polycyclic aromatic hydrocarbon compounds, and the groundwater also tends to be more alkaline and saline than the WCM regionally. The median concentrations for TDS and the major ions are: TDS 6,530 mg/L, sodium 1,815 mg/L, calcium 11 mg/L, chloride 2,995 mg/L, and bicarbonate 405 mg/L for the 6 monitoring bores with the most recent sample for each bore presented in the Piper diagram in **Figure 10**. The median field pH is 9.10. It should be noted that there is evidence of drilling fluids salts (principally potassium chloride) in these groundwater samples and therefore they may not be fully representative of the groundwater.

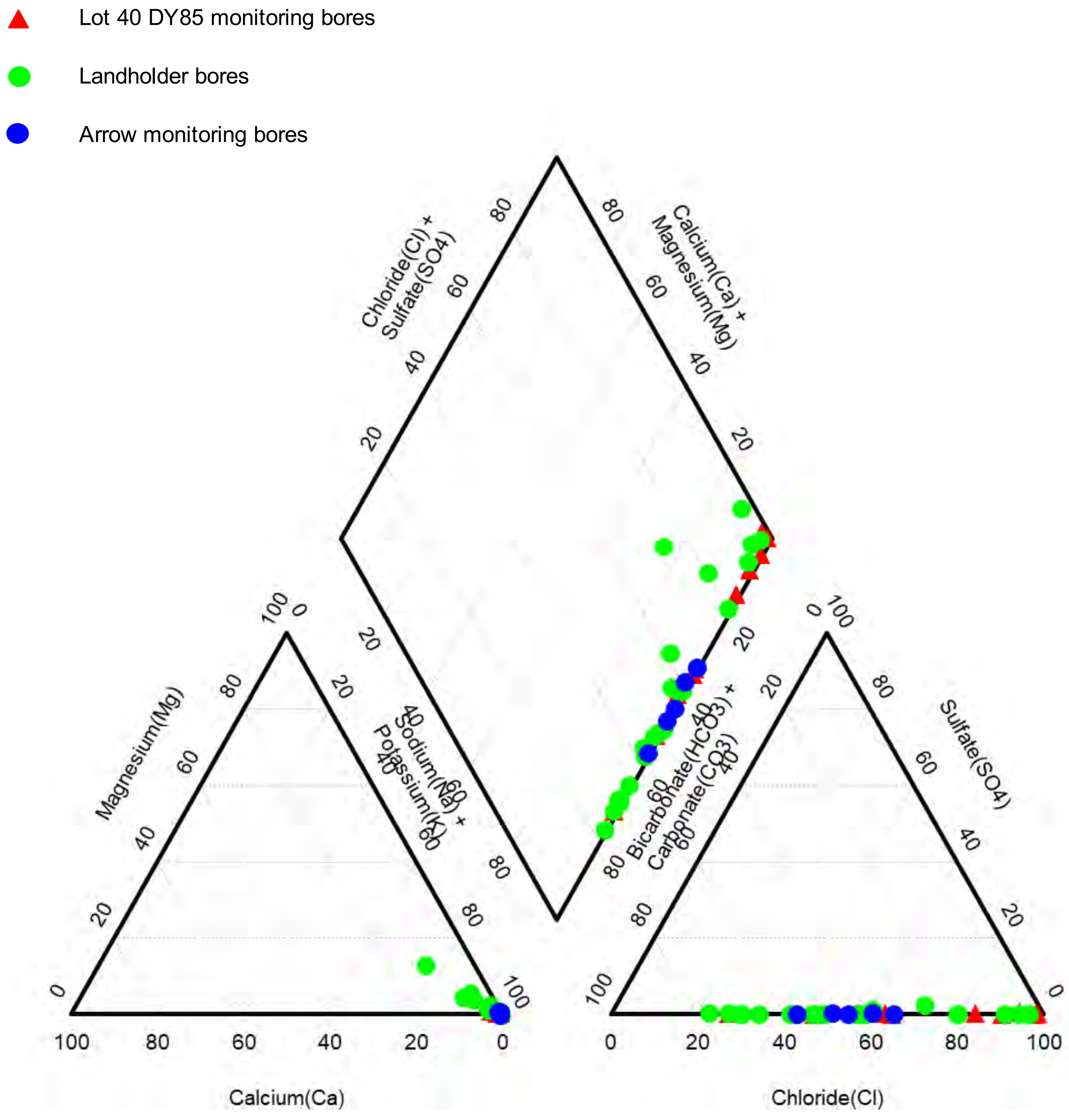


Figure 11 – Piper diagram of groundwater quality data for the Walloon Coal Measures within PL253

Hutton Sandstone

Conformably underlying the WCM, the middle Jurassic-aged Hutton Sandstone consists of fine- to medium-grained quartzose to sub-labile sandstone with interbedded siltstone and shale, and is heterogeneous with significant lateral and vertical facies changes. The permeable quartzose sandstones make the Hutton Sandstone a regionally important GAB aquifer. The 2019 Surat CMA UWIR classifies the Hutton Sandstone as a partial aquifer with medium transmissivity, bore yields that are vertically and laterally inconsistent at a regional scale and exhibiting a high degree of heterogeneity. From the limited drilling that has been undertaken through the Hutton Sandstone in PL253, the formation is up to 200 m thick, with a depth to the top of the formation ranging from approximately 655 m below ground level (mbgl) in the southwest of the tenement at Hopeland 17 to approximately 440 mbgl in the north at water bore 172538.

Development of groundwater resources within the Hutton Sandstone within PL253 has recently commenced, with the first water supply bore installed in July 2017. A review was undertaken for groundwater level data available on PL253 which is shown in Table 9, with a hydrograph in Figure 12. Based on this data, groundwater levels in the Hutton Sandstone range from approximately 17 to 25 mbgl (between 291 and 297 mAHD) when unaffected by significant pumping. The non-pumping water level in 172538 has decreased from approximately 25.2 to 26.6 mgbl over the 15 months since monitoring commenced, which is consistent with regional drawdown trends in the Hutton Sandstone reported by in the Surat CMA UWIR and is related to non-CSG stresses on the aquifer. The 2019 Surat CMA UWIR has identified that there is no IAA or LAA within PL253 for the Hutton Sandstone. Therefore, this aquifer is not affected or likely to be significantly affected by the exercise of underground water rights on PL253 and won't be considered further in this Appendix.

Groundwater quality data is available from one of the two landholder bores for the Hutton Sandstone, as provided in Attachment A. Groundwater from this bore is slightly alkaline, brackish, and of a sodium-bicarbonate type.

Table 9 – Groundwater level data for the Hutton Sandstone

Bore	Depth to Water (mbgl)	Water Level (mAHD)	Comment
172327	17.5 and 18.9	296.9 to 298.3	2 water levels, 2017
172538	25.2 to >52.3	<264.79 to 291.6	Water levels pump affected, hydrograph shown in figure

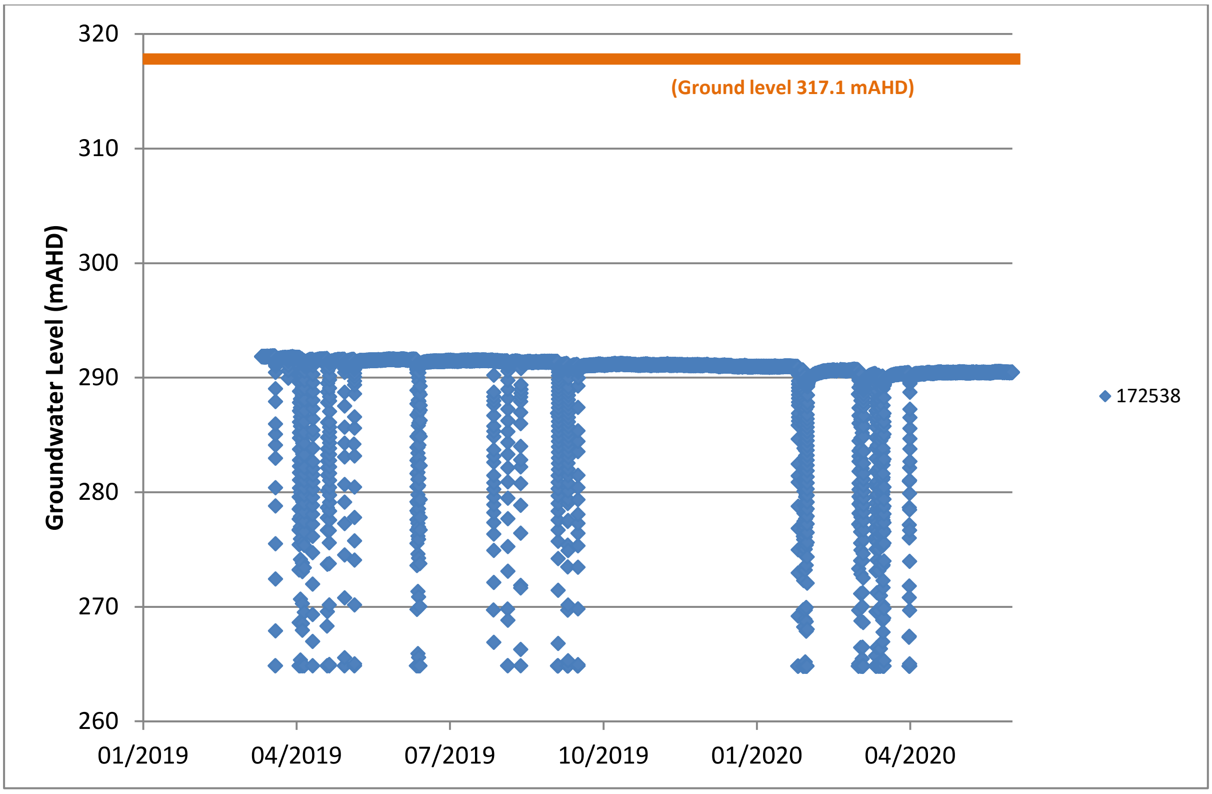


Figure 12 – Hydrograph for 172538, Hutton Sandstone

Evergreen Formation

The Evergreen Formation conformably underlies the Hutton Sandstone, and from the limited drilling logs (Hopeland 17 and regional monitoring bore 119965, location shown in Figure 2 and 5 respectively) comprises siltstone, mudstone and subordinate fine-grained labile sandstone and is up to 200m thick. The Evergreen Formation conformably overlies the Precipice Sandstone, however seismic surveys within PL253 indicate that basement highs may have precluded deposition of the Precipice Sandstone in the north of the tenement where the Evergreen Formation is expected to onlap onto basement. The Evergreen Formation is a regional aquitard in the GAB and locally, and there are no water bores completed in this formation in PL253.

Precipice Sandstone

The Precipice Sandstone is the lowermost formation in the Surat Basin sequence within PL253 and conformably underlies the Evergreen Formation. From the limited drilling undertaken into this formation (Hopeland 17 and 119965), the Precipice Sandstone is approximately 30 to 80 m thick in the southwest of the tenement, and consists of fine to coarse grained thickly bedded quartzose sandstone with minor siltstone.

The 2019 Surat CMA UWIR classifies the Precipice Sandstone as a laterally continuous regional aquifer in the Surat Basin with high transmissivity and bore yields that are vertically and laterally consistent at a regional scale. Within PL253 it unconformably overlies basement and pinches out against basement highs in the north of the tenement as discussed above.

A review was undertaken for groundwater level data available on PL253 for the Precipice Sandstone. Only one bore, regional monitoring bore 119965, accesses the Precipice Sandstone within PL253. For this bore, groundwater levels have reduced from approximately 10.2 to 14.6 mbgl (between 302.0 and 297.5 mAHD) over the 4.5 years since monitoring commenced as shown in Figure 13, which is consistent with regional drawdown trends in the Precipice Sandstone reported in the Surat CMA UWIR and is related to non-CSG stresses on the aquifer. The 2019 Surat CMA UWIR has identified that there is no IAA or LAA within PL253 for the Precipice

Sandstone. Therefore, this aquifer is not affected or likely to be significantly affected by the exercise of underground water rights on PL253 and won't be considered further in this Appendix.

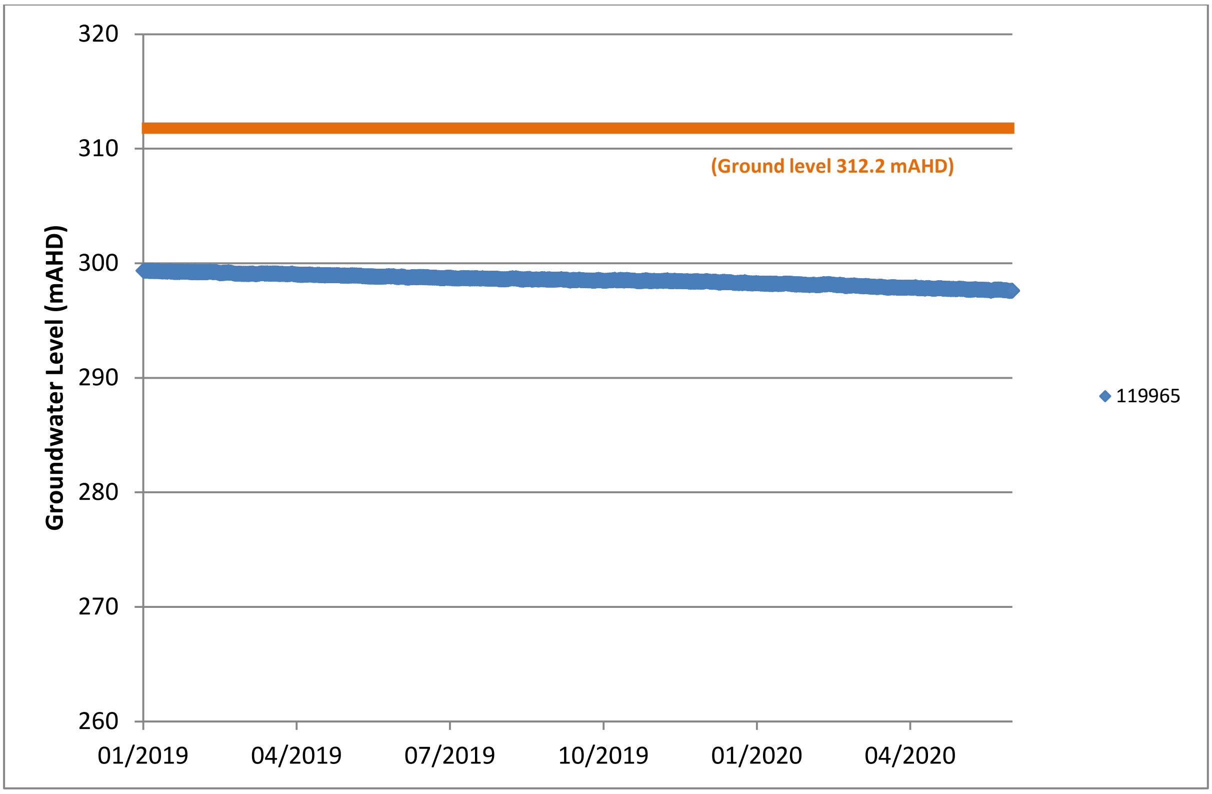


Figure 13 – Hydrograph for 119965, Precipice Sandstone

ii. an analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers and surface water

Groundwater flow processes, movement, connectivity and flow paths are described in more detail in the SGP EIS and SREIS as well as the 2019 Surat CMA UWIR for Arrow tenements including PL253.

Cenozoic sediments

Groundwater flow in the Cenozoic sediments is characterised by local flow in unconfined aquifer systems near the surface. These local flow paths are found in the relatively more permeable alluvial sediments found predominately along the watercourses. Mechanisms for recharge and discharge for the Cenozoic sediments indicate that aquifer recharge occurs via rainfall and leakage from stream beds, with little baseflow from aquifers to watercourses. Discharge from the Cenozoic sediments is also expected to occur by evapotranspiration from the terrestrial groundwater dependent ecosystems along the watercourses.

Surat Basin formations

Groundwater movement in the major confined aquifers of the Surat Basin is predominantly horizontal. The lower permeability units between these aquifers restrict vertical interconnection between the groundwater systems; however, vertical inter-aquifer flow may occur in areas where aquitards are thinner or eroded. In addition, if significant groundwater pressure differences occur across different formations, then inter-aquifer groundwater flow can occur.

The hydraulic connection between the unconfined aquifers in the Cenozoic sediments and the deeper confined aquifers of the Surat Basin is governed by the vertical permeability of the two formations in contact and the vertical pressure gradient. Vertical groundwater flow will occur readily where the two formations have similar high permeability's or where there is considerable vertical pressure driving the flow. Within PL253, the

Westbourne Formation is the main unit which underlies the Cenozoic sediments across the tenure. The Westbourne Formation is a tight aquitard, and therefor vertical groundwater flow will be retarded between the Cenozoic sediments and the underlying Surat Basin formations. In the north of the tenure, where the Springbok Sandstone subcrops under the Cenozoic sediments, vertical groundwater flow may occur into the Springbok Sandstone.

The WCM in the tenure area is not connected to any surface water and the Condamine alluvium is located to the north and north east of PL253. Groundwater flow in all the seam packages of the WCM within PL253 is to the south and west, as shown in the groundwater model developed for this EA amendment application in Appendix E and the Surat CMA UWIR, with groundwater flow toward the significant drawdown resulting from existing CSG operations on tenures adjoining PL253 to the west and south. This general flow direction is modified in the area of the former Linc Energy site on Lot 40 DY85 where the groundwater levels in the Macalister seam package have been lowered by the previous UCG operations. There is no evidence that groundwater flow in the Wambo seam package below Lot 40 DY85 have been altered by operations in the overlying unit.

The WCM is the main aquifer to be impacted due to the CSG water production. In areas of CSG development, such as at the Hopeland Pilot production wells or the tenures to the south and west of PL253, groundwater pressures began to fall in the WCM when development began. However, the coal formations are complex with relatively high-permeability coal seams existing in a relatively low-permeability matrix of mainly mudstones and siltstones. The individual coal seams do not extend over large distances and as a result, the pressure response to CSG water extraction within the formation is complex. Pressure falls quickly in coal seams at the start of development but falls more slowly in the interburden aquitard material and coal seams that remain disconnected. At this stage, pressure reductions of over 200 metres have been observed at the Hopeland 17 monitoring location within the WCM. Pressure impacts in the Walloon Coal Measures tend to be limited to the immediate vicinity of CSG production areas.

The Arrow geological model incorporates faults as presented on Figure 2, derived from drilling data and seismic surveys. These faults tend to be small, with fault throws less than 20m, such that juxtaposition of coal seams against overlying or underlying aquifers would be limited. The 2019 Surat CMA UWIR includes an analysis of smaller faults and indicates that although there is potential to increase connectivity with overlying aquifers at some locations, widespread connectivity is not expected.

Groundwater flow in the Springbok Sandstone within PL253 is to the south and west, as shown in the groundwater model developed for this EA amendment application in Appendix E and the Surat CMA UWIR. This general flow direction is modified in the area of the former Linc Energy site on Lot 40 DY85 where the groundwater levels have been lowered by secondary connection of the formation to the gasifier in the Macalister seam package of the WCM.

The Springbok Sandstone will, with the exercise of underground water rights in the underlying WCM, be the first aquifer to be affected. As reported in the 2019 Surat CMA UWIR, both the WCM and the Springbok Sandstone tend to be highly stratified and include significant proportions of siltstone and mudstone. As a result, the vertical permeability is much lower than in the horizontal direction. Interconnectivity between these two units is therefore considered likely to be low despite the direct erosional contact between the units (i.e. the absence of an intervening aquitard). However, since the contact between the two formations is erosional, there are areas where the Springbok Sandstone is in contact with the productive coal seams. A higher degree of interconnectivity is expected in these areas.

Groundwater flow in the deeper confined aquifer systems of the Hutton and Precipice Sandstones is regional and consistent with the overall groundwater flow patterns in the GAB as modelled in the Surat CMA UWIR. That is, regional groundwater flow in these strata is toward the west to south-west. This groundwater flow is dominantly horizontal because vertical groundwater flow is restricted by the low permeability mudstone and claystone beds within the WCM and the extensive low permeability Eurombah or Durabilla Formation at the base of the WCM. Vertical groundwater flow between the Hutton Sandstone and the Precipice Sandstone is restricted by the thick low permeability Evergreen Formation that separates these strata.

Springs

Arrow has no assigned responsibilities regarding potentially affected springs within PL253 under the Spring Impact Management Strategy (SIMS) in the 2019 Surat CMA UWIR. The SIMS is considered to adequately address the potential impact to springs and no further assessment has been undertaken. In addition, no springs within Arrow tenure other than those identified and considered in the Surat CMA UWIR are known to be present.

Within PL253 a spring has been identified which discharges to a small tributary off Wambo Creek, with the location shown in Figure 14. This spring has been included in the list of springs considered in the 2019 Surat CMA UWIR. It is listed as Spring Complex 765 “Orana” and being a Type 4a spring. Type 4a springs are semi-permanent fresh to palustrine wetland springs, mainly fed by local groundwater systems and associated with a riverine environment with deep, sandy alluvial deposits (non-GAB). 3D Environmental investigated this spring (referred to as the ‘Trebilco Spring’) for Arrow’s Stage 1 Water Monitoring and Management Plan and found that it is an ephemeral spring which is fed by groundwater stored intermittently in the sandy ridge located west of the creek and is not likely sourced from the underlying GAB aquifers subject to potential impact through Arrow’s activities. The groundwater in the sand is perched on low permeability clay and discharges where the phreatic surface intersects the lower slope of the creek bank at an elevation of approximately 301 m AHD. This is supported by the quality of the water which discharge from the spring, which is fresh and slightly acidic, with a dissolved solids of 146 mg/L and a sodium-chloride type as shown in the major ion chemistry in Attachment A. The conceptual model of the spring developed by 3D Environmental is provided in Plate 1. The source aquifer is attributed to Cenozoic sediments, and the 2019 Surat CMA UWIR spring risk assessment indicated the potential impacts at this spring are small and occur more than 100 years in the future. No mitigation measures are proposed by OGIA for this spring. OGIA will review its status in the next UWIR. It is considered unlikely that there will be any ecological impact to this sole non-GAB spring GDE as a result of the exercise of underground water rights.

Arrow is compliant with all its Responsible Tenure Holder obligations for Springs as prescribed in the 2019 Surat CMA UWIR.

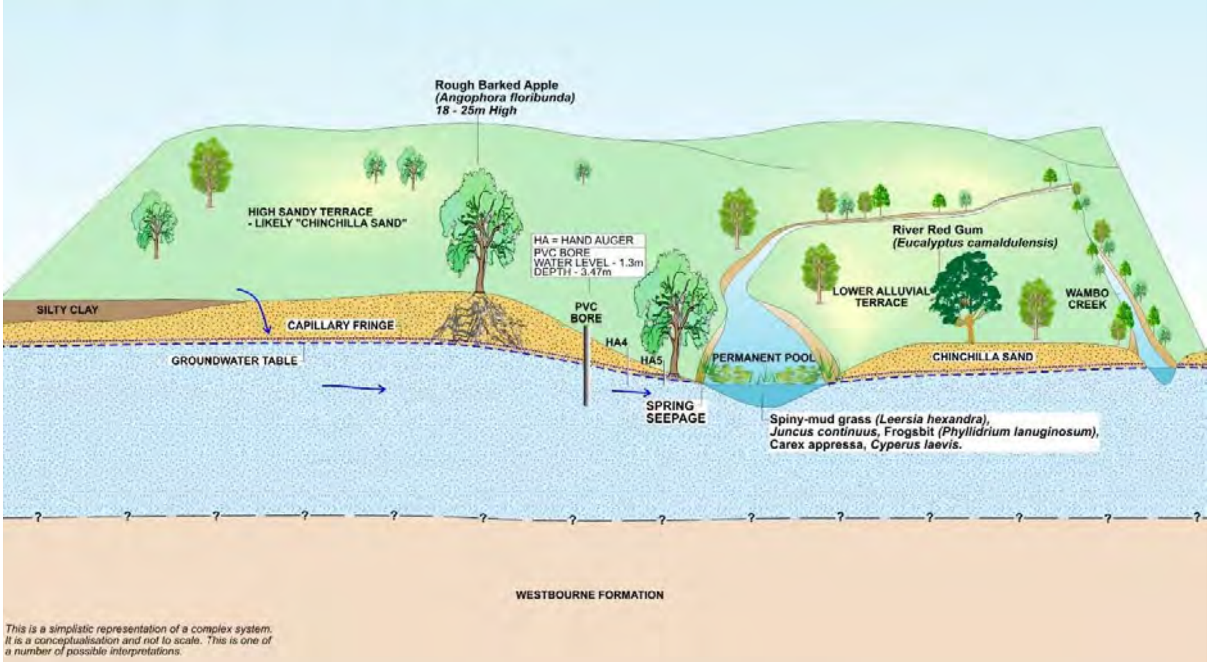
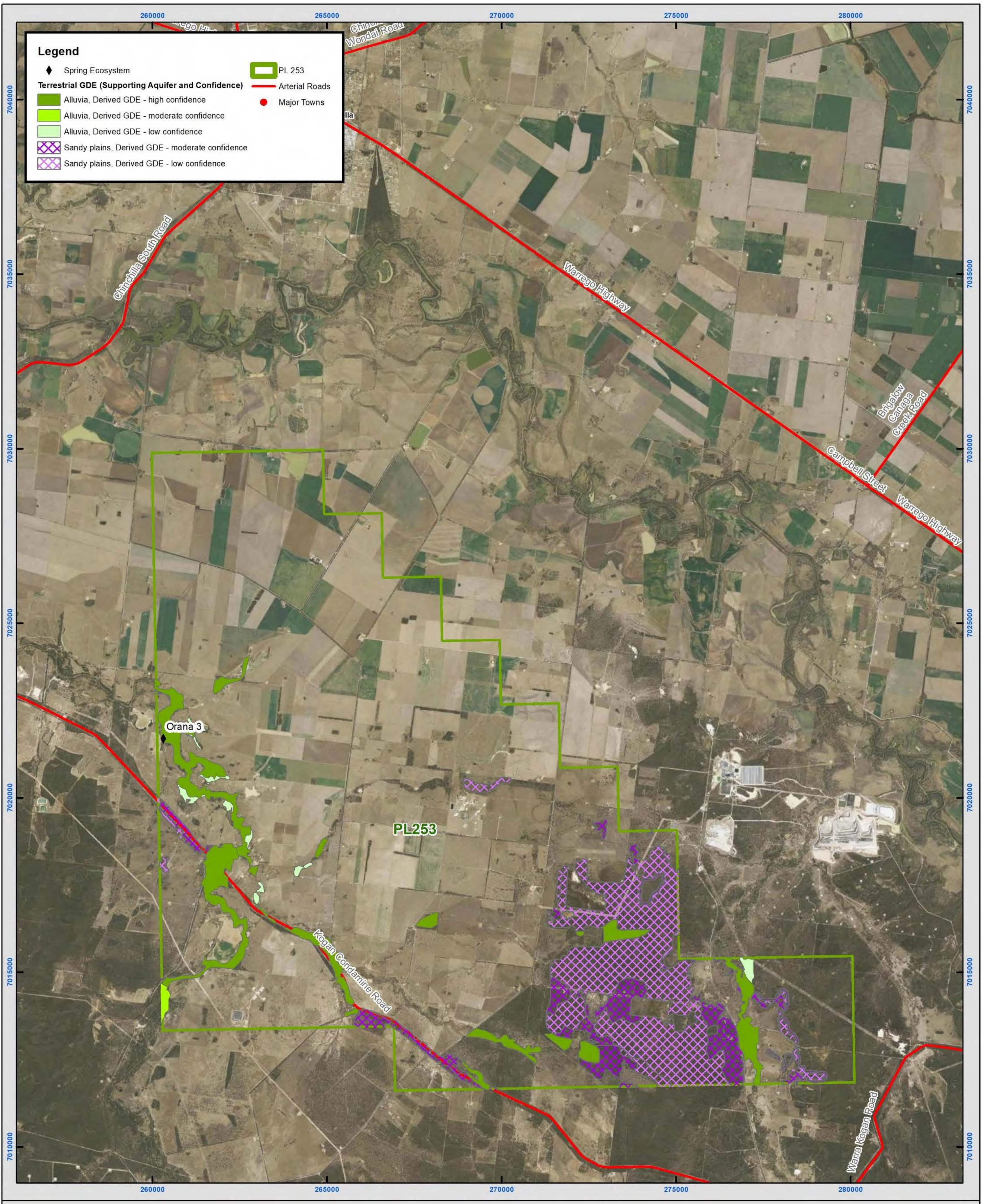


Plate 1 – Conceptual model of the Orana Spring

Non-Spring Groundwater Dependent Ecosystems

Riparian vegetation that represent terrestrial groundwater dependent ecosystems (GDEs) may be present along significant reaches of some watercourses and their tributaries as shown in Figure 14. Regional mapping, derived with varying levels of confidence 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. These GDE are described as ecosystems intermittently connected to aquifers with brackish to saline salinity and near neutral to alkaline pH in sandy plains or unconsolidated alluvia (https://wetlandinfo.des.qld.gov.au/wetlands/facts-maps/). These terrestrial GDE are supported by the shallow unconfined aquifers above the Westbourne Formation aquitard, and the 2019 Surat CMA UWIR determined that drawdown within the supporting aquifer would be less than 0.2 m within PL253 and therefor did not assign a risk rating to these terrestrial GDEs.



Groundwater Dependent Ecosystems within PL253

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 3/07/2020
Issued To: Final
Author: sdenner

0 0.75 1.5 3 4.5 6 Kilometers

Scale: 1:100,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

N

The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

Document: V:\Users\sdenner\Surat\PL253\PL253_GDEs_A3_Portrait.mxd

Figure 14 – Groundwater dependent ecosystems within PL253

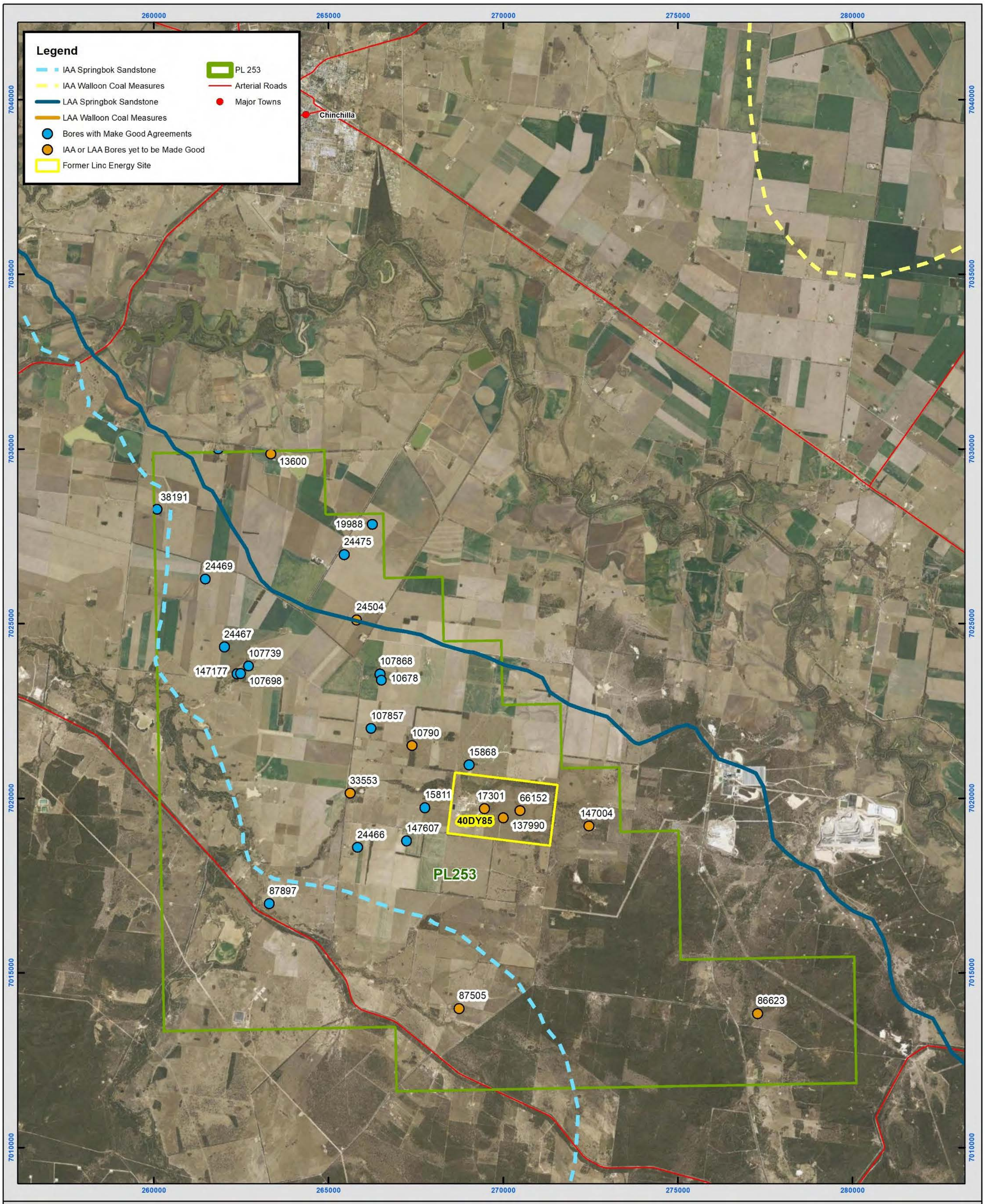
iii. a description of the area of the aquifer where the water level is predicted to decline because of the exercise of underground water rights

The 2019 Surat CMA UWIR identifies aquifers where groundwater levels are predicted to fall by more than the trigger threshold as specified in the *Water Act 2000* due to the exercise of underground water rights by petroleum tenure holders. The trigger thresholds are 2 m in unconsolidated aquifers and 5 m in consolidated aquifers. The areas of aquifers where groundwater level declines are predicted to exceed these thresholds within three years are defined as the Immediate Affected Areas (IAA). The areas of aquifers where groundwater level declines are predicted to exceed these thresholds at any time are defined as the Long-term Affected Area (LAA).

The 2019 Surat CMA UWIR model produced outcomes that indicate that all of the PL253 area is within the IAA for the WCM and part of PL253 is within the IAA for the Springbok Sandstone (Figure 15). The former Linc UCG site is not within the IAA of the Springbok Sandstone. PL253 is within the LAA for the WCM and Springbok Sandstone as shown in Figure 15.

There are no other IAAs or LAAs within any other aquifers within PL253, with any impact in these aquifers is predicted to be less than the trigger thresholds.

The modelled drawdown in all aquifers, as a result of the exercise of underground water rights on all tenures including PL253 in the Surat CMA, are presented in Appendix G of the 2019 Surat CMA UWIR.



Made Good Bores and IAA or LAA Bores yet to be Made Good within PL253

Source: Arrow Energy Pty Ltd
Geoscience Australia
Dept. Natural Resources and Mines

Date: 14/09/2021
Issued To: Final

0 0.75 1.5 3 4.5 6 Kilometers

Scale: 1:100,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

N

The dimensions, areas, number of lots, size & location of corridor information are approximate only and may vary.

Figure 15 – IAA and LAA for PL253 and status of bores with a make good agreement or yet to be made good

iv. *the predicted quantities of water to be taken or interfered with because of the exercise of underground water rights during the period in which resource activities are carried out.*

The predicted quantities of water to be taken or interfered with because of the exercise of underground water rights for PL253 is discussed in **Section 5** of this amendment application. A description of the project and proposed staging is provided in **Section** 4 of this amendment application.

As indicated in **Sections 5.1** and **5.2** of this amendment application, a total of 55 new production wells are proposed to be constructed. The CSG water production over the life of the project will be in the order of 10.4 GL, with a peak rate of approximately 11 ML/day in year 1 (2025) and diminishing quickly from this peak in 2026 and continue to diminish through the project.

Arrow provides its water production volumes and forecasts to the Office of Groundwater Impact Assessment (OGIA) for inclusion in the Surat CMA UWIR.

d) *the environmental values that will, or may, be affected by the exercise of underground water rights and the nature and extent of the impacts on the environmental values;*

An assessment of groundwater environmental values was undertaken as part of the Surat Gas Project EIS and SREIS, as well as the 2019 Surat CMA UWIR. The table below provides a summary of the values that relate to the system where impacts are predicted from the identified resource activities on PL253. Based on this, any impacts to environmental values will be in line with that presented in the EIS, SREIS and 2019 Surat CMA UWIR.

Table 10 – Existing environmental values that may be affected by the exercise of underground water rights

Existing Environment/Groundwater System	Intrinsic Characteristics and Hydrogeological Processes
Springbok Sandstone	• Groundwater from this system is of moderate biological importance due to generally brackish water quality • There are no known areas of physical connection between this groundwater system and surface features within PL253 • This aquifer is not known to support specific areas of cultural or spiritual significance • This aquifer provides a quality and supply generally suitable for agricultural uses • This aquifer forms a regional aquifer system across the GAB, and equivalent aquifers are common in many areas • There are multiple recharge mechanisms producing a moderately resilient system that can recover over the medium term • Rehabilitation can be achieved when impacts are removed
WCM	• Groundwater from this system is of moderate biological importance due to generally brackish water quality • There are no known areas of physical connection between this groundwater system and surface features within PL253 • This aquifer is not known to support specific areas of cultural or spiritual significance • The aquifers in the WCM provide a quality and supply generally suitable for agricultural uses • The coal seam gas groundwater system is a regional aquifer system across the GAB, and equivalent aquifers are common in many areas • The WCM groundwater system is less dynamic than other shallower systems, with limited recharge mechanisms. The aquifers within the WCM groundwater system are recharged through rainfall only where outcropping

	and through inter-aquifer leakage and can recover from groundwater drawdown slowly. • Rehabilitation can be achieved when impacts are removed.

Within PL253, there are 24 water bores predicted to be impacted by the exercise of underground water rights, within the IAA and LAA of the 2019 Surat CMA UWIR. The location of water bores that Arrow has made good as a result of this or previous UWIR are shown in **Figure 15**. There are 10 remaining bores for which Arrow will conduct bore assessments and make best endeavours to negotiate make good agreement with affected bore owners.

Arrow contributes with other CSG proponents to a subsidence monitoring program involving use of satellite imaging using Interferometric Synthetic Aperture Radar (InSAR) which provides baseline data and a regular interpretation of ground movement over the area of CSG extraction or planned extraction. Arrow's Stage 1 and Updated Water Monitoring and Management Plan includes a subsidence impact assessment which covers PL253. As part of the resulting monitoring and management strategy, a subsidence monitoring station has been installed in the southwest of PL253.

Additionally, the Surat Gas Project approval conditions require assessment of potential impacts on non-spring based groundwater dependent ecosystems. This assessment has been completed and involves the identification of potential GDE landscapes, use of modelling to predict areas of potential impact and a risk assessment to identify GDEs at risk of impact. This assessment is presented in the Stage 1 Water Monitoring and Management Plan, and based on this assessment there are no GDEs at risk of impact on PL253.

e) any impacts on the quality of groundwater that will, or may, happen because of the exercise of underground water rights during or after the period in which resource activities are carried out;

The SGP SREIS presented the groundwater within key aquifer units classified by its groundwater quality composition, based on major ion composition, total dissolved solids (TDS) and pH. The following section provides data specific to PL253 and represents the baseline water and reference point for any future assessment of impacts to groundwater quality.

The proposed CSG activities on PL253 has the potential to directly and indirectly degrade groundwater quality. Surface activities generally have the greatest potential to directly impact groundwater quality and subsurface activities (i.e. aquifer depressurisation) have the greatest potential to indirectly impact groundwater quality. The magnitude of both the potential direct and indirect impacts is a function of the depth below the surface of the receiving aquifer. Shallow unconfined aquifers have a higher potential to be directly impacted while the deeper confined aquifer have a lower probability of being directly impact; however, they do have a potential to be indirectly impacted.

In the broadest sense, direct impacts are mostly like to occur as the result of surface spills and uncontrolled releases of liquids and solids. Indirect impacts are most likely to occur as the result of changes in groundwater flux directions following groundwater pumping used to depressurise the WCM.

Potential direct impacts to groundwater quality could result from:

- Surface leaks and spills from CSG infrastructure. This includes drilling mud, chemical, solid and liquid waste, and associated water spills.
- Leaks from buried infrastructure such as pipelines, gathering lines and underground storage containers and tanks.
- Leaks from the untreated water storage dam at the Hopeland Pilot production wells.
- Associated water discharges to streams, which has the potential to infiltrate the subsurface profile and impact the groundwater systems.

Potential indirect impacts to groundwater quality could result from:

- Induced aquifer interflow and groundwater mixing in aquifers above and below the WCM caused by direct CSG water extraction from the WCMs.
- Induced changes in groundwater flux directions due to depressurisation from the WCM resulting in the migration of poorer quality groundwater to higher quality groundwater, or inducing inter-aquifer flows.
- Piezometric surface drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) resulting in the migration of poorer quality groundwater to higher quality groundwater.
- Piezometric surface drawdown surrounding non-CSG bores promoting the influx of comparatively poor quality water to the bore.
- Incomplete or incorrect well installation resulting in the interconnection of aquifers allowing the mixing of lower quality groundwater with higher quality groundwater.

Depressurisation of the WCM has the potential to increase the current flux from aquifers above the WCM and increase flux to the WCM from underlying aquifers. This potential increase to groundwater flux will act to reduce the potential of moving poorer quality deep groundwater of the Walloon Coal Measures into the overlying or underlying aquifers.

Potential Mobilisation of UCG Contaminants

UCG operations were conducted on Lot 40 DY85 within the area of PL253 by Linc Energy between 1999 and 2013 before the company went into liquidation. The site is now managed by the Queensland Department of Resources, and an investigation into contamination as a result of the UCG operations is currently being conducted.

Contamination of the groundwater in the Springbok Sandstone and WCM is evident in data supplied to Arrow by the Queensland Department of Environment and Science. Contaminants include phenolic compounds, polynuclear aromatic hydrocarbons, BTEX compounds (benzene, toluene, ethylbenzene and xylene), and other hydrocarbon or organic compounds. As discussed previously, the UCG operation has caused connection and enhanced permeability between the target of the UCG operation, the Macalister seam package, and the overlying Springbok Sandstone. The connection between the Springbok Sandstone and the Macalister seam package may result in movement of the contaminants as a result of the exercise of underground water rights within the WCM, by either increasing or changing the flow within or between units. Groundwater flow modelling and contaminant fate and transport modelling has been undertaken to assess the risk of migration of contaminants as a result of Arrow's proposed development, as presented in Appendix E of this EA amendment application.

f) strategies for avoiding, mitigating or managing the predicted impacts on the environmental values or impacts on the quality of groundwater mentioned in paragraph (e)

Potential impacts on groundwater systems for Arrows tenements including PL253 will be managed through a hierarchy of design, mitigation, monitoring and management options that form the basis for an adaptive management framework. This is detailed in Arrows SGP EIS and SREIS and Section 6.3 of this amendment application.

Arrow will implement the commitments it made in the EIS and updated in the SREIS in order to effectively manage and monitor the effects of CSG water extraction and related activities on local and regional groundwater values. These commitments are consistent with the existing legislative framework, specifically Chapter 3 of the Water Act. These legislative requirements are further detailed in the 2019 Surat CMA UWIR (Sections 8, 9 and 11, where applicable to the SGP) and Arrow's Stage 1 and Updated Water Monitoring and Management Plan (WMMP) (the direct links to these reports were provided above).

The commitments summarised below will be adapted to allow management decisions based on an increased knowledge developed over time.

Design and planning commitments

The following measures have been developed to manage the potential impacts on groundwater values during the design and planning phase of the project:

- Arrow has prepared a baseline assessment plan to establish benchmark data in registered third party bores (where possible) prior to the commencement of Arrow extraction activities in the PL253 area in accordance with the Water Act 2000, including the preparation and implementation of a groundwater monitoring and investigation strategy.
- Consider local biological, groundwater and surface water conditions when identifying sites for CSG infrastructure including storages.
- Consider local groundwater conditions when identifying sites and routes for the installation of buried infrastructure (e.g. gathering lines).
- Avoid unnecessary impervious surface coverings and minimise land footprint and vegetation clearing when designing facilities.
- Develop make-good agreements that include the outcome of bore assessments and implementation of make-good measures in the event that impaired capacity occurs.
- Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the amount of data on aquifer properties and groundwater movement that can be used in predictive numerical groundwater models.
- Ongoing collection of relevant geological and hydrogeological data from existing and future production wells, monitoring bores and registered third party bores (where possible) together with information collated collaboratively with other proponents and regulatory authorities.
- Maintain water balance models for long-term planning and management of CSG water. Review and update modelling in alignment with the production forecasting schedule.

Construction commitments

The following mitigation, monitoring and management measures have been developed to address the potential impacts on groundwater values during the construction phase of the project:

- Avoid disturbance of contaminated soil and groundwater when it is identified or observed during intrusive works.
- Manage disturbed contaminated soil or groundwater that cannot be avoided through physical investigation; manage quantification of the type, severity and extent of contamination; and remediate or manage in accordance with the relevant Queensland Government's legislation and guidelines.
- Construct all monitoring bores in accordance with the relevant regulation, such as the Minimum Construction Requirements for Water Bores in Australia, the Minimum Standards for the Construction and Reconditioning of Water Bores that Intersect the Sediments of Artesian Basins in Queensland, and the Code of Practice for the Construction and Abandonment of Petroleum Wells and Associated Bores in Queensland.
- Select drilling fluids to minimise potential impacts to groundwater. Oil based drilling fluids will not be used.
- Ensure well drilling is monitored by a suitably qualified geologist to ensure aquifers are accurately identified so wells are constructed correctly to protect groundwater.

Operational commitments

The following measures have been developed to address the potential impacts on groundwater values during the operations phase of the project:

- Carry out corrective actions immediately upon the identification of any contamination of soil or groundwater that has occurred as a result of project activities.
- Manage potential impacts to identified spring complexes by:
    - Supporting the identification of specific aquifers that serve as a groundwater source for discharge springs
    - Assessing springs that are predicted to be subject to unacceptable impacts through the source aquifer
    - Developing monitoring and mitigation strategies to avoid or minimise unacceptable impacts
- Implement a well integrity management system during commissioning and operation of production wells.
- Minimise impacts of groundwater depressurisation on sensitive areas (e.g. groundwater dependent ecosystems).
- Develop a procedure for investigating any impaired capacity of third party bores that may become evident through monitoring and landholder liaison.
- If impaired capacity is confirmed (bore can no longer produce quality or quantity of groundwater for the authorised purpose, and the impact is due to CSG activities), implement make-good measures in accordance with the Water Act.

Decommissioning commitments

All production wells and monitoring bores will be decommissioned or repaired either at the end of their operating life span or, in the event of a failed integrity test, in accordance P&G Act or Water Act 2000 and relevant regulations. Should production wells be converted into monitoring bores, it will be done in accordance with relevant regulations.

Regional groundwater monitoring program

The following describes in broad terms the proposed monitoring program and has been provided to the Australian Government consistent with Condition 17 (Updated CSG Water Monitoring and Management Plan) of the EPBC approval for the Surat Gas Project (EPBC 2010/5344). While the SGP EIS and SREIS described locations to be monitored, monitoring requirements have changed due to the absence of any CSG processing and CSG water discharges within the PL253 area.

A water monitoring strategy (WMS) is included in the 2019 Surat CMA UWIR. The WMS includes an integrated regional groundwater monitoring network to collect data on water pressure and water quality in the Surat CMA. The monitoring points and sites are designed to monitor all major aquifers and aquitards in the Surat CMA. The objectives of the WMS are to:

- Understand background trends
- Identify pressure changes near areas of P&G development
- Understand groundwater flow near connectivity features
- Understand groundwater flow near high value assets
- Improve conceptual understanding and future groundwater flow modelling.

The WMS assigns requirements to petroleum tenure holders to establish the regional monitoring network, undertake routine monitoring and reporting of results and report water production data from petroleum and gas wells. The OGIA will routinely assess the monitoring results and report on these annually. Arrow is compliant with the water monitoring strategy and spring impact management strategy as prescribed in the 2019 Surat CMA UWIR. This process has resulted in the collection of a significant data set describing baseline groundwater pressure and quality for reference purposes as required for the larger area and not limited to PL253. Arrow will continue to implement the elements of the UWIR WMS in future versions of the UWIR.

Arrow has installed a comprehensive regional groundwater monitoring network (that satisfies Arrow's obligations as described in the groundwater impact reports in the EIS/SREIS and confirmed in Chapter 8 of the UWIR) to:

- Establish baseline groundwater level and groundwater quality conditions
- Assess natural variation (i.e. seasonal variations) in groundwater levels
- Monitor groundwater levels during the operations phase
- Establish suitable datum levels for each aquifer system
- Target sensitive areas where more frequent monitoring and investigation is required (e.g. groundwater dependent ecosystems)
- Monitor groundwater drawdown as a result of CSG extraction
- Monitor impacts in accordance with the Water Act and regulations
- Provide an 'early warning system' that identifies areas potentially impacted by project activities to allow early intervention and adaptive management.

Commitments in relation to Lot 40DY85

Modelling allows Arrow to explore potential impacts in the future under different scenarios in order to assess the risk posed by our activities. It is important to understand that models do not represent a prediction of what may happen in the future. Rather, they determine the potential outcomes under a set of assumed conditions and are therefore a powerful tool to assess potential change, to indicate risk and to identify scenarios that have a low likelihood of occurring.

Arrow's 2021 groundwater model combined with contaminant fate and transport modelling for Benzene and Naphthalene from the 2020 model show:

- groundwater movement away from Lot 40 DY85 has been slow in all simulations since 2018
-
- Arrow's proposed development on PL253 will have no significant impact on either the rate of groundwater movement or the quality of groundwater. This is highlighted by:
    - Groundwater movement in the Springbok Sandstone and Macalister coal seam is impacted by less than 1m over 20 years

Given the above, the focus of our future management of groundwater on PL253 is appropriately placed on managing risk. The following will be undertaken:

- Arrow will maintain and sample on a quarterly basis the groundwater monitoring bores recently drilled up-gradient and down-gradient of Lot 40 DY85. These bores are appropriately placed to operate as an early warning trigger mechanism.
- Groundwater will continue to be sampled and reported to DES on an annual basis as per our existing Groundwater Characteristics Monitoring Program.
- Our groundwater model will be updated on an annual basis to include the current year of sampling results and predictions with regards to groundwater movement and particle tracking in the Springbok Sandstone and Macalister. This information will be included in the above-mentioned Groundwater Characteristics Monitoring Program.
- If the sampling results from any monitoring bores located off Lot 40 DY85 exceed any of the trigger limits specified in our Environmental Authority, Arrow will:
    - notify DES within forty-eight (48) hours of receiving the results
    - complete an investigation into the potential for environmental harm
    - provide a written report of the investigation to DES within 90 days of receiving the result, with the report outlining details of the investigation conducted and proposed actions to prevent environmental harm.
- Arrow will expand our monitoring program to validate and monitor the proposed activities and gas conditions.

Attachment A – Groundwater quality results

Bore ID	Formation	Date	pH	EC (uS/cm)	TDS (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	HCO3 as CaCO3 (mg/L)	CO3 as CaCO3 (mg/L)	OH as CaCO3 (mg/L)	Cl (mg/L)	SO4 (mg/L)	Total BTEX (ug/L)	Naphthalene (ug/L)
Orana 3 non-GAB spring	Cenozoic sediments	30/11/2016	5.36	151.7	146	21	5	1	1	4	<1	<1	30	9		
Hopeland 16	Westbourne Formation	26/04/2018	6.07	43559	30100	8630	37	655	821	325	<1	<1	14900	94	<1	<1
Hopeland 16	Westbourne Formation	4/10/2018	6.5	40234	32000	8740	36	711	707	331	<1	<1	14000	96	<1	<5
Hopeland 16	Westbourne Formation	23/05/2019	6.2	40259	29100	8270	33	600	746	324	<1	<1	15500	89	<1	<5
Hopeland 16	Westbourne Formation	26/10/2019	6.29	41816	29300	7730	32	614	732	320	<1	<1	14900	84	<1	<5
Hopeland 16	Westbourne Formation	1/11/2020	6.34	39303	26900	8130	36	612	752	322	<1	<1	15100	85	<1	<1
33553	Springbok Sandstone	16/01/2014	8.09	14200	9150	2720	21	328	150	233	<1	<1	5520	<1	<1	<5
33553	Springbok Sandstone	15/08/2019	8.14	7760	5040	1620	10	52	10	325	<1	<1	2580	<1	<1	<5
87505	Springbok Sandstone	24/10/2019	7.19	29000	20000	6370	26	460	224	105	<1	<1	10700	2		
87897	Springbok Sandstone	21/03/2019	8.56	3770	2450	848	3	10	<1	515	40	<1	976	<1	<1	<5
87897	Springbok Sandstone	30/04/2019	7.99	3840	2500	848	4	10	<1	502	61	<1	932	<1		
107857	Springbok Sandstone	26/09/2019	7.93	9220	5990	1900	12	121	29	225	<1	<1	3160	<1	<1	<5
107857	Springbok Sandstone	2/03/2020	6.99	9440	5410	1870	11	94	28	234	<1	<1	3070	<1		
107868	Springbok Sandstone	18/02/2013	7.87	9350	5210	1970	14	32.9	12.8	357	<1	<1	3007	1.3	<1	
107868	Springbok Sandstone	20/08/2018	8.25	10700	6960	2140	8	53	14	359	<1	<1	3520	<1		
15868	Springbok Sandstone	19/03/2020	7.69	22200	15000	4340	21	423	266	327	<1	<1	8110	<1	<1	<5
15868	Springbok Sandstone	23/08/2018	8.36	8360	5430	1720	8	70	56	770	281	<1	2440	<1	<1	<5
15868	Springbok Sandstone	16/11/2018	8.17	6410	4170	1270	5	56	34	946	<1	<1	1530	<1	<1	<5
147004	Springbok Sandstone	23/08/2018	8.01	11400	7410	2200	15	110	79	528	<1	<1	3840	<1	<1	<5
147004	Springbok Sandstone	26/02/2020	7.8	11200	7200	2400	14	93	85	494	<1	<1	3900	<1	<1	<5
147004	Springbok Sandstone	22/06/2020	7.99	11400	6200	481	<1	<1	3680	<1	2370	16	123	88	<1	<5
147004	Springbok Sandstone	17/09/2020	7.93	11600	6380	496	<1	<1	3870	<1	2130	14	86	77	<1	<5
147004	Springbok Sandstone	25/11/2020	7.56	11200	6380	514	<1	<1	3670	<1	2200	15	96	81	<1	<5
147004	Springbok Sandstone	30/03/2021	7.81	10800	6400	512	<1	<1	3790	<1	2260	15	95	83	<1	<5
147004	Springbok Sandstone	12/07/2021	8.13	11300	6280	476	<1	<1	3990	<1	2230	14	95	80	<1	<5
Hopeland 22	Springbok Sandstone	16/03/2020	7.56	7320	4230	1330	289	41	6	204	<1	<1	2220	<1	<1	<5
Hopeland 22	Springbok Sandstone	20/06/2020	6.76	7890	4340	89	<1	<1	2490	3	1320	270	46	8	<1	<5
Hopeland 22	Springbok Sandstone	17/09/2020	6.58	7900	4290	45	<1	<1	2660	4	1320	232	49	9	<1	<5
Hopeland 22	Springbok Sandstone	24/11/2020	6.26	7740	4260	57	<1	<1	2560	4	1330	233	54	9	<1	<5
Hopeland 22	Springbok Sandstone	8/04/2021	6.6	7800	4420	30	<1	<1	2700	2	1360	194	62	9	<1	<5
Hopeland 22	Springbok Sandstone	15/07/2021	6.55	7760	4490	32	<1	<1	2860	<1	1380	180	57	9	<1	<5
Hopeland 25	Springbok Sandstone	29/03/2020	7.05	13100	8280	2340	192	161	46	54	<1	<1	4580	3	<1	<5
Hopeland 25	Springbok Sandstone	21/06/2020	6.3	14100	8590	64	<1	<1	5170	<10	2420	360	172	47	<1	<5
Hopeland 25	Springbok Sandstone	19/09/2020	5.77	13700	8380	10	<1	<1	5010	7	2280	287	166	48	<1	<5
Hopeland 25	Springbok Sandstone	28/11/2020	5.4	14100	8460	3	<1	<1	5250	<1	2400	263	176	50	<1	<5
Hopeland 25	Springbok Sandstone	31/03/2021	5.27	14000	8880	2	<1	<1	5020	<1	2370	219	174	49	<1	<5
Hopeland 25	Springbok Sandstone	29/06/2021	5.72	13900	9220	5	<1	<1	5120	<1	2320	202	179	50	<1	<5
8685	Walloon Coal Measures	20/06/1989	9	3500	2370	1000	2.8	4.1	3.1	1600	145		410	4		
10790	Walloon Coal Measures	26/07/1989	8.7	4700	2931	1150	4.5	7.1	3.4	1000	48.5		1200	10		
10790	Walloon Coal Measures	28/02/2020	8.38	5420	3080	1190	4	7	2	724	27	<1	1290	<1	<1	<5
10790	Walloon Coal Measures	2/03/2020	7.8	5540		1240	5	6	2	615	70	<1	1380	<1		

10790	Walloon Coal Measures	19/06/2020	8.28	6100	3500	594	<1	<1	1580	6	1250	5	6	3	<1	<5
10790	Walloon Coal Measures	18/09/2020	8.36	6080	3560	680	15	<1	1600	1	1340	5	6	3	<1	<5
10790	Walloon Coal Measures	26/11/2020	8.2	6260	3450	665	<1	<1	1680	<1	1320	5	7	3	<1	<5
10790	Walloon Coal Measures	9/04/2021	8.46	5940	3560	661	26	<1	1690	1	1470	5	6	4	<1	<5
10898	Walloon Coal Measures	9/07/2013	8.49	3730	2220	955	3	4	4	1400	61	<1	480	<1	<1	<5
10898	Walloon Coal Measures	1/02/2018	8.81	3880	2520	970	4	10	6	973	202	<1	600	<1	<1	<5
13600	Walloon Coal Measures	13/04/1966	8.8	3600		1025		4	2	1995	57		370	5		
13600	Walloon Coal Measures	21/06/1989	8.7	3500	2316	950	3.4	2.7	1.4	1850	84		345	4		
13600	Walloon Coal Measures	4/03/2020	7.38	3873	2270	955	4	3	1	1310	167	<1	384	<1		
15811	Walloon Coal Measures	18/04/1966	8.8	2550	1995	641		3	2	857	29		460	2		
15811	Walloon Coal Measures	14/08/2018	8.88	2550	1660	556	2	3	<1	649	103	<1	450	<1		
15811	Walloon Coal Measures	19/03/2020	8.94	2470	1400	589	2	4	<1	597	141	<1	439	<1	<1	<5
15811	Walloon Coal Measures	19/06/2020	8.89	2530	1440	537	126	<1	440	<1	580	2	2	<1	<1	<5
15811	Walloon Coal Measures	17/09/2020	9.02	2530	1380	565	118	<1	461	<1	602	2	3	<1	<1	<5
15811	Walloon Coal Measures	26/11/2020	8.91	2420	1380	565	146	<1	432	<1	563	2	3	<1	<1	<5
15811	Walloon Coal Measures	1/04/2021	8.99	2510	1410	586	140	<1	436	<1	581	2	3	<1	<1	<5
15811	Walloon Coal Measures	15/07/2021	8.95	2460	1460	616	106	<1	474	<1	633	3	2	<1	<1	<5
15868	Walloon Coal Measures	20/04/1966	8.4	8000	4877	1810		35	62	512			2620	1		
15868	Walloon Coal Measures	5/07/1989	8.6	3800	2346	920	4.1	5.1	1.6	1150			790	4		
15868	Walloon Coal Measures	23/08/2018	8.36	8360	5430	1720	8	70	56	770	281	<1	2440	<1	<1	<5
15868	Walloon Coal Measures	16/11/2018	8.17	6410	4170	1270	5	56	34	946	<1	<1	1530	<1	<1	<5
15868	Walloon Coal Measures	29/03/2020	7.55	11500	7060	2220	11	158	105	646	<1	<1	4040	<1		
15868	Walloon Coal Measures	19/06/2020	8.07	8460	4700	819	<1	<1	2380	<1	1640	7	87	59	<1	<5
15868	Walloon Coal Measures	17/09/2020	8.28	8020	4450	863	<1	<1	2310	<1	1580	7	78	56	<1	<5
15868	Walloon Coal Measures	26/11/2020	8.05	7610	4190	898	<1	<1	2130	<1	1550	7	72	51	<1	<5
19988	Walloon Coal Measures	19/04/1966	8.5	3380		932		4	2	1745	18		410	5		
19988	Walloon Coal Measures	22/06/1989	8.7	3200		940	2.5	1.7	1	1550	70		385	4		
19988	Walloon Coal Measures	8/07/2013	8.2	7612	1990	860	2	2	1	1410	46	<1	417	<1	<1	<5
19988	Walloon Coal Measures	20/09/2017	8.4	3490		914	2	4	1	1300	40		419	<1		
24466	Walloon Coal Measures	18/04/1966	8.5	2400	1413	584		3.2		780	57.6		384			
24466	Walloon Coal Measures	6/07/1989	8.6	2350	1400	570	2.1	2.9	1.2	800	25.5		390	4		
24466	Walloon Coal Measures	2/04/2018	8.55	2500	1620	578	2	3	1	685	49	<1	420	<1	<1	<5

24467	Walloon Coal Measures	11/07/2013	8.5	3460	1940	846	4	11	2	668	37	<1	825	<1	<1	<5
24467	Walloon Coal Measures	3/09/2014	8.56	2780	1810	721	3	6	2	821	50	<1	466	<1		
24469	Walloon Coal Measures	12/12/2016	7.81	12400	8060	2540	12	170	63	258	<1	<1	4400	<1	<1	<5
24479	Walloon Coal Measures	15/04/1966	8.4	2410	2052	621		4	9	988			370			
24479	Walloon Coal Measures	12/11/2018	8.97	3300	2140	661	2	19	12	646	130	<1	665	<1	<1	<5
24479	Walloon Coal Measures	17/06/2019	8.75	4640	3020	1030	6	8	3	923	137		972	1		
24504	Walloon Coal Measures	19/06/2019	8.23	2693	1920	664	2	10	8	695	30		580	<1		
37177	Walloon Coal Measures	10/04/2018		3640	2370	763	9	36	16	808	<1	<1	728	17	10	<5
38191	Walloon Coal Measures	15/05/2009	9.45	3660		800		7.2	9	37.8			240			
38191	Walloon Coal Measures	12/07/2013	8.48	2880	1700	761	2	2	1	1230	61	<1	312	10	<1	<5
38191	Walloon Coal Measures	12/12/2016	8.17	2650	1720	697	2	5	2	1080	54	<1	293	<1	<1	<5
66146	Walloon Coal Measures	18/12/2012		16560	9360	3580	31.5	60	54	354	<1	<1	5200	99.5	2	<5
66146	Walloon Coal Measures	13/04/2018		14500	9420	2870	11	31	18	525	118	<1	4590	<1	<1	<5
107868	Walloon Coal Measures	18/02/2013	8.2	9350	5210	1970	14	32.9	12.8	357	<1	<1	3007	1.3	<1	
107868	Walloon Coal Measures	20/08/2018	7.33	10700	6690	2140	8	53	14	359	<1	<1	3520	<1		
119075	Walloon Coal Measures	24/10/2013		2990	1690	511	2	67	45	484	<1	<1	766	32	<1	<5
119484	Walloon Coal Measures	17/07/2013	8.6	3920	2080	975	4	3	1	1460	147	<1	476	<1	<1	<5
119484	Walloon Coal Measures	1/06/2016	8.61	3780	2460	998	3	5	1	1400	146	<1	417	<1	<1	<5
147001	Walloon Coal Measures	27/04/2016	8.55	9490	6170	2070	7	25	8	655	62	<1	2920	<1	<1	<5
147001	Walloon Coal Measures	5/02/2018	8.6	10400	6760	2200	8	34	10	50	62	<1	3300	<1	<1	<5
147607	Walloon Coal Measures	31/03/2016		2210	1440	572	2	3	1	672	103	<1	326	<1		
147607	Walloon Coal Measures	27/10/2016	8.78	2210	1440	572	2	3	1	672		<1	326	<1	<1	<5
147607	Walloon Coal Measures	5/04/2018	8.58	4460	1450	474	1	2	1	686	61	<1	337	<1	<1	<5
160158	Walloon Coal Measures	22/01/2020	8.88	3740	2230	890	3	4	1	769	147	<1	727	<1	<1	<5
160158	Walloon Coal Measures	22/06/2020	8.58	3720	2110	815	59	<1	730	<1	904	3	5	1	<1	<5
160158	Walloon Coal Measures	17/09/2020	8.57	3780	2200	836	43	<1	781	<1	914	3	4	2	<1	<5
160158	Walloon Coal Measures	25/11/2020	8.33	3610	2010	883	16	<1	735	<1	834	3	4	1	<1	<5
160158	Walloon Coal Measures	30/03/2021	8.46	3480	2100	835	41	<1	738	<1	837	3	4	1	<1	<5
160158	Walloon Coal Measures	12/07/2021	8.66	3680	2160	795	73	<1	792	<1	753	2	3	1	<1	<5
Hopeland 21	Walloon Coal Measures	16/03/2020	8.59	5250	2890	1130	112	7	2	770	47	<1	1170	2	<1	<5
Hopeland 21	Walloon Coal Measures	18/06/2020	8.94	4760	2670	692	140	<1	1060	<1	1000	91	6	2	<1	<5
Hopeland 21	Walloon Coal Measures	20/09/2020	8.92	4650	2720	746	157	<1	1050	1	990	78	4	2	<1	<5

Hopeland 21	Walloon Coal Measures	25/11/2020	8.9	4580	2520	694	152	<1	1040	<1	987	80	4	2	<1	<5
Hopeland 21	Walloon Coal Measures	29/03/2021	9	4360	2650	655	165	<1	1090	<1	992	72	4	2	<1	<5
Hopeland 21	Walloon Coal Measures	14/07/2021	8.98	4640	2640	558	226	<1	1120	<1	912	60	2	2	2	<5
Hopeland 23	Walloon Coal Measures	21/03/2019	8.62	2720	1520	584	20	5	<1	541	49	<1	532	1	<1	<5
Hopeland 23	Walloon Coal Measures	20/06/2020	8.51	2570	1420	554	38	<1	497	<1	565	10	4	<1	<1	<5
Hopeland 23	Walloon Coal Measures	20/09/2020	8.63	2510	1480	598	46	<1	508	15	567	8	4	<1	<1	<5
Hopeland 23	Walloon Coal Measures	29/11/2020	8.55	2420	1340	606	37	<1	497	<1	576	8	3	<1	<1	<5
Hopeland 23	Walloon Coal Measures	7/04/2021	8.71	2400	1320	567	63	<1	475	<1	530	6	3	<1	<1	<5
Hopeland 23	Walloon Coal Measures	1/07/2021	8.55	2330	1360	598	39	<1	480	<1	560	5	3	<1	<1	<5
Hopeland 24	Walloon Coal Measures	23/03/2020	8.85	3090	1850	791	45	4	1	731	144	<1	508	<1	<1	<5
Hopeland 24	Walloon Coal Measures	20/06/2020	8.92	3300	1880	720	137	<1	552	<1	722	57	2	<1	<1	<5
Hopeland 24	Walloon Coal Measures	16/09/2020	9.02	3420	1880	732	169	<1	618	<1	707	52	2	<1	<1	<5
Hopeland 24	Walloon Coal Measures	23/11/2020	8.85	3520	1960	757	170	<1	663	<1	772	56	3	1	<1	<5
Hopeland 24	Walloon Coal Measures	31/03/2021	8.94	3620	2090	814	165	<1	669	<1	824	50	3	1	<1	<5
Hopeland 24	Walloon Coal Measures	1/07/2021	8.85	3490	2070	850	136	<1	693	2	824	46	2	1	<1	<5
Hopeland 26	Walloon Coal Measures	1/04/2020	8.62	3480	2020	706	93	8	1	550	45	<1	804	10	<1	<5
Hopeland 26	Walloon Coal Measures	23/06/2020	8.72	3550	1980	545	86	<1	793	<1	745	93	8	2	<1	<5
Hopeland 26	Walloon Coal Measures	18/09/2020	8.85	3630	2180	592	114	<1	831	9	702	97	5	2	<1	<5
Hopeland 26	Walloon Coal Measures	29/11/2020	8.67	3340	1850	645	67	<1	751	2	715	69	6	2	<1	<5
Hopeland 26	Walloon Coal Measures	30/03/2021	8.76	3150	1820	619	90	<1	647	4	656	53	5	2	<1	<5
Hopeland 26	Walloon Coal Measures	30/06/2021	8.67	3140	1930	638	68	<1	699	1	631	55	5	2	<1	<5
Hopeland 27	Walloon Coal Measures	3/04/2020	8.5	3680	2270	694	60	4	2	910	47	<1	691	4	<1	<5
Hopeland 27	Walloon Coal Measures	21/06/2020	8.86	3770	2140	791	155	<1	658	<1	792	74	4	1	<1	<5
Hopeland 27	Walloon Coal Measures	17/09/2020	8.83	3600	2130	950	139	<1	612	<1	779	59	3	1	<1	<5
Hopeland 27	Walloon Coal Measures	27/11/2020	8.73	3500	1920	977	113	<1	606	<1	811	54	4	1	<1	<5
Hopeland 27	Walloon Coal Measures	1/04/2021	8.79	3390	1960	980	137	<1	530	<1	784	43	3	1	<1	<5
Hopeland 27	Walloon Coal Measures	30/06/2021	8.65	3250	1930	1010	102	<1	536	<1	789	38	2	1	<1	<5
Unregistered	Walloon Coal Measures	9/07/2013		3740	2270	963	3	2	1	1390	92	<1	463	29		
Unregistered	Walloon Coal Measures	31/01/2018		4120	2680	1060	3	6	1	1290	252	<1	461	<1		
Hopeland 5T	Walloon Coal Measures	18/11/2016		6280	3560	1430	7	8	1	1070			1290	<1		
Hopeland 6	Walloon Coal Measures	18/11/2016		6080	3440	1380	8	9	2	991			1310	<1		
Hopeland 7	Walloon Coal Measures	18/11/2016		6220	3460	1370	16	8	2	1040			1320	<1		

Hopeland 8	Walloon Coal Measures	18/11/2016		6160	3410	1370	5	8	1	1010			1300	<1		
Hopeland 9	Walloon Coal Measures	18/11/2016		6940	3890	1530	6	11	2	986			1540	<1		
Hopeland 5T	Walloon Coal Measures	2/05/2017	9.07	6450	3650	1440	7	6	1	930			1370	<1		
Hopeland 6	Walloon Coal Measures	2/05/2017	9.07	6170	3380	1320	8	6	2	780			1340	<1		
Hopeland 7	Walloon Coal Measures	2/05/2017	9.1	6670	3560	1420	14	7	2	850			1480	<1		
Hopeland 8	Walloon Coal Measures	2/05/2017	9.11	6190	3480	1350	5	6	2	802			1380	<1		
Hopeland 9	Walloon Coal Measures	2/05/2017	9.09	7070	4010	1510	7	8	2	837			1640	<1		
Hopeland 5T	Walloon Coal Measures	17/09/2017	8.32	6180	3560	1450	6	7	1	1100			1400	<1		
Hopeland 6	Walloon Coal Measures	17/09/2017	8.31	5850	3230	1340	8	9	2	961			1340	<1		
Hopeland 7	Walloon Coal Measures	17/09/2017	8.37	6120	5010	1380	17	9	2	1040			1380	<1		
Hopeland 8	Walloon Coal Measures	17/09/2017	8.35	5920	3350	1300	5	9	1	948			1360	<1		
Hopeland 9	Walloon Coal Measures	17/09/2017	8.35	6710	3690	1560	7	11	2	984			1590	<1		
172327	Hutton Sandstone	5/12/2017	8.16	3180	2070	798	2	2	<1	1460	50	<1	166	1	<1	<5

Appendix C – Ecology Report

Appendix C

Surat Gas Project

Terrestrial Ecology Report

PREPARED FOR ARROW ENERGY PTY LTD
June 2017

Surat Gas Project

Terrestrial Ecology Report

June 2017

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INTENDED USE: EcoSmart Ecology has prepared this report at the request of Arrow Energy Pty Ltd. Information and recommendations contained herein are purpose and project specific and EcoSmart Ecology accepts no liability for the use or interpretation of any information contained in this report for any other purposes other than intended.

The report should be read in its entirety. No responsibility is accepted for portions of text taken out of context. This report does not provide legal advice. Legal advice should only be sort from qualified practitioners.

DOCUMENT CONTROL

Name of Project:	Detailed Terrestrial Ecology Surveys
Project Number:	ARW_1601
Project Manager:	Mark Sanders
Document Author(s):	Mark Sanders, David Stanton, Jesse Rowland
Name of Document:	Interim Terrestrial Ecology Report
File Name:	SGP_Ecology Report_v1_Jun 17.docx
Version:	Version 1.0

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APPENDICES

EXECUTIVE SUMMARY

At the request of Arrow Energy, EcoSmart Ecology and 3D Environmental undertook seasonal terrestrial flora and fauna surveys throughout the Surat Gas Project study area. This study area has a total extent of 202,915 ha, which for the purposes of the ecological survey was divided into three distinct regions (Figure 2.1):

- The northern region encompassing an area of 7,601 ha located just south of Wandoan,
- A central region of 53,048 ha located to the north-east of Miles, and
- A southern region of 142,266 ha located to the west of Dalby

Remnant vegetation in the northern (Wandoan) region was sparse, representing 2.8% (164.7 ha) of the area. However large continuous patches of remnant vegetation are present within the central (67%; 35,554 ha) and southern (28.7%, 104,035.8 ha) regions. Survey effort predominantly focused on these later two regions.

Survey Methods

A desktop assessment was undertaken prior to field investigations to gather relevant information and literature for the Surat Gas Project study area. This work included a gap assessment to identify areas, species or features which required targeted or additional field survey.

The flora gap assessment rated areas of interest at a property scale as follows:

1. Priority 1 – Properties with mapped Endangered or Of Concern vegetation, prior records of EVNT Flora species, Protected Plant high risk trigger areas, mapped as Core Habitat Known in the SGP Supplementary EIS (3d Environmental 2013),
2. Priority 2 – Properties with well-preserved remnant vegetation, limited prior sampling and strong indications of habitat suitability for a range of threatened flora species although no prior records, and
3. Priority 3 – Properties with intact, least concern remnant vegetation not recognised as hosting populations of EVNT species or habitats of any specific legislative significance, and
4. Priority 4 – Properties subject to intensive sampling effort during previous survey events.

In total, 114 Priority 1, 74 Priority 2, 65 Priority 3 and 31 Priority 4 properties were identified. Field surveys aimed to sample vegetation on all priority 1 and priority 2 properties throughout the course of the 'wet' and 'dry' season surveys, though access limitations prevented sampling some properties (i.e. 86 of 114 Priority 1 and 66 of 74 Priority 2 properties were sampled).

The flora field survey was consistent with Queensland Herbarium standards (Neldner *et al* 2012) and included secondary, tertiary and quaternary sites. In total 218 secondary, 17 tertiary and 2,223 quaternary flora survey sites have been sampled throughout the Surat

Gas Project study area (including sites sampled in previous work identified during the desktop assessment).

The fauna gap assessment used sampling locations from existing works to identify large areas of remnant vegetation which had not been subject to previous fauna survey. Once identified, Broad Vegetation Group mapping by the Queensland Herbarium (version 3.0) was used to identify the location and extent of Broad Vegetation Groups at a 2 million scale. The contribution of each Broad Vegetation Group to the extent of remnant vegetation was calculated and theoretical trap effort distributed accordingly.

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 (Koala [SAT] and Glossy Black Cockatoo ort searches, tripline, artificial shelter).

Desktop Results

The desktop assessment identified the following ecological values:

- Two major wetlands of High Ecological Significance; i) Lake Broadwater, a major lacustrine Wetland of National Significance and ii) Long Swamp, a palustrine wetland which follows a shallow sinuous path to the north of Lake Broadwater,
- Protected Plant 'High Risk Buffers' (see Section 4.1.3), and
- The following Environmentally Sensitive Areas:
  - Category A - National Parks and Conservation Parks, specifically Lake Broadwater Conservation Park (Lot 68/SP139357),
  - Category B – Regional Ecosystems scheduled as Endangered (Biodiversity Status) by Queensland Department of Environment and Heritage Protection, and
  - Category C – which includes the following:
    - Lake Broadwater Resources Reserve (Lot69/DY6009),
    - Regional Ecosystems with 'Of Concern' Biodiversity Status,
    - State Forest areas (detailed Section 2.3), and
    - Essential Habitat (see Section 4.1.2).

Flora Survey Results

The flora surveys identified three Threatened Ecological Communities listed under the *Environment Protection and Biodiversity Conservation Act 1999* within the study area including:

- Brigalow (*Acacia harpophylla* dominant and co-dominant) (Endangered),
- Weeping Myall Woodlands (Endangered), and

- Coolibah – Black Box Woodlands of the Darling Riverine Plains and Brigalow Belt South Bioregions (Endangered).

These communities occupied 954.3, 0.9 and 22.6 hectares respectively.

Twenty Regional Ecosystems were recorded, three are listed as Endangered and six as Of Concern, with the remainder being classed as Least Concern under the *Vegetation Management Act 1999*. Endangered Ecosystems include:

- Regional Ecosystem 11.3.1 – *Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains. Total extent within the study area = 217.5 hectares,
- Regional Ecosystem 11.4.3 - *Acacia harpophylla* and/or *Casuarina cristata* shrubby open forest on Cainozoic clay plains. Total extent within the study area = 388.7 hectares, and
- Regional Ecosystem 11.9.5. *Acacia harpophylla* and/or *Casuarina cristata* open forest on fine-grained sedimentary rocks. Total extent within the study area = 4.3 hectares.

Of Concern Ecosystems include:

- Regional Ecosystem 11.3.17 - *Eucalyptus populnea* woodland with *Acacia harpophylla* and/or *Casuarina cristata* on alluvial plains. Total extent within the study area = 213.5 hectares,
- Regional Ecosystem 11.3.2. *Eucalyptus populnea* woodland on alluvial plains. Total extent within the study area = 580.7 hectares,
- Regional Ecosystem 11.3.3c. Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* woodland to open-woodland (to scattered trees) with a sedge or grass understorey in back swamps and old channels. Total extent within the study area = 26.8 hectares,
- Regional Ecosystem 11.3.4. *Eucalyptus tereticornis* and/or *Eucalyptus spp*. tall woodland on alluvial plains. Total extent within the study area = 898.6 hectares,
- Regional Ecosystem 11.9.7. *Eucalyptus populnea, Eremophila mitchellii* shrubby woodland on fine-grained sedimentary rocks. Total extent within the study area = 1.5 hectares, and
- Regional Ecosystem 11.9.10. *Eucalyptus populnea* open forest with a secondary tree layer of *Acacia harpophylla* and sometimes *Casuarina cristata* on fine-grained sedimentary rocks. Total extent within the study area = 15 hectares.

A total of 438 flora species were recorded during the flora surveys including 38 exotic species, 2 Conifers, 2 ferns, 90 grasses, 2 species of grasstree and a balance of trees, shrubs and forbs across 65 plant families.

Only one threatened flora species, *Philotheca sporadica* (Near Threatened under the *Nature Conservation Act 1992* and Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999*), has been recorded within the study area during previous assessments completed by Arrow Energy and the current 2016 – 2017 surveys. However database records (Herbrecs and Australia's Virtual Herbarium) indicate a number of additional threatened species have been recorded either within the Surat Gas Project study area including:

- *Crytandra ciliata* (Near Threatened, *Nature Conservation Act 1992*),
- *Solanum papaverifolium* (Endangered, *Nature Conservation Act 1992*),
- *Fimbristylis vagans* (Endangered, *Nature Conservation Act 1992*), and
- *Digitaria porrecta* (Near Threatened, *Nature Conservation Act 1992*).

Based on historic records these four species are considered present, though it is noted that some have no contemporary records despite extensive searches in suitable habitat.

Fauna Survey Results

The terrestrial fauna surveys identified a total of 266 vertebrate species within the Surat Gas Project study area including 20 amphibians, 55 reptiles, 151 birds and 40 mammals.

The likelihood of thirty-nine threatened species known to occur within the local area (i.e. the study area plus a 50km buffer) was assessed based on record relevance (i.e., record location and date) and habitat suitability. Based on results from the current 2016-17 surveys, six were recognised as occurring within the study area including:

- *Strophurus taenicauda* (Golden-tailed Gecko) – Near Threatened, *Nature Conservation Act 1992,*
- *Hemiaspis daemeli* (Grey Snake) – Endangered, *Nature Conservation Act 1992,*
- *Calyptorhynchus lathami* (Glossy Black-Cockatoo) – Vulnerable, *Nature Conservation Act 1992,*
- *Phascolarctos cinereus* (Koala) – Vulnerable, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992,*
- *Petauroides volans* (Greater Glider) – Vulnerable, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992,* and
- *Nyctophilus corbeni* (South-eastern Long-eared Bat) – Vulnerable, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992.*

The following five species were assessed to be either likely or possible within the study area:

- *Jalmenus eubulus* (Pale Imperial Hairstreak) – Vulnerable, *Nature Conservation Act 1992*,
- *Acanthophis antarcticus* (Common Death Adder) – Vulnerable, *Nature Conservation Act 1992*,
- *Furina dunmalli* (Dunmall's Snake) – Vulnerable, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992,*
- *Rostratula australis* (Australian Painted Snipe) – Endangered, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992,* and

- *Grantiella picta* (Painted Honeyeater) – Vulnerable, *Environment Protection and Biodiversity Conservation Act 1999* and *Nature Conservation Act 1992.*

Three Migratory species, listed under the *Environment Protection and Biodiversity Conservation Act 1999*, were recorded during the 2016-17 surveys including:

- Rufous Fantail (*Rhipidura rufifrons*),
- White-throated Needletail (*Hirundapus caudacutus*), and
- Fork-tailed Swift (*Apus pacificus*).

Thirteen other Migratory species are known to occur, most are vagrants restricted to habitats around Lake Broadwater.

1.0 INTRODUCTION

Arrow Energy (Arrow) has received Federal and State government approval for its Environmental Impact Statement (EIS) for the Surat Gas Project (SGP). The approval includes Federal conditions requiring flora and fauna surveys in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) survey guidelines (or as otherwise agreed with the Commonwealth Department of the Environment and Energy) and State (Department of Environment and Heritage Protection) survey guidelines.

To meet these obligations Arrow engaged EcoSmart Ecology, in conjunction with 3D Environmental, to undertake seasonal terrestrial flora and fauna surveys. This work aimed to:

- Complete detailed seasonal terrestrial ecological surveys sampling the range of habitats within the SGP study area and targeting likely threatened species to satisfy State and Federal survey guidelines. Surveys considered:
    - Environmentally Sensitive Areas (ESAs),
    - Wetlands and watercourses, particularly wetlands of High Ecological Significance,
    - Endangered or Of Concern Regional Ecosystems (REs), or Threatened Ecological Communities (TECs),
    - Essential Habitat,
    - Areas of high connectivity,
    - Protected plants high risk areas, and
    - *Core Habitat Known* and *Core Habitat Possible* identified in the SREIS for EPBC listed taxa.
- Validate and refine existing RE mapping, including wetlands of High Ecological Significance, and
- Refine *Core Habitat Known and Core Habitat Possible* mapping for *Environment Protection and Biodiversity Act 1999* (EPBC Act) and *Nature Conservation Act 1992* (NC Act) taxa.

This document supports a separate GIS package which includes revised RE mapping, location records of significant taxa and features, and revised threatened species habitat mapping (see Appendix A for list of contents).

2.0 STUDY AREA DESCRIPTION

2.1 STUDY AREA AND EXTENT

The SGP Study Area has a total extent of 202,915 ha, which for the purposes of this ecological study has been divided into three distinct regions (Figure 2.1):

- The northern region encompassing an area of 7,601 ha located just south of Wandoan,
- A central region of 53,048 ha located to the north-east of Miles, and
- A southern region of 142,266 ha to the west of Dalby

Remnant vegetation in the northern (Wandoan) region is sparse, representing 2.8% (164.7 ha) of the area. However large continuous patches of remnant vegetation are present within the central (67%; 35,554 ha) and southern (28.7%, 104,035.8 ha) regions, and as such, survey effort has predominantly focused on these later two regions.

2.2 GEOLOGY AND WATER RESOURCES

Geology

The SGP study area is characterised by relatively gentle topography. In the larger southern region, the dominant landform is the expansive alluvial deposits of the Condamine River. These deposits form a gently undulating fertile clay to sandy clay plain geologically referred to as the 'Condamine Alluvium' which covers the south-eastern portion of the SGP study area stretching northwards to near Chinchilla. The Condamine Alluvium is bound to the west by low hills formed by indurated exposures of the Kumbarrilla Beds, a thick sequence of Jurassic to Cretaceous aged sandstones and fine grained sedimentary rocks. Small indurated sandstone caprock occurs in some localities which form suppressed jump-ups and low mesas.

The Kumbarilla Beds outcrop dominates the central area, overlain in some localities by a weakly consolidated blanket of Tertiary aged alluvial and colluvial sediments to form a gently undulating landscape of low stony rises and gently incised gullies and intermittent streams.

A major change in topography occurs between the central (Miles) and northern (Wandoan) sections where a steep breakaway escarpment exposes the fine grain metasedimentary and volcanic rocks of the Injune Creek Group. The landscape in the vicinity of Wandoan has much more pronounced topography with low rounded hills formed on fine grained sedimentary rock with characteristic heavy clay soils and rounded rocky lag deposited on the soil surface.

Water Resources

Drainage systems in the SGP study area are divided into those contributing to the west flowing Condamine River (part of the Murray River Catchment) and the Dawson River catchment (part of the Fitzroy River catchment).

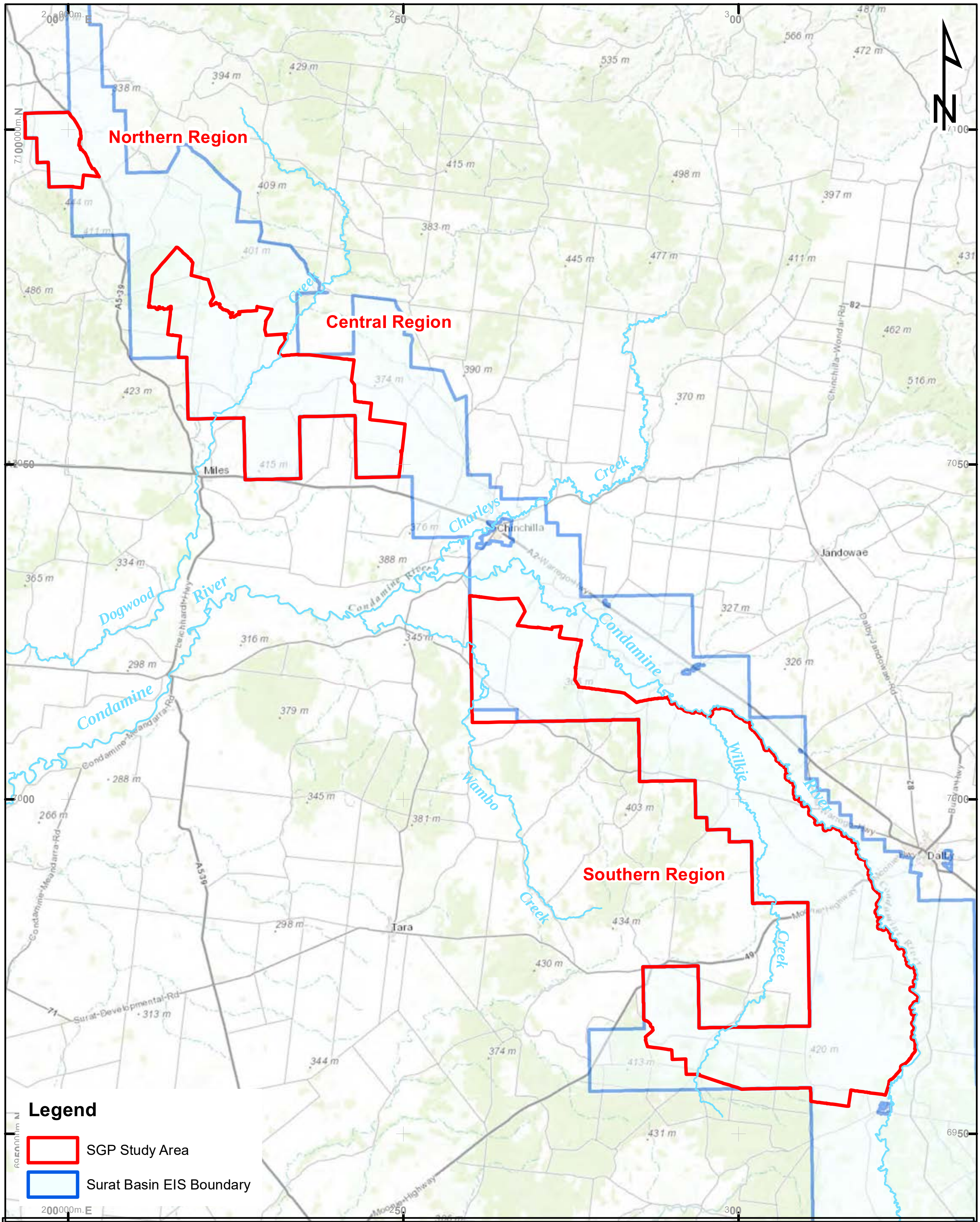

FIGURE 2.1 SGP study area location

Client ARROW ENERGY

0 12 24 36 48

Kilometers

Scale	1:750,000	**Drawn By**	DG	**Date**	23-Jun-17	A4

3D Environmental

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3D ENVIRONMENTAL

www.3denvironmental.com.au

C:\Users\Owner\Documents\Clients\3D Environmental\Arrow_Aug_2016\May17\3d_Arrow_Mapping_May_17_A4P.mxd

Within the SGP study area the Condamine River is by far the largest catchment, supplemented by the tributaries of Wambo, Wilkie, Charleys and Dogwood Creeks. The fertile alluvial soils of the Condamine River floodplain provide an extremely productive agricultural area that has been historically sustained and supplemented by an abundant source of groundwater within the underlying Condamine Alluvium aquifer.

In contrast, the Dawson River catchment forms only a minor portion of the study area and is characterised by Juandak Creek which flows through the township of Wandoan.

2.3 PROTECTED ESTATE

The SGP study area and nearby surrounds includes numerous State Forests and Conservation Reserves (Figure 2.2). In the southern (Dalby) region of the study area this includes:

- The Kumbarilla State Forest area (including the adjacent Waar Waar and Vickery State Forests), located immediately south of the Moonie Highway,
- Dunmore, Western Creek, and Boondandilla State Forest areas, which form a large continuous patch of remnant vegetation connected to the southern boundary of Kumbarilla State Forest, extending south to near the Gore Highway,
- Lake Broadwater Resource Reserve and Conservation Park, a small area of vegetation connected by remnant vegetation to Kumbarilla State Forest,
- Braemer State Forest to the north of the Moonie Highway, and
- Dalby State Forest just east of Kogan.

Together these areas of state forest, and intervening vegetation, form a large near-contiguous tract of remnant vegetation separated only by roads and highways.

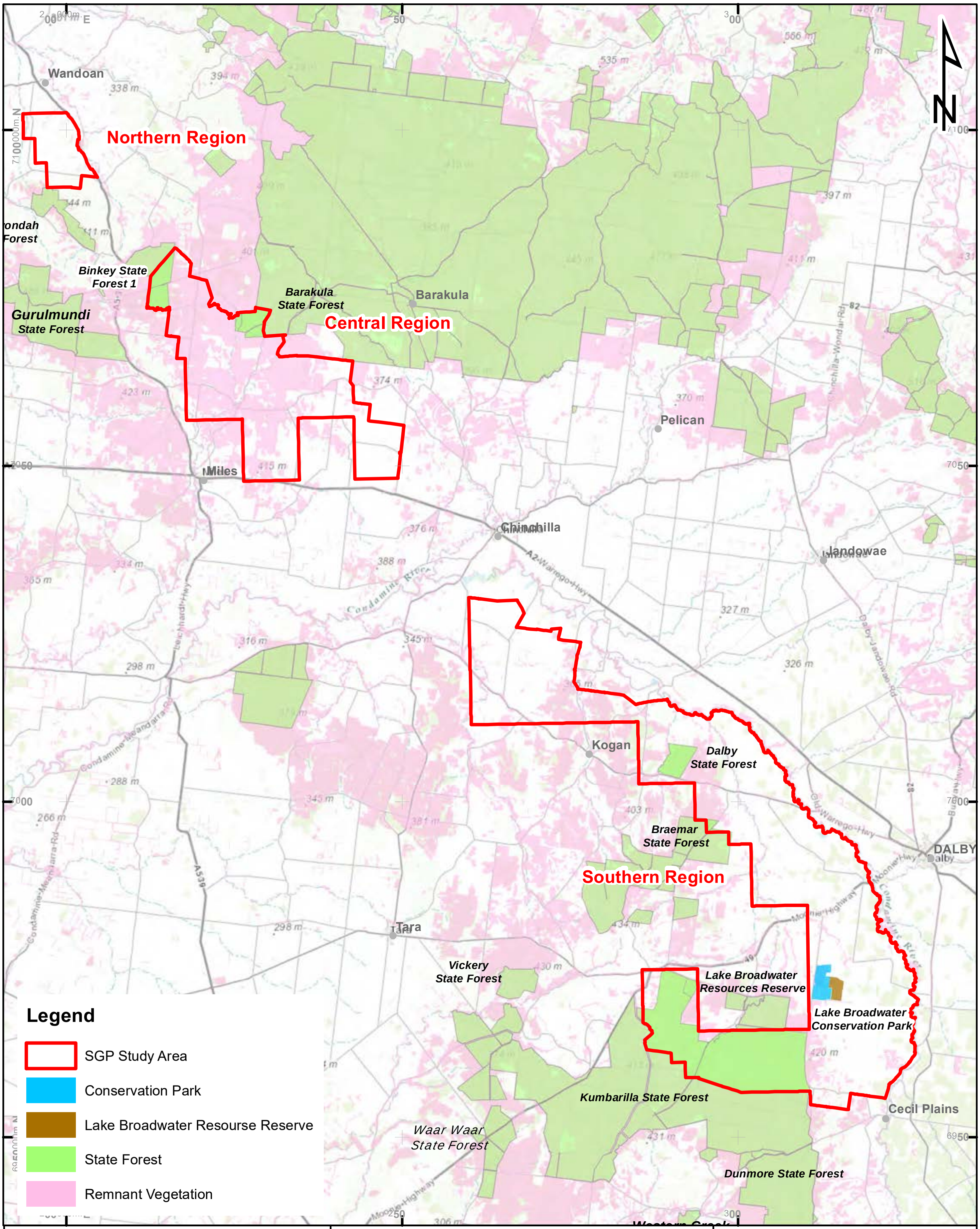
Protected Estate within or adjacent the central (Miles) region includes:

- Barakula State Forest to the immediate north-east,
- Blinkey State Forest 1 in the north of the SGP study area,
- Cherwondah State Forest to the north-west, and
- Gurulmundi State Forest to the west.

These forested areas and the intervening vegetation form a very large near-continuous patch of remnant vegetation separated only by roads and highways.

2.4 FIRE HISTORY

Vegetation within the SGP study area has been subjected to repeated fire events spaning several decades, though most fires have occurred between 2012 and 2014. With the exception of three, historic fires were limited in their extent (Figure 2.3) and, based on current vegetation condition, cool fires which did not cause extensive canopy death or damage. These cooler fires are likely to have little long-term impact on ecological values.



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NOTES:
Biodiversity status of pre-clearing and 2015 remnant regional ecosystems - version 10.0 - South East Qld. Department of Science, Information Technology and Innovation

FIGURE 2.2 Protected Estate within and surrounding the SGP Study Area

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale	1:750,000	Drawn By	DG	Date	23-Jun-17	A4

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Two hot wildfires, one extending from Barakula State Forest south to near Miles, and a second within Kumbarilla State Forest, affected large areas of vegetation in 2012. A third wildfire occurred in the eastern portion of Kumbarilla State forest in December of 2016 (i.e., between spring and summer sampling for this work).

These wildfires caused extensive canopy damage, and in many locations complete canopy loss. While the vegetation and habitat should recover in time (provided there are no subsequent wildfires), the damage will affect flora and fauna community composition with fire sensitive species likely to be absent for many decades.

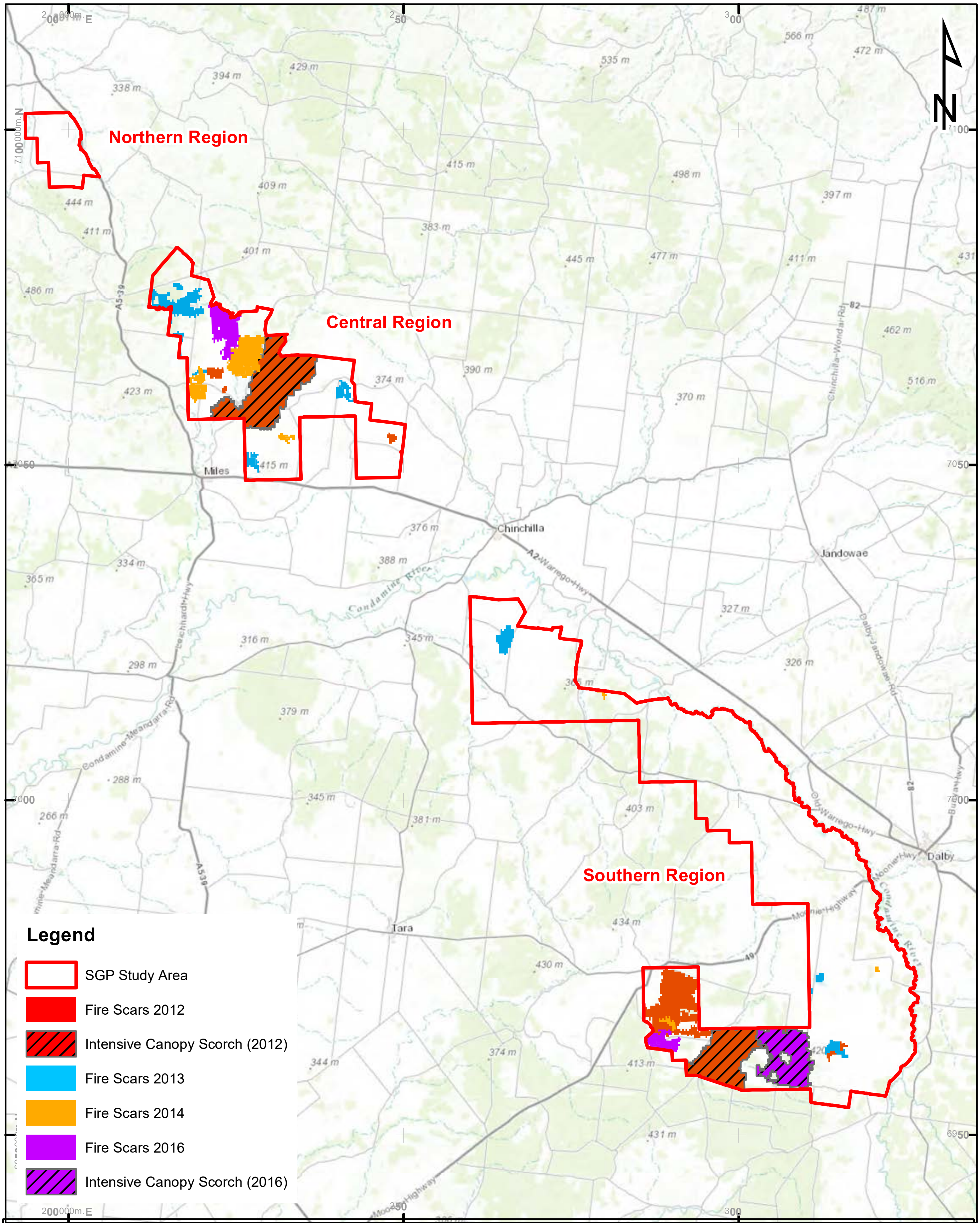

FIGURE 2.3 Historic fire scars within the SGP Study Area

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale 1:750,000	**Drawn By** DG	**Date** 21-May-17	A4

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3.0 METHODS, SURVEY CONDITIONS AND LIMITATIONS

3.1 DESKTOP DATA

A detailed desktop review of available ecological information was undertaken as part of the SGP Supplementary EIS Terrestrial Ecology Assessment (3D Environmental/EcoSmart Ecology 2013). The results from this earlier assessment, as well as the data contained therein, has been used throughout this work. However several sources have been re-inspected to ensure the data is current. Data sourced during this work included:

- The Essential Habitat spatial layer,
- Birdlife atlas database, including geo-referenced data for threatened taxa,
- Wildnet database, including inspecting threatened species profile data to gather geo-referenced locations (where possible),
- The EPBC Act Protected Matters Search Tool,
- Queensland Herbarium Herbrecs database of vouchered specimen collections within a 50km buffer surrounding the assessment area,
- *Vegetation Management Act 1999* (VM Act) Status and Biodiversity Status of Pre-clearing and Remnant Regional Ecosystems Queensland - Version 10.0 (EHP 2015),
- Queensland Wetland Data Version 4.0 (EHP 2016),
- Matters of State Environmental Significance datasets (EHP 2014),
- Australia's Virtual Herbarium (AVH 2016) for vouchered specimen records sourced from a number of Australian Herbarium,
- Nature Conservation Act protected plants flora survey trigger map spatial layer – Version 4.1 (EHP 2016),
- Prior flora and fauna assessment within or in close proximity to the SGP study area including:
    - The SGP EIS Terrestrial Ecology Specialist Report (3D Environmental 2011),
    - The SGP Supplementary EIS Terrestrial Ecology Specialist Report (3D Environmental 2013),
    - Surat Gas Pipeline Project surveys (Aecom 2009) and addition field data collected by various consultants including Ecosure, RPS and SKM between 2009 and 2013, and
    - The Daandine CGPF and Daandine Phase 1 Projects (EcoSmart Ecology 2014a, b).

The assessment included a compilation of survey data from prior surveys.

3.2 FLORA FIELD SURVEY METHODS

Flora surveys were conducted under license Number WISP10337Grey011 (non-protected estate), TWB/14/2016 (State Forests) and WITK17580216 (Lake Broadwater National Park). Table 3.1 provides details of the survey team.

Table 3.1. Terrestrial Fauna Field Team Qualifications and Experience

Name	Qualifications	Exp (yrs)	Role	Survey
David Stanton	BSc (Hons)	22	Team leader/field ecologist	Dry/wet season
Paul Williams	BSc (Hons), PhD (Ecology)	22+	Team leader/field ecologist	Dry/wet season
David Fell	Associate Diploma of Applied Science	25+	Team leader/field ecologist	Dry
Eleanor Collins	BSc (Hons)	22+	Field Ecologist	Dry/wet season
Peter Wagner	BSc (Hons), MSc	5+	Team leader/field ecologist	Wet season
Lincoln Smith	BSc (Env)	15	Field ecologist	Dry/wet season
Bill Hoskins	BSc (Hons). Grad Dip Environmental Rehabilitation	30+	Field ecologist	Dry/wet season

3.2.1 Survey Overview and Site Selection

Prior to field surveys the 284 properties which make up the SGP study area were assessed using desktop resources for:

- The presence and extent of remnant vegetation,
- The presence of 'Of Concern' or 'Endangered' REs under the VM Act or TECs under the EPBC Act,
- Prior records of threatened flora taxa on, or in close proximity to, the property including Protected Plant high risk trigger areas,
- The quality of habitat including disturbance, vegetation structure and contiguity with larger remnant patches, and
- The spatial location and intensity of prior floristic surveys (see Section 3.1)

With the further aid of aerial imagery, properties were prioritised for access based on the following criteria:

5. Priority 1 – Properties with mapped Endangered or Of Concern vegetation, prior records of EVNT Flora species, Protected Plant high risk trigger areas, mapped as Core Habitat Known in the SGP Supplementary EIS (3d Environmental 2013),
6. Priority 2 – Properties with well-preserved remnant vegetation, limited prior sampling and strong indications of habitat suitability for a range of threatened flora species although no prior records,

7. Priority 3 – Properties with intact, least concern remnant vegetation not recognised as hosting populations of EVNT species or habitats of any specific legislative significance, and
8. Properties subject to intensive sampling effort during previous survey events.

In total, 114 Priority 1, 74 Priority 2, 65 Priority 3 and 31 Priority 4 properties were identified. While the field assessment aimed to sample all Priority 1 and Priority 2 properties throughout the course of the 'dry' and 'wet' season surveys, not all of these were able to be sampled due to access limitations (i.e. 86 of the 114 (or 75%) Priority 1 and 66 of the 74 (89%) Priority 2 properties were sampled).

3.2.2 Flora Survey Techniques

Surveys collected floristic data consistent with Queensland Herbarium standards (Neldner *et al* 2012) and included secondary, tertiary and quaternary sites. 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.

Secondary sites consisting of 50 m x 10 m plots were located within the vegetation to avoid sampling across community boundaries. Crown intercept transects were extended to 100 m for the purpose of providing sufficient data for reference sites where an assessment of remnant / non-remnant status was required. Full species lists for all strata were established during the secondary sampling procedure, and supplemented by a detailed search of the nearby vicinity. The abundance of all species within the plot was recorded by stem counts, or by visual assessment as a 1-5 cover-abundance ranking using the braun-blanquet method (Neldner *et al.* 2012). Groundcover was assessed using five 1x1 m subplots placed at 10 m intervals along transects with visual cover estimations of dominant species. Ecological and structural data together with full species lists were compiled. In some instances identification to species level was not possible due to the lack of fertile material, particularly for grasses. Unidentified species were classified to the next highest denominator (typically genus level) and would account for <1% of all identifications.

Tertiary sites were completed in a similar fashion to the secondary procedure, although non-woody species were not recorded. Quaternary sites included a description of floristic structure, composition, and associated landform, and were used specifically for the purpose of mapping unit verification.

During the 'dry' season survey (September 2016) a total of 896 floristic survey sites were established including 58 secondary, 1 tertiary and 837 quaternary survey points. The wet season assessment completed in early February 2017 (plus an additional 3 day survey in late March 2017) resulted in a further 47 secondary and 682 quaternary survey points. In total, 1,625 floristic survey sites were established by 3D Environmental during this work, and combined with previous works, a total of 2,458 locations have been subject to structured floristic survey within the SGP study area (Table 3.2). The distribution of these survey points in relation to survey events is shown in Figure 3.1.

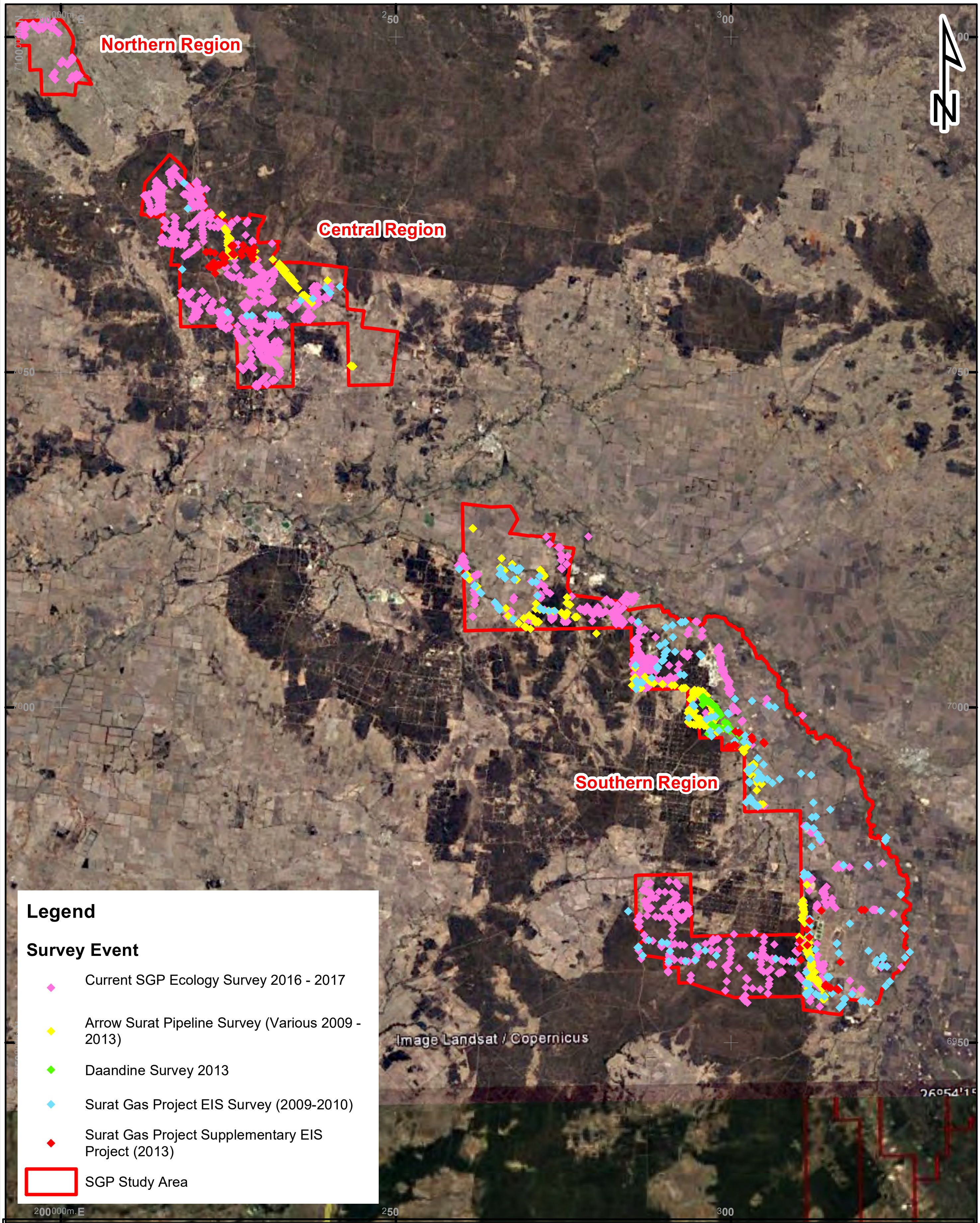

FIGURE 3.1 Floristic survey locations within the SGP Study Area

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale 1:750,000 **Drawn By** DG **Date** 21-May-17 A4

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Table 3.2. The contribution of individual floristic surveys to overall survey effort within the SGP study area

Survey/Project	**Year**	**Seasonal Effort**	**Undertaken By**	**No of Survey Sites**			**Total Sites**
				Sec	**Tert**	**Quat**	
Current SGP Ecology Survey	2016	Dry	ESE/3DE*	58	1	837	896
Current SGP Ecology Survey	2017	Wet	ESE/3DE	47	0	682	729
Daandine CGPF and Phase 1 Project (EcoSmart Ecology 2014a, b)	2014	Late Wet	ESE/3DE	5	1	32	38
Surat EIS (3d Environmental 2011)	2009/10	Dry/Wet	3DE	46	2	170	218
SGP Supp. EIS (3d Environmental 2013)	2013	Wet	3DE	28	3	37	68
Arrow Surat Pipeline (Aecom 2009 - 2013)	2009/13	Mostly Wet	Ecosure/ Aecom	34	10	465	509
Totals				**218**	**17**	**2,223**	**2,458**

*EcoSmart Ecology and 3D Environmental

3.2.3 Mapping Scale and Attributes

Vegetation linework was established at a scale of 1:25,000 providing an accuracy of hard boundaries of +/-25 m and a minimum polygon size of 0.5 ha. A polygon of 0.5 ha represents the minimum patch size threshold for both the Brigalow and Weeping Myall Woodlands Ecological Communities, listed an Endangered under the EPBC Act and known to occur within the SGP Ecology Survey area.

A seamless GIS dataset has been produced to incorporate mapped REs, TECs and habitat mapping for all threatened species (flora and fauna) known from the study area including the mapping of Core Habitat Known and Possible. The habitat mapping will assist in locating future project infrastructure to minimise impacts and the determination of offset requirements where avoidance cannot be achieved.

GIS shapefiles of all floristic survey sites within the surveyed area have been provided to Arrow in a separate package to accompany this report, which also includes the locations and findings of previous and current survey efforts.

3.3 FAUNA FIELD SURVEY METHODS

Fauna surveys were conducted under licenses WISP14610914 (non-protected estate), TWB/14/2016 (State Forests) and WITK17580216 (Lake Broadwater National Park). Table 3.3 below provides details of the terrestrial fauna survey team's qualifications and experience.

Table 3.3. Terrestrial Fauna Field Team Qualifications and Experience

Name	**Qual**	**Exp (yrs)**	**Role**	**Survey**
Mark Sanders	BSc (Hons)	20+	Team leader/field ecologist	Dry/wet
Terry Reis	BSc (Hons)	22+	Team leader/field ecologist	Dry/wet
Greg Ford	B. App. Sc.; Grad. Dip. Res. Mgt.	25	Team leader/field ecologist	Dry/wet
Dr Ed Meyer	BSc (Hons), PhD (Zoology)	20+	Team leader/field ecologist	Dry/wet
Angus McNab	BSc (Hons), MSc.	10+	Field ecologist	Dry
Anders Zimny	BSc (Hons)	8+	Field ecologist	Dry
Dr Katrine Lowe	BSc (Hons), PhD	10+	Field ecologist	Dry/wet
Lincoln Smith	BSc (Env)	15	Field ecologist	Dry/wet
Jesse Rowland	BSc (Env Man)	10+	Field ecologist	Wet
Kate Grundy	BSc (Hons)	7+	Field ecologist	Wet

3.3.1 Stratification, Survey Design and Site Selection

3.3.1.1 Spatial Stratification

Remnant vegetation mapping shows the bulk of land within the northern region of the SGP study area is cleared, with remaining vegetation fragmented and minor in extent. The likelihood of significant terrestrial fauna values within this section is greatly reduced, lessening the need for detailed seasonal surveys. Further, those threatened taxa most likely to occur in these fragmented areas (e.g., Squatter Pigeon, Painted Honeyeater) can be detected using rapid survey methods. Detailed trapping was not therefore deemed necessary for the northern region of the SGP study area. By contrast the central and southern regions retain large areas of remnant vegetation, and while some detailed fauna work has occurred, fauna values in these two regions remains poorly known.

Within the central and southern regions areas of vegetation with little, or no, historic survey effort was identified by overlaying the locations of previous fauna work (see Section 3.1) on pre-existing RE mapping (Queensland Herbarium V10.0) (Figure 3.2). The identified areas were the focus of the current SGP fauna survey.

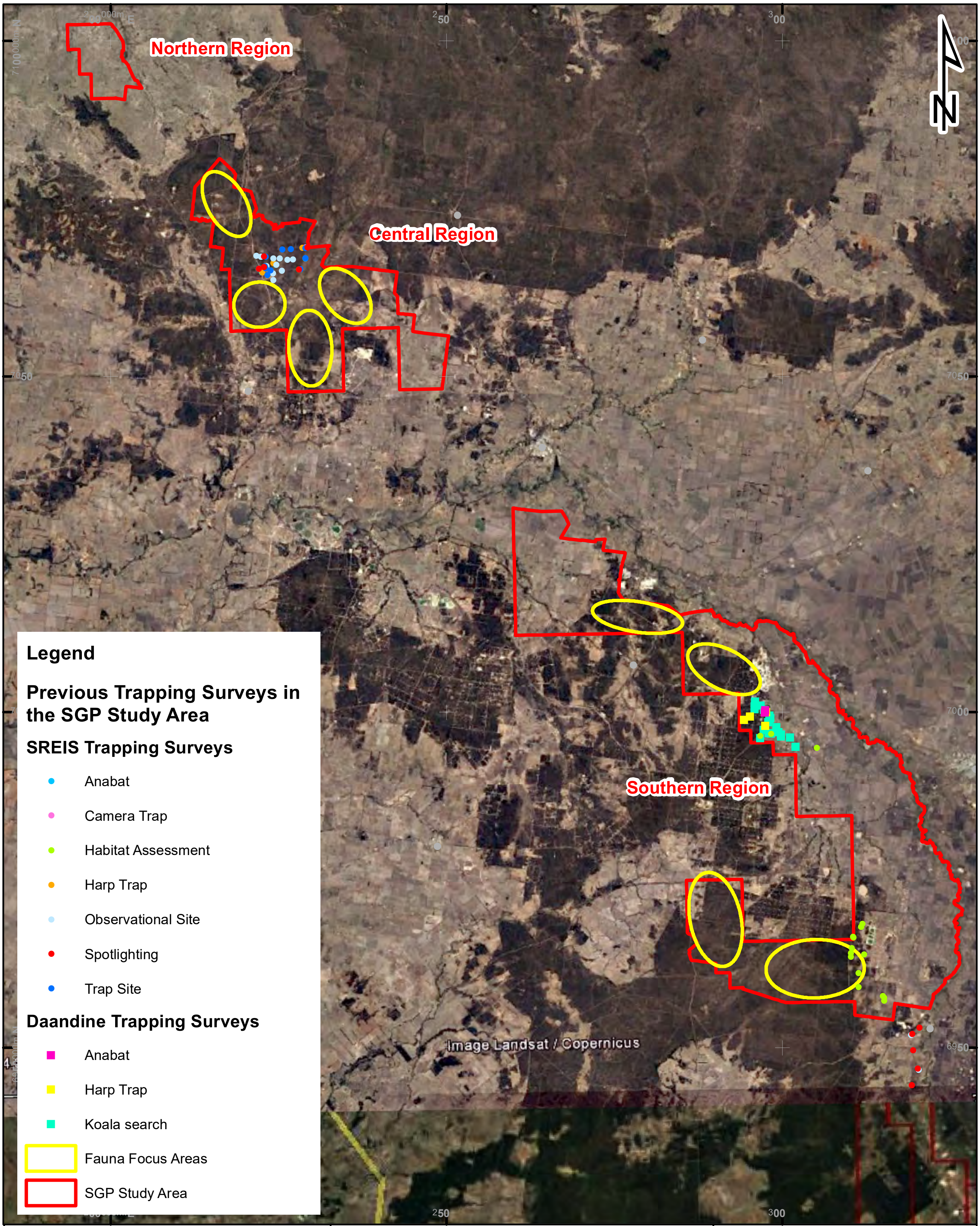

FIGURE 3.2 Previous fauna survey locations within the SGP Study Area

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale 1:750,000 **Drawn By** DG **Date** 23-Jun-17 A4

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While Lake Broadwater National Park lies within the SGP study area, it was not the focus of detailed works. Frequent surveys are conducted in the National Park by Griffith University, and the area has been frequently visited by EcoSmart Ecology staff over many years. The fauna communities and values within the National Park are well documented and understood. All observations within the Park during this survey were taken ad-hoc.

3.3.1.2 Habitat Stratification

To stratify the trapping program and encapsulate habitat variety, Broad Vegetation Group (BVG) mapping by the Queensland Herbarium (version 3.0) was used to identify the location and extent of BVGs[1] at the 2 million (2M) scale. The contribution of each BVG to the extent of remnant vegetation was calculated and theoretical trap effort distributed accordingly.

3.3.1.3 Survey Design

Having completed the above spatial and habitat analyses, a survey program was developed to fill the identified gaps and included:

- A five-day pilot study (August 2016) to visually inspect the SGP study area, identify survey constraints, and locate possible detailed fauna trap sites,
- Two, 12-day detailed surveys were completed, one during the 'dry' (September 2016) and one during the 'wet' (February/March 2016) season, by four teams (eight ecologists/survey). Each team serviced 10 detailed trap sites over the 12 days, with each trap site operational for four consecutive nights, and
- A three-day follow-up survey (March 2016) 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.

3.3.1.4 Survey Site Selection

Detailed Survey Sites

The location of detailed survey sites (which included Elliot, Pitfall, Funnel, white-flash camera, detailed bird survey, spotlight, active searches, Spot Assessment Technique (SAT) searches) were determined during the pilot study, which used the above spatial and BVG stratification, as well as considering:

- Landholder access constraints - access was not granted to some parcels of land, while others had stringent conditions preventing ease of movement on or off the property,
- Travel logistics and limitations, trap sites must be located so they could be cleared before 9.00 am each morning,
- Any notable geomorphological features such as rock outcrops, caves etc,
- Habitats likely to support specially protected species, and

---

[1] as described in Nelder *et al* 2015.

- Vegetation condition and in particular fire scaring (see Section 2.4).

Once selected, each site was inspected and approved by traditional owners to ensure trapping activities would not impact upon indigenous cultural values. As no pitfall trapping could occur without prior cultural heritage assessment, trap site locations could not be relocated after the pilot study. The pilot study occurred prior to the flora investigations and did not account for any subsequent vegetation mapping changes.

Where possible trap sites were surveyed during both the 'dry' and 'wet' season, though in some cases this was not possible without compromising spatial or BVG representation. Trap site effort within each BVG is documented in Table 3.4 and trap locations are shown in Figure 3.3a and b.

Table 3.4. Number of trap sites by BVG based on ground-truthed vegetation mapping

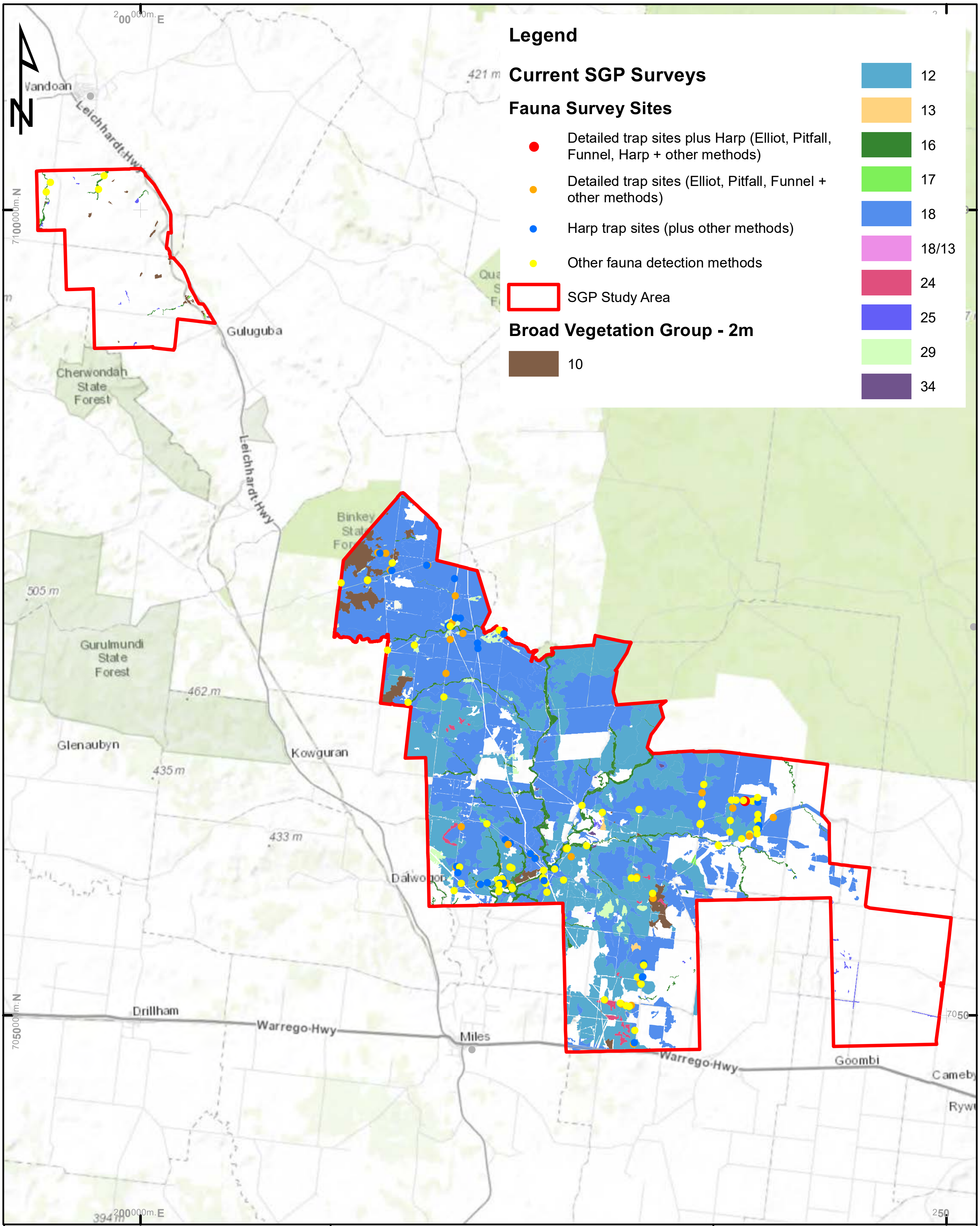
BVG#	**Description**	**Mapped Extent (ha)+**	**No. Detailed sites***	**No. Target Sites**
10	*Corymbia citriodora* dominated open forests to woodlands on undulating to hilly terrain	1,040 (1.3%)	2	2
12	Dry eucalypt woodlands to open woodlands, mostly on shallow soils in hilly terrain (mainly on sandstone and weathered rocks)	22,186 (28.6%)	23	49
13	Dry to moist eucalypt woodlands and open forests, mainly on undulating to hilly terrain of mainly metamorphic and acid igneous rocks	5,448 (7.0%)	4	17
16	*Eucalyptus* spp. dominated open forest and woodlands drainage lines and alluvial plains	3,211 (4.1%)	4	27
17	*Eucalyptus populnea* or *E. melanophloia* (or *E. whitei*) dry woodlands to open woodlands on sandplains or depositional plains	1,189 (1.5%)	0	5
18	Dry eucalypt woodlands to open woodlands primarily on sandplains or depositional plains	41,158 (53.0%)	43**	90**
24	*Acacia* spp. on residuals. Species include *A. clivicola*, *A. sibirica*, *A. shirleyi*, *A. microsperma*, *A. catenulata*, *Acacia rhodoxylon*	176 (0.2%)	0	0
25	*Acacia harpophylla* sometimes with *Casuarina cristata* open forests to woodlands on heavy clay soils	886 (1.1%)	0	3
29	Heathlands and associated scrubs and shrublands on coastal dunefields and inland rocky substrates	467 (0.6%)	1	2
30	*Astrebla* spp. (mitchell grass), *Dichanthium* spp. (bluegrass) tussock grasslands	0 (0%)	0	1***
34	Wetlands. Swamps (wooded or otherwise) and lakes (permanent or ephemeral), claypans. Includes fringing woodlands and shrublands	630 (0.8%)	0	3
18/13	Mixed community of BVGs 18 and 13.	1,233 (1.6%)	3	1
N/A	Non-remnant regrowth	N/A		3
	Total	77,624	80	203

+BVG extent and trap position with relation to BVG based on 3DE ground-truthed mapping.

*Replicated sites are counted twice, once for each survey.

**Includes one detailed site and two target sites placed in advanced regrowth.

***An area of derived grassland previously mapped as remnant by the Queensland Herbarium.



NOTES:
Other methods includes one or more of the following techniques; opportunistic bird survey, spotlight, active search, Anabat, remote sensor camera, and/or Glossy Black Cockatoo and Koala signs/scat searches.

FIGURE 3.3A Detailed fauna trapping sites within the SGP Study Area - Northern and Central Regions

Client ARROW ENERGY

0 5 10 15 20
Kilometers

Scale	1:312,525	**Drawn By**	DG	**Date**	23-Jun-17	A4

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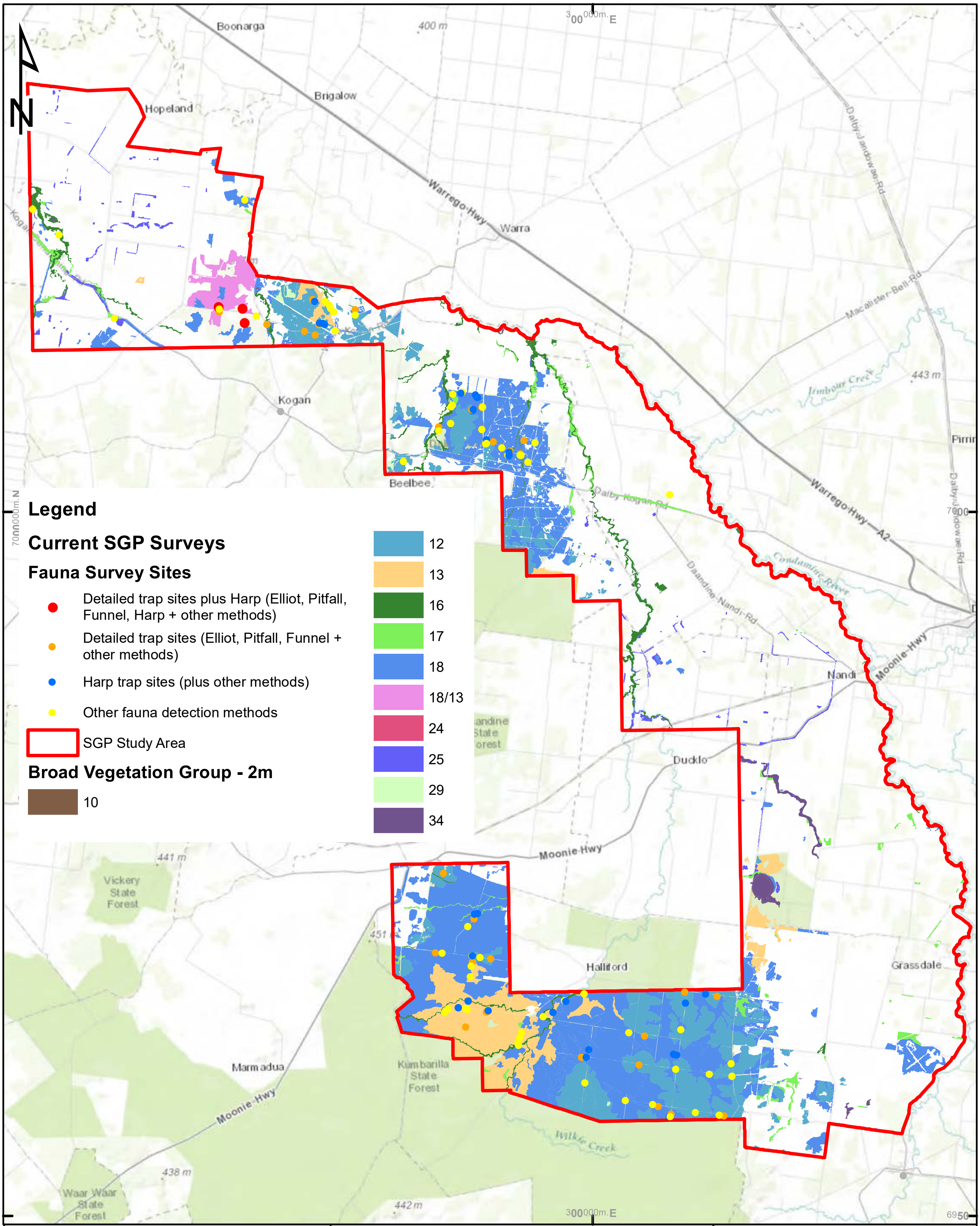

N O T E S:
Other methods includes one or more of the following techniques; opportunistic bird survey, spotlight, active search, Anabat, remote sensor camera, and/or Glossy Black Cockatoo and Koala signs/scat searches.

FIGURE 3.3B Detailed fauna trapping sites within the SGP Study Area - Southern Region

Client ARROW ENERGY

0 5 10 15 20
Kilometers

Scale 1:357,316 **Drawn By** DG **Date** 23-Jun-17 A4

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The allocation of actual detailed fauna survey sites across the BVG's varied slightly from 'theoretical' due to survey constraints (e.g., travel times, access conditions, and recent fire damage) and changes to RE mapping following the flora investigations. No detailed trap sites were located in five BVG's (17, 24, 25, 30 or 34):

- Detailed trap sites where positioned in areas mapped as BVG 17 during the pilot study (based on Queensland Herbarium mapping). Mapping inaccuracies were corrected by ground-truthed assessment and resulted in no detailed trap sites remaining in BVG 17. Due to cultural heritage restrictions, the pre-survey selected trap locations could not be altered to account for these changes (see discussion above),
- It was not until vegetation mapping and fauna surveys had been completed that BVG 24 was identified within the SGP study area,
- While the existing RE mapping showed patches of accessible Brigalow (BVG 25), field inspection found these areas to be incorrect. Rather, Brigalow was restricted to small, usually linear, fragments which were often separated from other vegetation by considerable distance. Travel logistics prevented trapping these habitats in detail, though sampling using rapid survey methods (e.g., bird survey, habitat search) was undertaken during a three-day follow-up survey,
- Queensland Herbarium mapping showed a small are of BVG 30 which was separated from other vegetation by considerable distance. Travel logistics prevented trapping of this habitat. The vegetation was altered following the completion of the flora surveys to 'derived grassland' and does not therefore represent a remnant community, and
- Surface water and the risk of possible flooding prevents trapping (particularly pitfall) in wetlands (BVG 34), though wetland locations were sampled using other survey methods (e.g., bird survey and active search).

Those BVG not subject to detailed trapping represent only a very small portion of remnant vegetation within the SGP study area (representing only 3.6% of total remnant vegetation).

Targeted Survey Sites

Targeted survey sites were used throughout the survey to supplement data collected at the detailed survey sites. Methods used at targeted sites varied from site to site and could include one or more of the following: opportunistic bird survey, spotlight, white- or black-flash camera, Harp trap, active search, SAT search, Glossy Black Cockatoo search, and Anabat. Two target sites included tripline over waterbodies to target michrochiropteran bats and artificial shelter to detect grassland reptiles.

Targeted sites are used to sample BVG that cannot be sampled by trapping (see above), or to increase spatial representation.

3.3.1.5 Contingency Survey

In December 2016 a wildfire roared through the eastern portion of the SGP study area in the Kumbarilla State Forest, significantly damaging the vegetation and habitat (Photo 1). The affected area included the five detailed fauna sites that were to be surveyed in March

2017 (i.e., the 'wet' season survey). A one-day contingency survey was undertaken in February 2017 to select new survey locations in the eastern area of the study area and gain the necessary cultural clearance. The locations of new trap sites were constrained by the extent and damage of both the December 2016 and 2012 wildfires (see Section 2.4 for fire extent).

Photo 1. Fire scaring following the December 2016 wildfire in the south-east portion of the SGP study area (i.e., Kumbarilla State Forest) (photo taken during the February contingency survey)

3.3.2 Survey Techniques

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 (Koala [SAT] and Glossy Black Cockatoo ort searches, tripline, artificial shelter). These methods, detailed below, were replicated in both the dry and wet season survey unless otherwise indicated.

3.3.2.1 Fauna Trapping

Fauna trapping includes Elliot, pitfall, funnel and harp trapping. With the exception of Harp trapping, all trap methods remain at a designated location for the duration of the survey. These locations are the detailed fauna survey sites discussed in Section 3.3.1. Twenty detailed fauna sites (designated with a prefix of 'Det' in the associated GIS package) were operational within both the central and southern regions four consecutive nights during both the 'dry' (October) and 'wet' (March) season survey. The location of detailed trap sites is shown in Figure 3.3a and b. A summary of trap effort is provided in Section 3.3.3.

Elliot, Pitfall and Funnel Trapping

Pitfall trapping consisted of four 20L buckets and two drift fences set in a T configuration. Six funnel traps, positioned in pairs at the end of each fence, augmented the pitfall traps. This configuration is consistent with Eyre *et al* (2012) and resulted in a survey effort of 1276 bucket nights[2] and 1,914 funnel nights.

Ten Elliot traps, positioned approximately five to ten meters apart, were located in the vegetation immediately surrounding each pitfall/funnel array. Each Elliot trap was baited with a combination of peanut butter, rolled oats, and vanilla essence. Elliot survey effort was 3,190 nights[2].

All trapping sites were visited twice daily, once in the morning and once in the late afternoon. Animals were identified and released at the site of capture.

Harp Trapping

Insectivorous (microchiropteran) bat capture using harp traps was undertaken along flyways, which are linear clearings through vegetation such as tracks and creeks. Flyways are not necessarily located in areas suitable for other trapping methods, and as such, harp trapping did not coincide with pitfall, funnel or Elliot techniques. Unlike other trapping methods, harp traps are not used in a single location over consecutive nights but rather moved to a new location each night. Due to flyway width, two harp traps were placed at each harp trap location, side-by-side.

While each 'dry' and 'wet' season survey aimed to have 16 harp traps operational for three nights within both the central and southern areas, the lack of flyways and adverse weather reduced trap effort. Total harp survey effort was 86 harp nights (43 locations) in the 'dry' season survey and 78 harp nights (39 locations) during the 'wet' season survey.

3.3.2.2 Observation Based Detection

Observation based detection methods included bird survey (detailed bird survey and opportunistic bird survey), nocturnal spotlighting, and active searches. These methods are used at each trap site in both the 'dry' and 'wet' season survey, as well as additional locations as indicated in Figure 3.3a and b. Opportunistic bird surveys and active searching was also undertaken during the follow-up survey.

Bird Surveys

Detailed bird surveys were undertaken on two separate mornings at each detailed trap site, typically before 9am. Each survey took 30 minutes, but less time may have been spent if bird activity was poor, with the balance of time spent at the site whenever bird activity was high. Thus, a minimum of one hour birding over a minimum of two mornings was dedicated to detailed bird survey at each trap site. During each survey the maximum number of

---

[2] One trap site (4 buckets, 6 funnels and 10 Elliots) was closed for one night during the 'wet' season survey at the central region (see Section 3.5.1).

individuals for each species was recorded, though no abundance was noted if heard calling in the far distance or seen as flying-over. Total detailed bird survey effort was 80hrs.

Opportunistic bird surveys of an indeterminate period, but usually approximating 20 minutes, were undertaken at additional survey locations (Figure 3.3a and b). These surveys were not replicated and typically occurred between the hours of 9 and 11 am. Unlike detailed bird surveys, opportunistic bird surveys did not attempt to record the number of individuals, but rather only recorded species as 'present'. Opportunistic bird survey effort was approximately 8hrs during the 'dry' season, 13hrs during the 'wet season' and 5hrs during the follow-up survey (26hrs total).

Nocturnal (spotlighting) Surveys

Nocturnal foot-based surveys included two observers walking through habitats spotlighting for arboreal mammals, including small and medium sized terrestrial mammals, frogs, geckoes, nocturnal snakes and birds. Animals were detected by eye shine, call, or direct observation. Surveys typically lasted between 30-60 min per site, and were conducted by between two and three observers. Nocturnal foot surveys were undertaken at each trap site, as well as other locations. Nocturnal spotlight effort was approximately 72hrs during the 'dry' season and 68hrs during the 'wet' season.

Active Search

Active searches of habitats were undertaken at each trap site as well as additional locations. Active habitat searches involved two observers spending 30 minutes rolling rocks and logs, searching debris, inspecting trees for scratches and searching for scats or feeding remains. Greater Glider and Koala scats (or signs), and Glossy Black Cockatoo feeding remains (orts) were noted during the search.

Active searching was undertaken for approximately 56hrs/region during the 'dry' season and 64hrs/region during the 'wet season' (excluding the north region). Five hours of active search was also conducted during the follow-up survey.

Opportunistic Observations

Opportunistic observations of fauna not previously noted or infrequently observed were recorded throughout the surveys. Sightings were recorded from direct observation, or from indirect signs such as scats, tracks, scratch marks, nests, feeding indicators, or remains. Opportunistic observations were also used while traversing the SGP study area in a vehicle, a method recognised as suitable for detecting Squatter Pigeon. Traverses made by the flora teams, who are familiar with Squatter Pigeons, have been included within the traverse survey effort. It is estimated that 160hrs of traversing was undertaken in both the 'dry' and 'wet' season surveys (320hrs total) and 18hrs in the follow-up survey. An additional 700hrs of traverse through the SGP study area was undertaken during the pilot study, two flora surveys and the contingency survey.

3.3.2.3 Automatic Detection Methods

Ultrasonic bat call detectors and remote sensors cameras were used in both the 'dry' and 'wet' season surveys.

Ultrasonic Bat Call Detection

Ultrasonic calls of microchiropteran bats were recorded using ANABAT devices selectively positioned across the central and southern regions of the SGP study area. The ANABAT devices were set to record from dusk till dawn and sampled a new location each night. Locations were selected based on the likelihood of high bat activity, such as along flyways or over water bodies. Total Anabat survey effort was 33 Anabat nights in the 'dry' season (17 in the central region and 16 in the southern) and 35 Anabat nights in the 'wet' season (17 Anabat nights in the central region and 18 in the southern region). Recordings were analysed by Greg Ford.

Remote Sensor Cameras

Remote sensor cameras were used to survey small to large terrestrial vertebrates and is preferred over cage or hair-tube trapping as it is non-invasive, allows for greater detection rates, whilst minimising stress on animals (de Bondi *et al*. 2010; Claridge *et al*. 2010; Meek *et al*. 2012). Further, camera traps are effective for many species which are difficult to capture using cage or hair tubes (Vine *et al*. 2009; Robley *et al*. 2010).

Twenty-four white-flash cameras (Reconyx HC550) were in operation over four consecutive nights in both the central and southern regions during the 'dry' and 'wet' season surveys. One of these white-flash cameras was positioned in proximity to each detailed trap site (n=20), while another four were located at random positions. An additional 12 cameras were operational at one site (A7_Det06) for two consecutive nights during the follow-up survey. Each camera was baited by smearing quantities of peanut butter and Macadamia oil on the ground within the detection zone. Total white-flash camera effort was 396 camera nights.

In addition to the white-flash cameras, four black-flash (infra-red) cameras were located within the central and southern regions and baited with peanut butter, Macadamia oil and chicken wings. These cameras, which are intended to target exotic pests, were located near a track or road and were operational for four consecutive nights. Total black-flash camera effort was 64 camera nights.

3.3.2.4 Targeted Detection

Targeted detection methods included targeted searches for Koala evidence (scratches and scats) and Glossy Black Cockatoo feeding remains (called orts) as well as the use of artificial shelter.

Targeted Searches

Targeted searches were used for detecting Greater Glider, Koala and Glossy Black Cockatoo in areas of suitable habitat. Koala detection was based on the SAT method (Phillips and Callaghan 2011), but due to high densities of non-koala feed trees and only requiring confirmation of Koala presence, the method was modified to include twenty eucalypt trees (rather than 30 trees of any species) or Koala evidence, whichever occurred first. Greater Glider scats were also noted during SAT searches. In total two SAT searches were undertaken in the northern region, 50 in the central region and 57 in the southern region during the surveys.

Searches were also conducted under stands of Allocasuarina for Glossy Black Cockatoo feeding remains (orts). *Allocasuarina inophloia, A. cristata* and *A. litoralis* are the primary food tree of this species in the Southern Brigalow Belt. Ort searches were conducted until 20 feed trees had been searched or feeding remains located. Searches were only conducted in suitable habitat, which was greatly reduced following a wildfire in the best areas of habitat prior to the 'wet' season survey. In total, nine dedicated ort searches were undertaken during the surveys.

Artificial Shelter

Nine hardwood tiles, approximately 40x40x4 cm in size, were scattered throughout the only area of mapped native grassland within the SGP study area[3]. These artificial shelters were positioned during the 'dry' season survey and later collected during the 'wet' season survey, allowing them to remain in-situ for approximately 20 weeks. The tiles were collected in the early morning, when ambient temperatures were low, to increase the likelihood of reptile capture. This method is frequently used to detect grassland reptiles (Sadlier *et al.* 2011).

3.3.3 Summary of Fauna Survey Effort

Table 3.5 provides a summary of 2016-2017 fauna survey effort within the SGP study area. Appendix B compares the survey effort with EPBC survey guidelines, which are intended to be applied to small areas of interest. The application of these guidelines across large areas (as required in this project) will result in an unachievable survey effort.

3.4 ASSESSING LIKELY OCCURRENCE OF THREATENED TAXA

While an assessment of the likely occurrence of threatened taxa was completed for the approved EIS (3d Environmental and EcoSmart Ecology 2011), this assessment was based on data available in 2011. Since this assessment was completed the conservation status of several species has changed, and it is possible that new populations have been discovered or previously known populations are no longer present. A new assessment has therefore been undertaken.

The likelihood that individual threatened species could occur within the study area over the life of operation is based on habitat (existence and quality as assessed during field investigations) and existing record relevance (the number of records, record date, and proximity to the SGP study area). Each species is ranked as present, likely, possible, unlikely, or transient base on criteria outlined in Table 3.6.

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[3] Mapped as remnant by Queensland Herbarium but re-classed as non-remnant vegetation during this work.

Table 3.5. Terrestrial Fauna Survey Effort.

Method	Unit	'Dry' season (Oct)	'Wet' Season (Mar)	Follow-up (Mar)	TOTAL
Pitfall	Trap nights	640	636		1276
Funnel		960	954		1914
Elliot		1600	1590		3190
Harp		86	78		164
Anabat		36	33		69
Camera trap (white-flash)		186	186	24	396
Camera trap (black-flash)					64
Active Search	Person hrs	56.25	64	5	125.25
Detailed Bird		40	40		80
Opportunistic Bird		8	13	5	26
Foot Spotlight		71.75	68		139.75
Vehicle Spotlight		9.58	17.5		27.08
Traverse (fauna surveys)		160	160	18	338
Traverse (flora surveys & other)		Includes traverses during the pilot study, dry (Sept) and wet (Feb) season flora surveys and the contingency survey			700
SAT	Sites	60	43	8	111
GBC ort search		8	3		11

Table 3.6. Assessment guidelines for determining species likelihood

Likelihood	Criteria	Probability
Present	Recorded within and/or immediately adjacent study area during this work. Likely resident populations of these species are known from within the SGP study area within the last 10 years.	100%
Likely	Suitable habitat within or adjacent the study area; numerous relevant records (less than 20 years old and within 10 km) from desktop assessment.	>80%
Possible	Suitable habitat within or adjacent the study area; numerous records from desktop assessment study area but records > 10 km away or 20-50 years old. OR Marginal habitat within or adjacent the study area; few, but recent (<20 yrs), records within 10 km of study area.	10-80%
Unlikely	Little suitable habitat or habitat marginal; few records from desktop assessment, usually >50years old, and records > 10 km from study area.	<10%
Transient	Species highly mobile and known to occasionally appear in areas away from known population centres (usually birds). These species could occur sporadically over time (i.e., >10% likelihood), but records and observations are unlikely to represent an established population worthy of special protection. This category does not include species which might occur seasonally or frequently.	N/A

3.5 SURVEY CONDITIONS AND LIMITATIONS

3.5.1 Survey Conditions

August Pilot Survey

The pilot survey was conducted between the 29th August and 2nd September 2016. Chinchilla received a total of 117 mm of rain between the 15th and 20th of September resulting in the presence of some surface water during the pilot survey. Maximum daily temperatures during the survey ranged from 23°C (31st Aug) to 27°C (2nd Sept), while minimum overnight temperatures ranged between 3.2°C (29th Sept) and 14.9°C.

'Dry' Season Surveys

The 'dry' season flora surveys were conducted between the 12th and 23rd September 2016 working progressively north from Kumbarilla State Forest toward Wandoan over the 12 day period. Significant rainfall occurred during the survey with 152.4mm of rainfall recorded in Miles between September 15th to September 22nd and 63.5mm recorded at Dalby (Bureau of Meteorology data) for the same period. This caused localised flooding, limiting access to foot traverses on a large number of properties.

The 'dry' season fauna surveys were conducted between the 18th and 28th October 2016, with works concentrating on the central region (Miles) on the 18th and 22nd October, and the southern region (Dalby) between the 23rd and 27th October. Accumulative rainfall at Miles in the months (Jun – Oct) prior to the work was 260mm, while 259mm of rain fell at Dalby over the same period.

During the fauna 'dry' season survey Miles received 10.8mm, 0.8mm and 6.0mm of rainfall on the 18th, 21st and 23rd of October. However this rainfall was patchy and affected only some areas within the SGP study area. The storm front which moved through on the 21st of October coincided with nocturnal spotlighting, and while the SGP study area did not receive rain, lighting, thunder and high humidity was widespread. These conditions promote nocturnal fauna activity and ideal conditions for nocturnal fauna searches.

Minimum overnight temperatures during the fauna survey ranged between 5.0°C (24th) and 17.7°C 22nd). Spotlighting coincided with minimum overnight temperatures of between 12.9°C and 17.7°C while working in the central region, but due to a wide-spread cold front, dropped to ~ 5.0°C before recovering to 11.2°C while surveying the southern region.

'Wet' Season Surveys

Wet season flora surveys were completed between February 6th and 18th 2017. This period coincided with extremely hot weather where the initial 9 days of survey had maximum temperatures exceeding 43°. The conditions both slowed the rate of field surveys as well as wilted some groundcover forb species and caused general scorching of groundcovers in some habitats. This may have resulted in an under-sampling of total floristic diversity in some habitats, particularly grassy woodlands.

'Wet' season fauna surveys were undertaken between the 7th and 16th March 2017 (inclusive) with works commencing on the southern (Dalby) region (7th-11th) and finishing in the central (Miles) region (12th-16th). A total of 213mm of rainfall was recorded at Miles, and 273mm at Dalby, in the months preceding the work (Nov 16-Mar 17).

Temperatures at Miles during the fauna survey ranged from a minimum of 14.2°C on one night and a minimum of 18.8 °C thereafter, to a maximum of 35 °C. Rainfall fell over three nights at Miles totalling 18.8mm, however rainfall was patchy with some areas receiving much greater rainfall events causing localised flooding. This flooding caused the closure of some traps (i.e., A02_Det05 was abandoned after three nights) due to access concerns.

Temperatures at Dalby during the fauna survey ranged from a minimum of 14.8 °C to a maximum of 33.2 °C. No rain fell while surveying the southern region.

3.5.2 Survey Limitations

While unlikely to have significantly affected the results of this work, the following limitations are recognised:

- Floristic surveys were hampered by extremely wet weather during the 'dry' (September) season survey meaning access was restricted in some localities and nearly all unsealed roads were impassable for a period of several days. This reduced site coverage in the first stage of the survey.
- Access was not possible to a small subset of properties. Generally this is unlikely to have affected survey results as surveys on adjacent land allowed assessment of a similar vegetation/habitat unit. However it is possible that some smaller features, such as wetlands or waterbodies, may have been overlooked.
- 'Dry' season fauna surveys conducted in the southern (Dalby) region coincided with unseasonably cold night temperatures. Temperatures quickly dropped to near 12-13°C within the first hour after sunset. These conditions, which affected only two nights of survey effort in the southern region, are largely unsuitable for the detection of a variety of fauna species, particularly nocturnal reptiles and bats.
- The coincidence of extremely hot weather with the 'wet' season flora survey effort may have resulted in the under-sampling of some of the more sensitive grass and forb species in woodland habitats. Of the EVNT species, this may have reduced the effectiveness of searches for the grass species *Digitaria porrecta*. The 'Endangered' forb species *Solanum papaverifolium* was observed flowering in populations observed outside the assessment area during the wet season survey and the effectiveness of searches for this species are not expected to have been affected.
- Rainfall was experienced during both the 'dry' season and 'wet' season fauna surveys in the central (Miles) region. However no rain fell while undertaking fauna surveys in the southern region (Dalby) and this is likely to have affected frog activity and detectability in the region.
- An extreme wildfire impacted the eastern portion of the southern region (Kumbarilla SF) prior to the 'wet' season survey. This affected the spatial distribution of trap effort within Kumbarilla State forest, but did not affect BVG representation. The fire inhibited surveys over the impacted area during the 'wet' season.

4.0 RESULTS

4.1 DESKTOP RESULTS

4.1.1 Wetlands of High Ecological Significance

The SGP study area contains an extensive mosaic of palustrine wetland habitats, many of which are associated with the Condamine River floodplain. Across Queensland, comprehensive mapping has been undertaken to identify Wetland Management Areas (WMAs) which categorise wetlands as either General Ecological Significance (GES) or High Ecological Significance (HES). These units include habitats associated with RE 11.3.27, 11.3.25 and RE 11.4.3a.

Wetland Management Areas are of specific relevance to the project, requiring adherence to appropriate management buffers and specific mitigation measures. The location of Wetland Management Areas in the SGP study area is shown in Figure 4.1. Two major wetlands of HES occur within the SGP study area; i) Lake Broadwater, a major lacustrine Wetland of National Significance and ii) Long Swamp, a palustrine wetland which follows a shallow sinuous path to the north of Lake Broadwater. Further characterisation of these habitats based on field assessment is provided in Section 4.1.1.

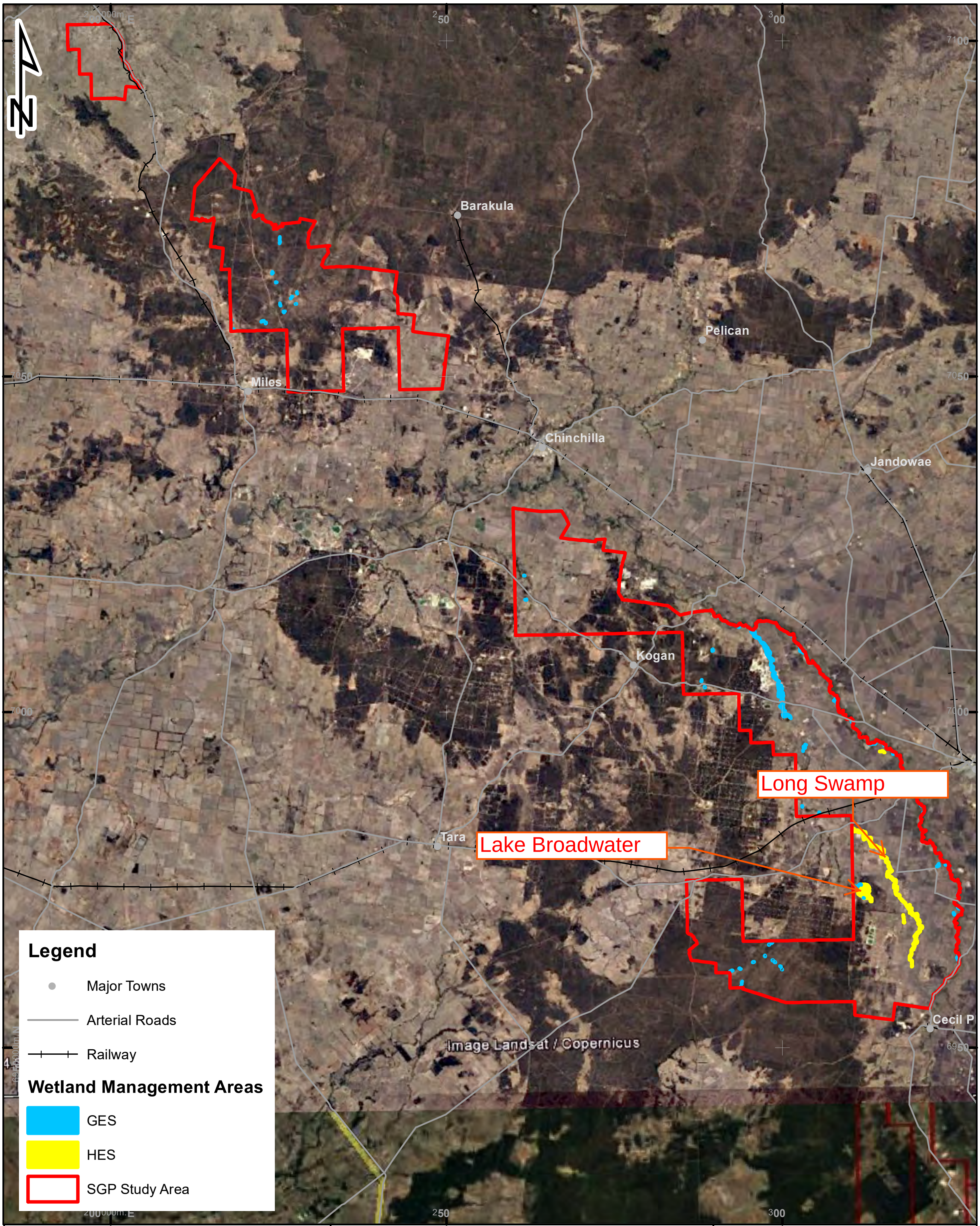
4.1.2 Essential Habitat

The essential habitat layer (Version 4.41; available at http://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q=essential+habitat) represents the most up-to-date essential habitat available. This layer however, is updated infrequently by the Queensland Government and at the time of preparing this report included essential habitat for species no longer specially protected under Queensland legislation (and therefore includes areas that should no longer constitute essential habitat). Unfortunately, recent government changes require property by property examination of Essential Habitat, which limits its use for assessments over large areas encompassing many properties and areas of essential habitat. Closer examination will be required in the future to assess essential habitat values.

4.1.3 **Protected Plant 'High Risk' Buffer**s

A 'High Risk' plant buffer protects plants listed as Endangered, Vulnerable and Near Threatened under the NC Act. These protected areas are generated by placing a 2km wide buffer around confirmed locations of individuals to show where protected plant species are considered likely to be present.

The locations of High Risk buffers for protected plants that were assessed in accordance with Flora Survey Guidelines – Protected Plants (DEHP 2016) during SGP Surveys are shown in Figure 4.2.



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NOTES:
Queensland wetland data version 4 (2016)

FIGURE 4.1 Wetland Management Areas
within the SGP Study Area

Client	ARROW ENERGY

0 5 10 15 20
Kilometers

Scale	1:750,000	**Drawn By**	DG	**Date**	23-Jun-17	A4

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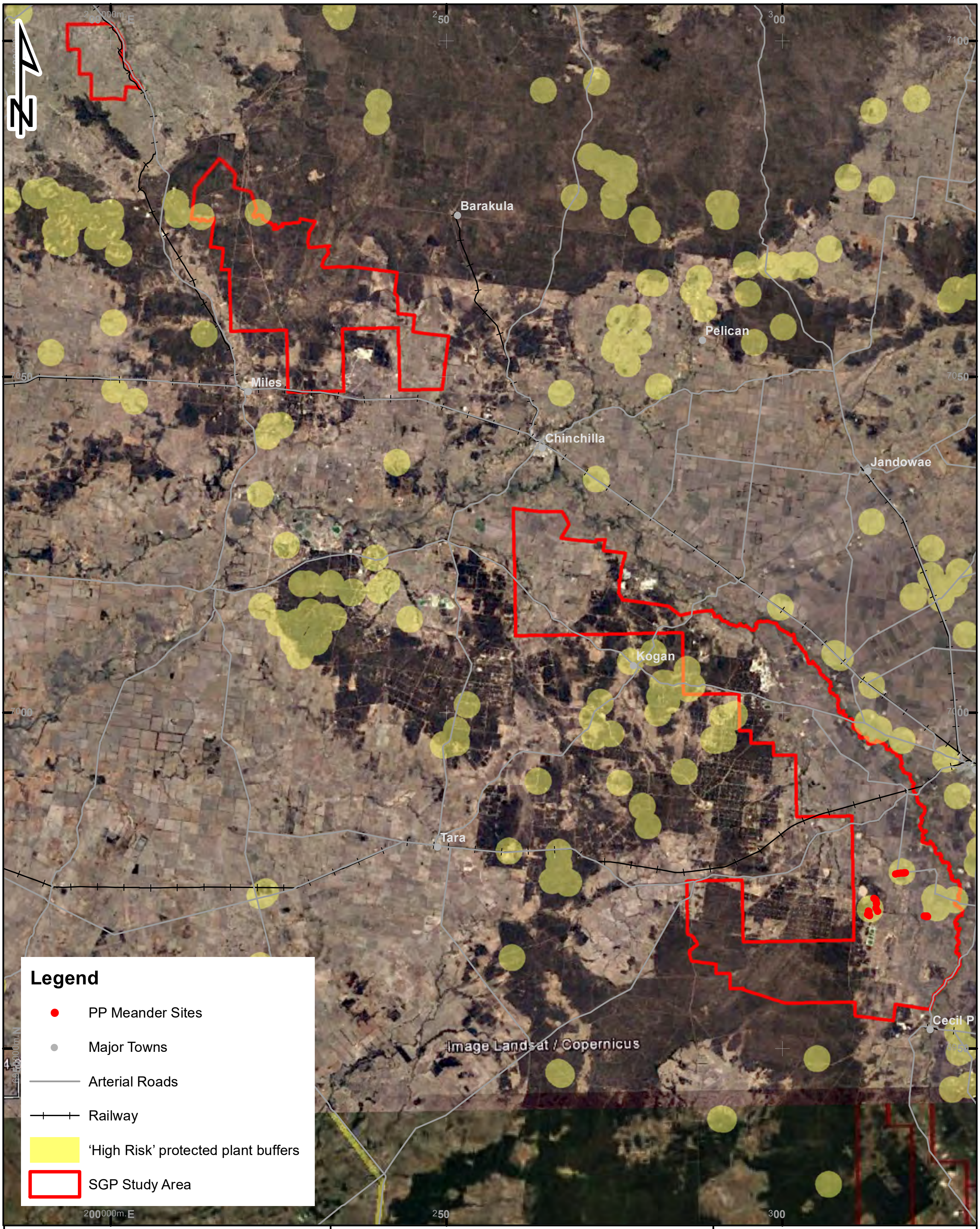

FIGURE 4.2 'High Risk' protected plant buffers assessed during SGP Study

Client ARROW ENERGY

0	12	24	36	48

Kilometers

Scale 1:750,000	**Drawn By** DG	**Date** 24-Jun-17	A4

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4.1.4 Environmentally Sensitive Areas

Environmentally Sensitive Areas relevant to the SGP study area include:

- Category A - National Parks and Conservation Parks, specifically Lake Broadwater Conservation Park (Lot 68/SP139357),
- Category B - REs scheduled as Endangered (Biodiversity Status) by Queensland Department of Environment and Heritage Protection (DEHP), and
- Category C – which includes the following:
  - Lake Broadwater Resources Reserve (Lot69/DY6009),
  - Regional Ecosystems with 'Of Concern' Biodiversity Status,
  - State Forest areas as previously detailed in Section 2.3, and
  - Essential Habitat as described in Section 4.1.2.

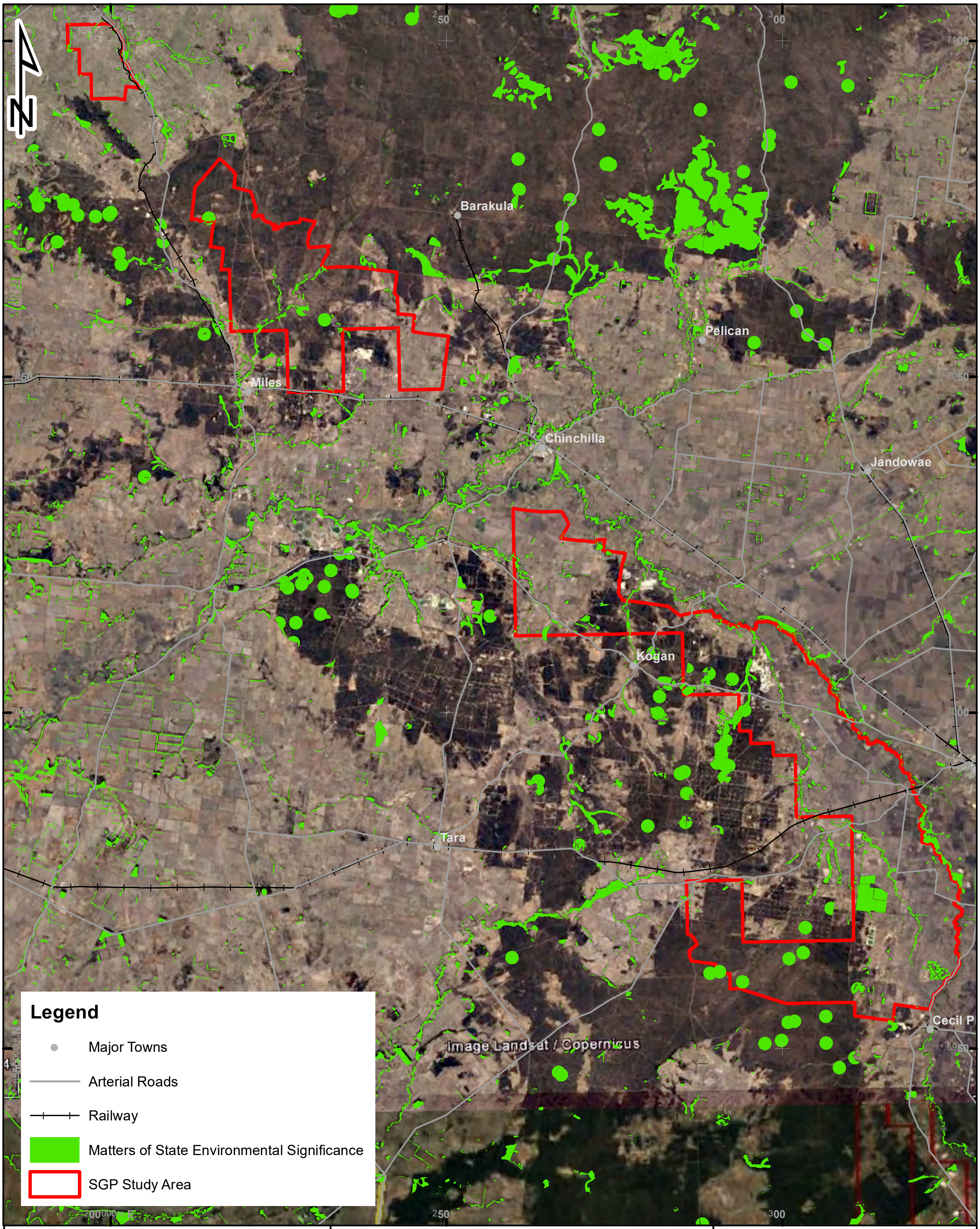
It should be noted that a property designated as a Category A ESA based on tenure overrides any attribution of ESA status based on vegetation composition (i.e. Of Concern and Endangered Biodiversity Status).

4.1.5 Matters of State Environmental Significance

Impacts to Matters of State Environmental Significance (MSES) may trigger a requirement for offsets under the Queensland Environmental Offsets Policy (Version 1.1). Within the SGP assessment area, the following features may be considered MSES:

- Areas or habitats that contains plants that are Endangered or Vulnerable wildlife (including those within protected plant High Risk buffers,
- Habitat (e.g. foraging, roosting, nesting or breeding habitat) for an animal that is Endangered, Vulnerable or a Special Least Concern animal,
- Remnant Endangered REs,
- Remnant Of Concern REs,
- Least Concern REs intersecting a watercourse or associated with a wetland,
- VM Act wetland habitats,
- National Parks and Nature Refuges, and
- Connectivity (as calculated using the Landscape Fragmentation and Connectivity (LFC) tool)

The Queensland Government has mapped MSES throughout the SGP study area and more broadly throughout Queensland with a comprehensive MSES dataset (DEHP 2014). MSES in the assessment area, as per DEHP (2014) is shown in Figure 4.3. It should be noted that this data excludes those areas identified in the current survey as habitat for protected animals or plants.



NOTES:
Matters of State environmental significance (version 4.1), Queensland Government

FIGURE 4.3 MSES in the SGP Study Area based on DEHP 2014.

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale 1:750,000	**Drawn By** DG	**Date** 24-Jun-17	A4

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4.1.6 Threatened Flora and Fauna

Examination of relevant databases and literature (see Section 3.1) identified threatened flora and fauna species recorded within 50km of the SGP study area, or having some possibility of occurring. While a long list of threatened species are known to occur within the SGP study area, not all are likely to occur with frequency, but rather, records may represent species which have become locally extinct or individuals which periodically appear but do not represent a permanent or seasonal population (i.e., particularly mobile fauna species). Closer analysis (see Appendix C) recognises a subset as being resident (i.e., present), or considered likely/possible. Present, or taxa likely to occur, are assessed further in Sections 4.2.3 (flora) and 4.3.1 (fauna) and have been provided detailed habitat maps in the attached GIS package.

4.2 TERRESTRIAL FLORA RESULTS

4.2.1 Threatened Ecological Communities and Regional Ecosystems

4.2.1.1 Threatened Ecological Communities

Past and present flora surveys have identified three TECs listed under the EPBC Act within the SGP study area. These communities are:

- Brigalow (*Acacia harpophylla* dominant and co-dominant) (Endangered),
- Weeping Myall Woodlands (Endangered), and
- Coolibah – Black Box Woodlands of the Darling Riverine Plains and Brigalow Belt South Bioregions (Endangered).

The spatial extent of these TECs within each of the three regions of the SGP study area are provided in Table 4.1 and their locations show in Figure 4.4.

Table 4.1. Spatial extent of TECs within the SGP study area

TEC	**Area (ha) / SGP study area region**			**Total Area (ha)**
	North	**Central**	**South**	
Brigalow (*Acacia harpophylla* dominant and co-dominant)	16.6	66.8	870.9	954.3
Weeping Myall Woodlands	0	0	0.9	0.9
Coolibah – Black Box Woodlands	0	0	22.6	22.6

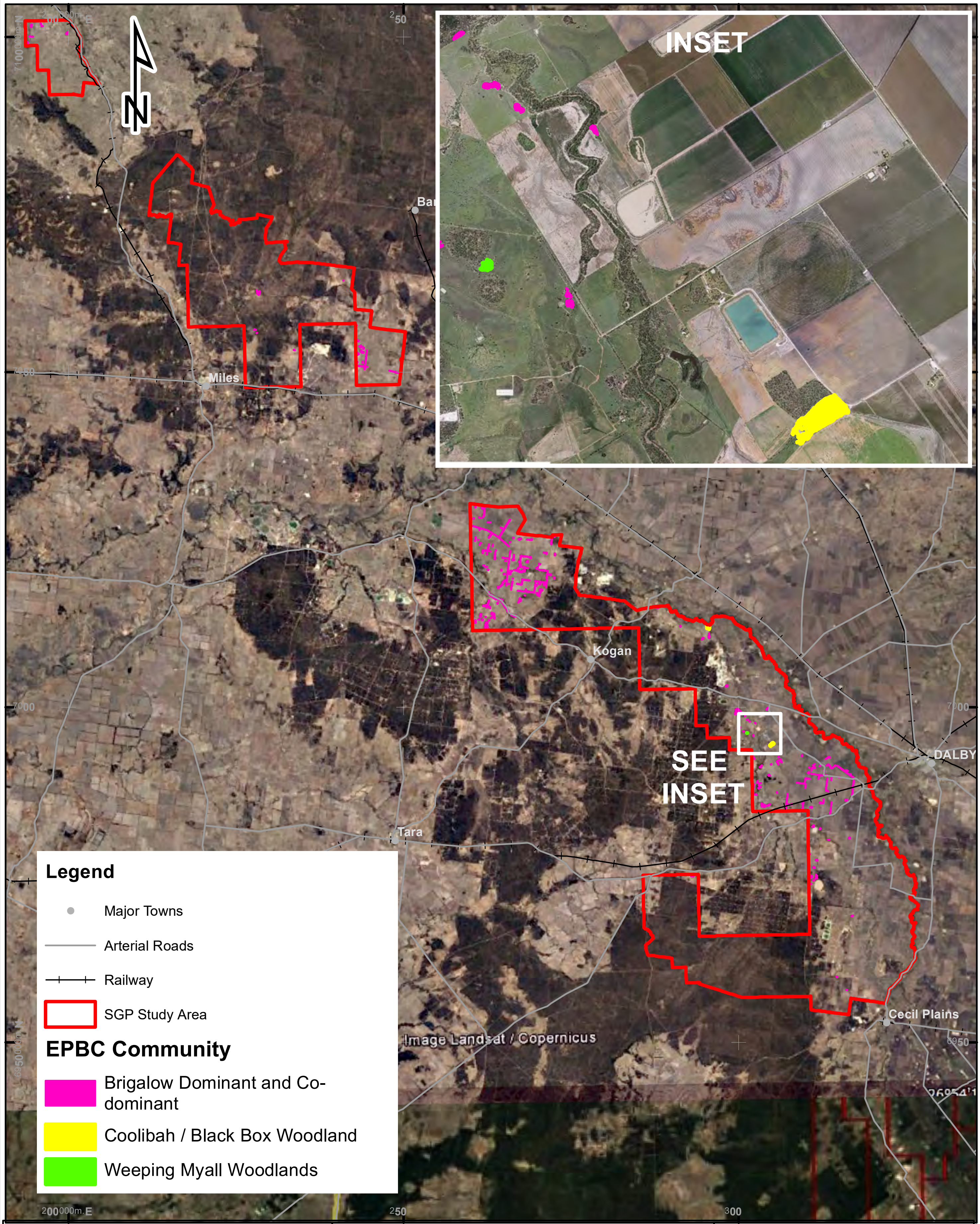

FIGURE 4.4 Threatened Ecological Communities within the SGP Study Area.

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale	1:750,000	**Drawn By**	DG	**Date**	14-May-17	A4

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4.2.1.2 Regional Ecosystems:

Of the 20 REs recorded within the SGP study area, three are listed as Endangered and six as Of Concern, with the remainder being Least Concern under the VM Act. The extent of each RE within the three regions of the SGP study area is provided in Table 4.2 and their spatial distribution based on VM Act is shown in Figure 4.5 to Figure 4.7 and biodiversity status (as surrogate for ESA status) shown in Figure 4.8 to Figure 4.10. A detailed description for each RE listed as occurring within the SGP study area is provided within Appendix D.

It should be noted that heterogeneous polygons of RE11.3.25 and 11.3.4 are often mapped along riparian corridors, represented as either 'Of Concern Dominant' or 'Of Concern Sub-dominant' (under the VM Act) dependent on relative proportion. This is the result of scale limitations where large numbers of contiguous riparian polygons fall below the 0.5ha mapping threshold.

Table 4.2. Regional Ecosystem extent within the three regions of the SGP study area.

RE	Description	VM Act Stat.	Biodiversity Stat.	Extent by region (ha)		
				North	Central	South
11.3.1	*Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains.	E	E	7.7	14.8	195.0
11.3.14	*Eucalyptus* spp., *Angophora* spp., *Callitris* spp. woodland on alluvial plains.	LC	NCAP	0	127.1	205.23
11.3.17	*Eucalyptus populnea* woodland with *Acacia harpophylla* and/or *Casuarina cristata* on alluvial plains.	OC	E	12.3	0	201.2
11.3.18	*Eucalyptus populnea, Callitris glaucophylla, Allocasuarina luehmannii* shrubby woodland on alluvium.	LC	NCAP	0	0	418.4
11.3.2	*Eucalyptus populnea* woodland on alluvial plains.	OC	OC	9.9	3.0	580.7
11.3.25	*Eucalyptus tereticornis* or *Eucalyptus camaldulensis* woodland fringing drainage lines.	LC	OC	61.6	804.23	778.7
	11.3.25g: Seasonal vegetation associated with larger waterholes and areas of open water.			3.8	-	-
11.3.26	*Eucalyptus moluccana* or *E. microcarpa* woodland to open forest on margins of alluvial plains.	LC	NCAP	0	18.3	7.1
11.3.27	11.3.27a: Palustrine wetland (e.g. vegetated swamp). Mixed grassland or sedgeland with areas of open water +/- aquatic species.	LC	OC	0	36.1	256.5
	11.3.27d: Palustrine wetland *Eucalyptus camaldulensis* and/or *Eucalyptus tereticornis* woodland			1.5	0	15.15

RE	Description	VM Act Stat.	Biodiversity Stat.	Extent by region (ha)		
				North	Central	South
	11.3.27f: *Eucalyptus coolabah* and/or *E. tereticornis* open woodland to woodland fringing swamps.			0	0	320.8
11.3.3	11.3.3c: Palustrine wetland (e.g. vegetated swamp). Eucalyptus coolabah woodland to open-woodland (to scattered trees) with a sedge or grass understorey in back swamps and old channels.	OC	OC	0	0	26.82
11.3.4	*Eucalyptus tereticornis* and/or *Eucalyptus* spp. tall woodland on alluvial plains.	OC	OC	5.8	476.3	898.61
11.4.3	*Acacia harpophylla* and/or *Casuarina cristata* shrubby open forest on Cainozoic clay plains	E	E	0	0	388.7
	11.4.3a: Palustrine wetland (e.g. vegetated swamp). *Melaleuca bracteata* woodland associated with *Acacia harpophylla* communities.			0	0	56.64
11.5.1	11.5.1: *Eucalyptus crebra, Callitris glaucophylla, Angophora leiocarpa, Allocasuarina luehmannii* woodland on Cainozoic sand plains/remnant surfaces	LC	NCAP	0	17,972.06	18,607.9
	11.5.1a: *Eucalyptus populnea* woodland with *Allocasuarina luehmannii* low tree layer.			0	23.2	327.7
11.5.20	*Eucalyptus moluccana* and/or *E. microcarpa/E. pilligaensis*[4] ± *E. crebra* woodland on Cainozoic sand plains.	LC	NCAP	0	20.9	6635.7
11.5.21	*Corymbia bloxsomei* ± *Callitris glaucophylla* ± *Eucalyptus crebra* ± *Angophora leiocarpa* woodland on Cainozoic sand plains/remnant surfaces.	LC	NCAP	0	2,238.9	0
11.5.4	*Eucalyptus chloroclada, Callitris glaucophylla, C. endlicheri, Angophora leiocarpa* woodland on Cainozoic sand plains and/or remnant surfaces	LC	NCAP	0	287.4	2941
11.7.4	*Eucalyptus decorticans* and/or *Eucalyptus* spp., *Corymbia* spp., *Acacia* spp., *Lysicarpus angustifolius* on Cainozoic lateritic duricrust.	LC	NCAP	0	176.4	0
11.7.5	Shrubland on natural scalds on deeply weathered coarse-grained sedimentary rocks.	LC	NCAP	0	5,669.9	7243.6
	11.7.5b: *Acacia aprepta* shrubland.			0	371.2	95.4

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[4] *E. pilligaensis* has been recently consumed within the broader reclassification of *E. woollsiana.*

RE	Description	VM Act Stat.	Biodiversity Stat.	Extent by region (ha)		
				North	Central	South
11.7.6	*Corymbia citriodora* or *Eucalyptus crebra* woodland on Cainozoic lateritic duricrust.	LC	NCAP	0	950.8	5.3
11.7.7	*Eucalyptus fibrosa* subsp. *nubila* ± *Corymbia* spp. ± *Eucalyptus* spp. on Cainozoic lateritic duricrust.	LC	NCAP	0	6,297.2	2,988.5
11.9.2	*Eucalyptus melanophloia +/- E. orgadophila* woodland on fine-grained sedimentary rocks	LC	NCAP	48.27	0	0
11.9.5	*Acacia harpophylla* and/or *Casuarina cristata* open forest on fine-grained sedimentary rocks.	E	E	4.3	0	0
11.9.7	*Eucalyptus populnea, Eremophila mitchellii* shrubby woodland on fine-grained sedimentary rocks	OC	OC	1.5	0	0
11.9.10	*Eucalyptus populnea* open forest with a secondary tree layer of *Acacia harpophylla* and sometimes *Casuarina cristata* on fine-grained sedimentary rocks	OC	E	15	0	0

E = Endangered, OC = Of Concern, LC = Least Concern, NCAP = No Concern at Present

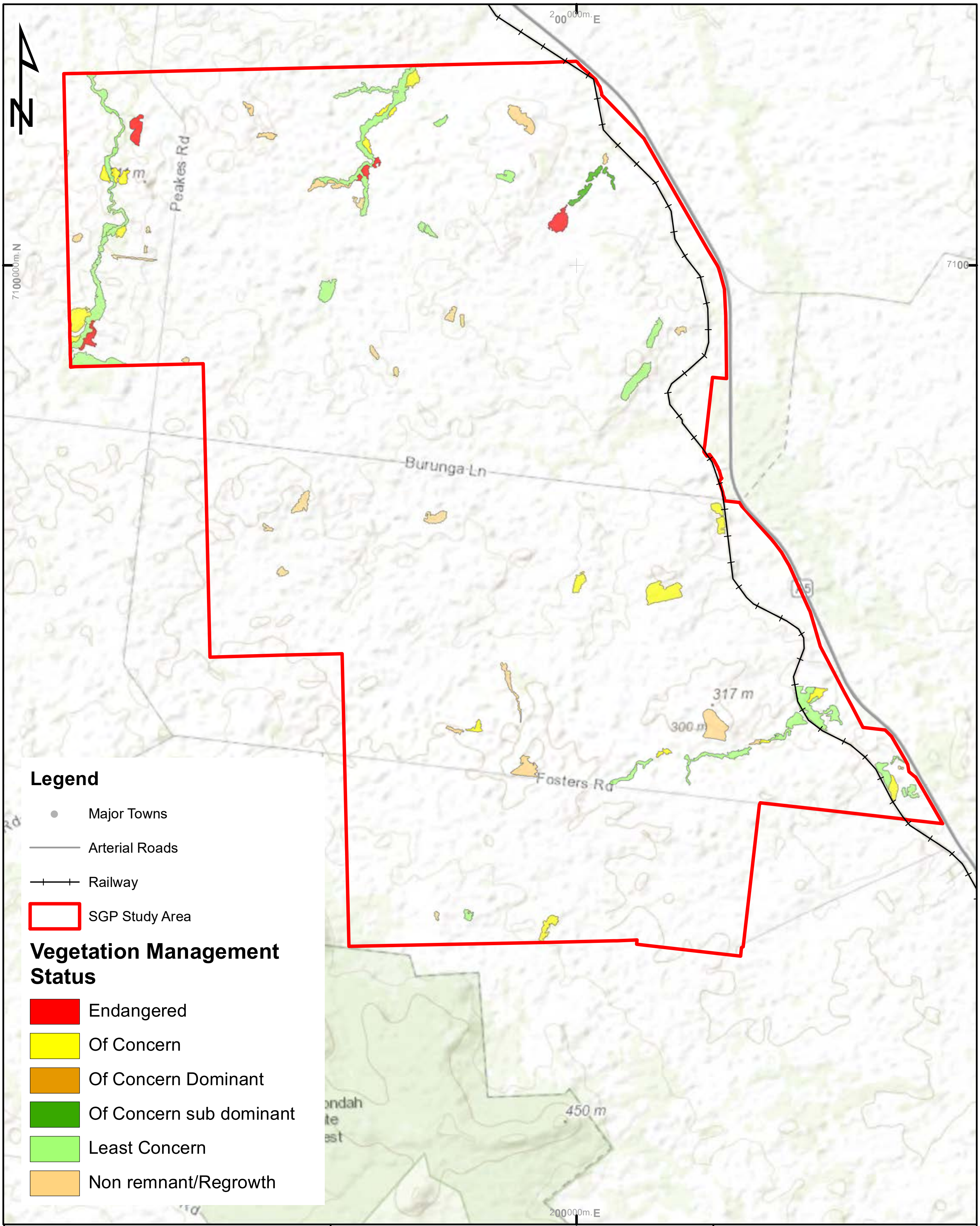

FIGURE 4.5 Endangered, Of Concern, and Least Concern REs within the northern region of the SGP Study Area

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0 1 2 3 4
Kilometers

Scale 1:63,440 **Drawn By** DG **Date** 25-Jun-17 A4

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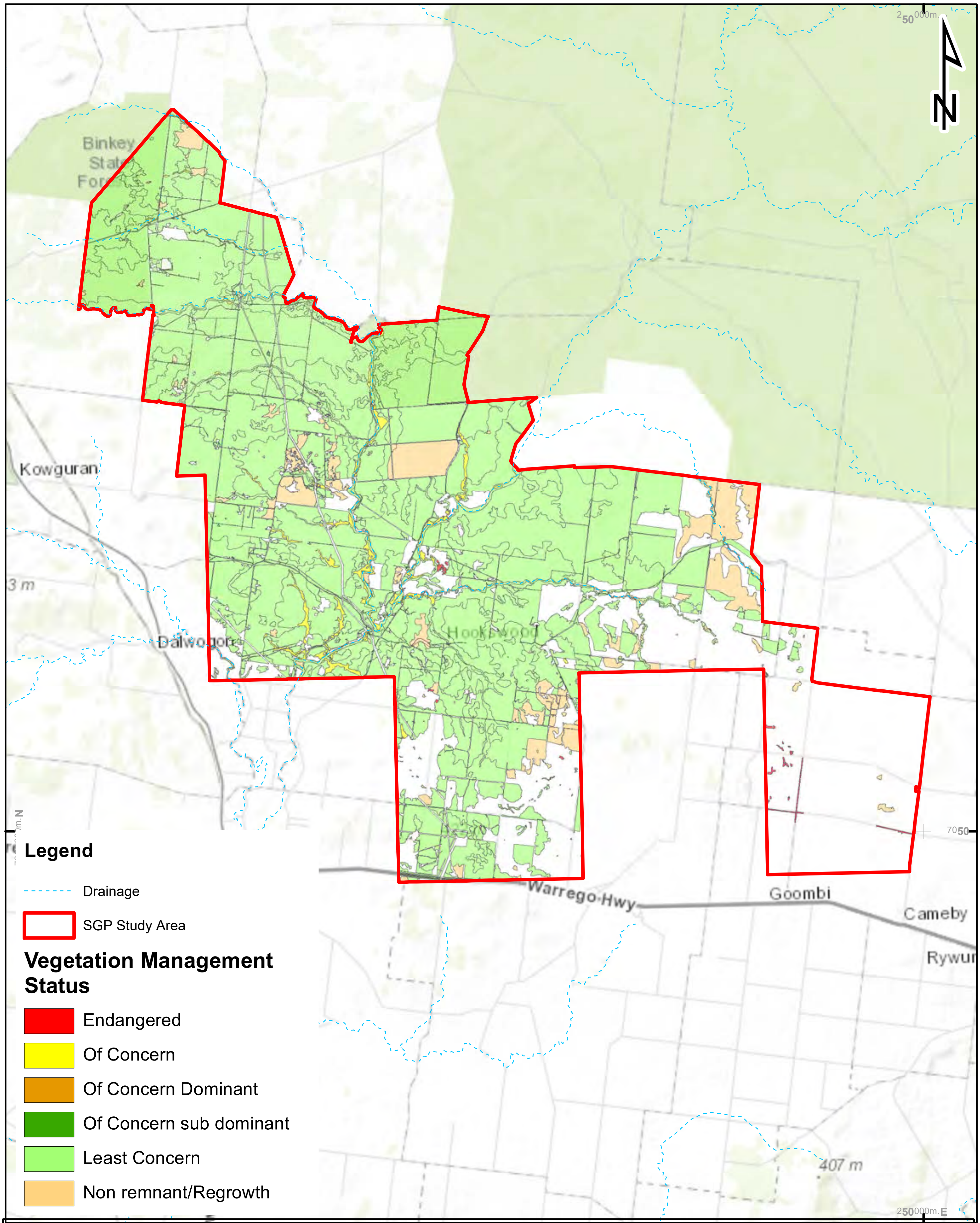

FIGURE 4.6 Endangered, Of Concern, and Least Concern REs within the central region of the SGP Study Area

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0 4 8 12 16
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Scale 1:226,000 **Drawn By** DG **Date** 21-May-17 A4

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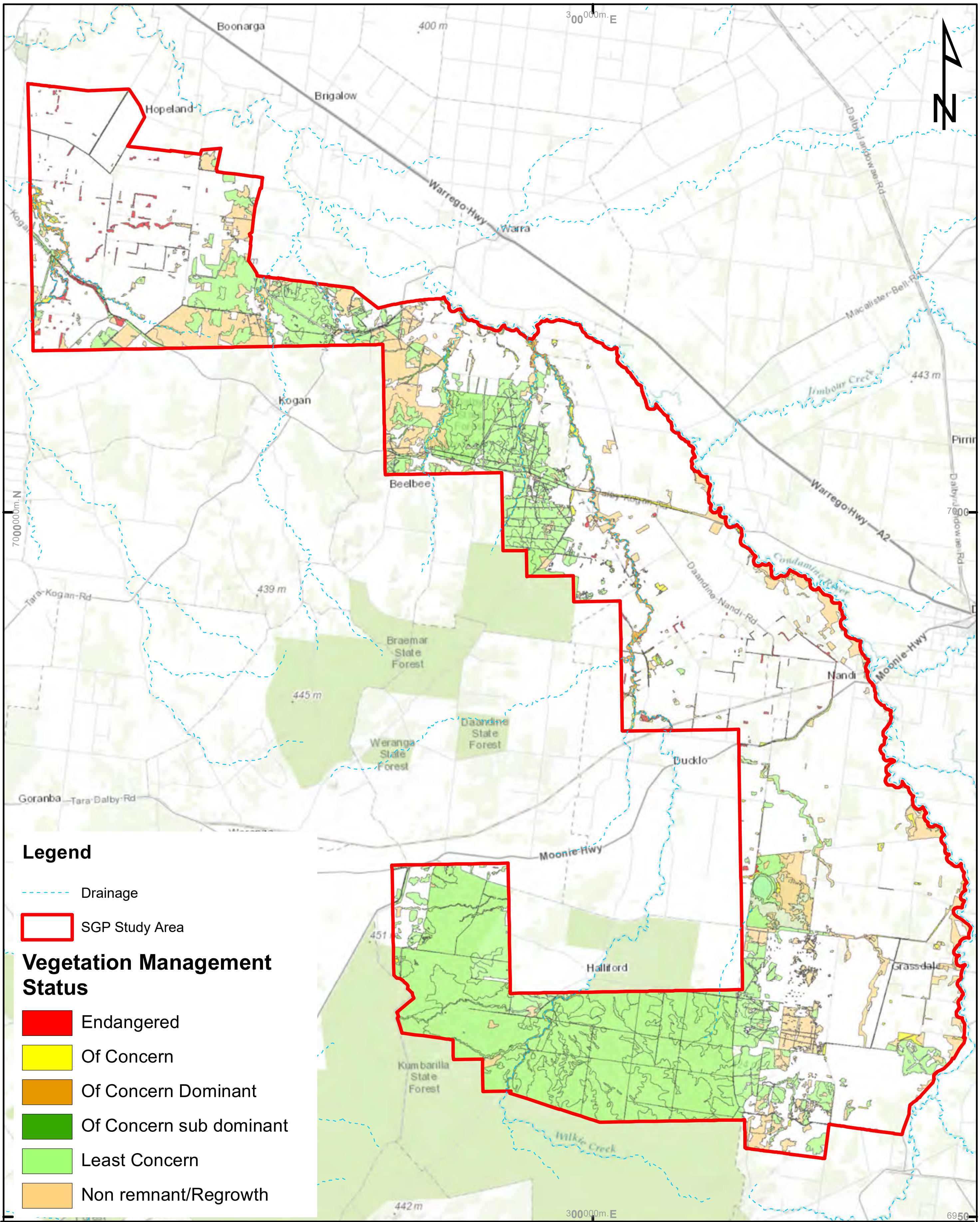

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FIGURE 4.7 Endangered, Of Concern, and Least Concern REs within the southern region of the SGP Study Area

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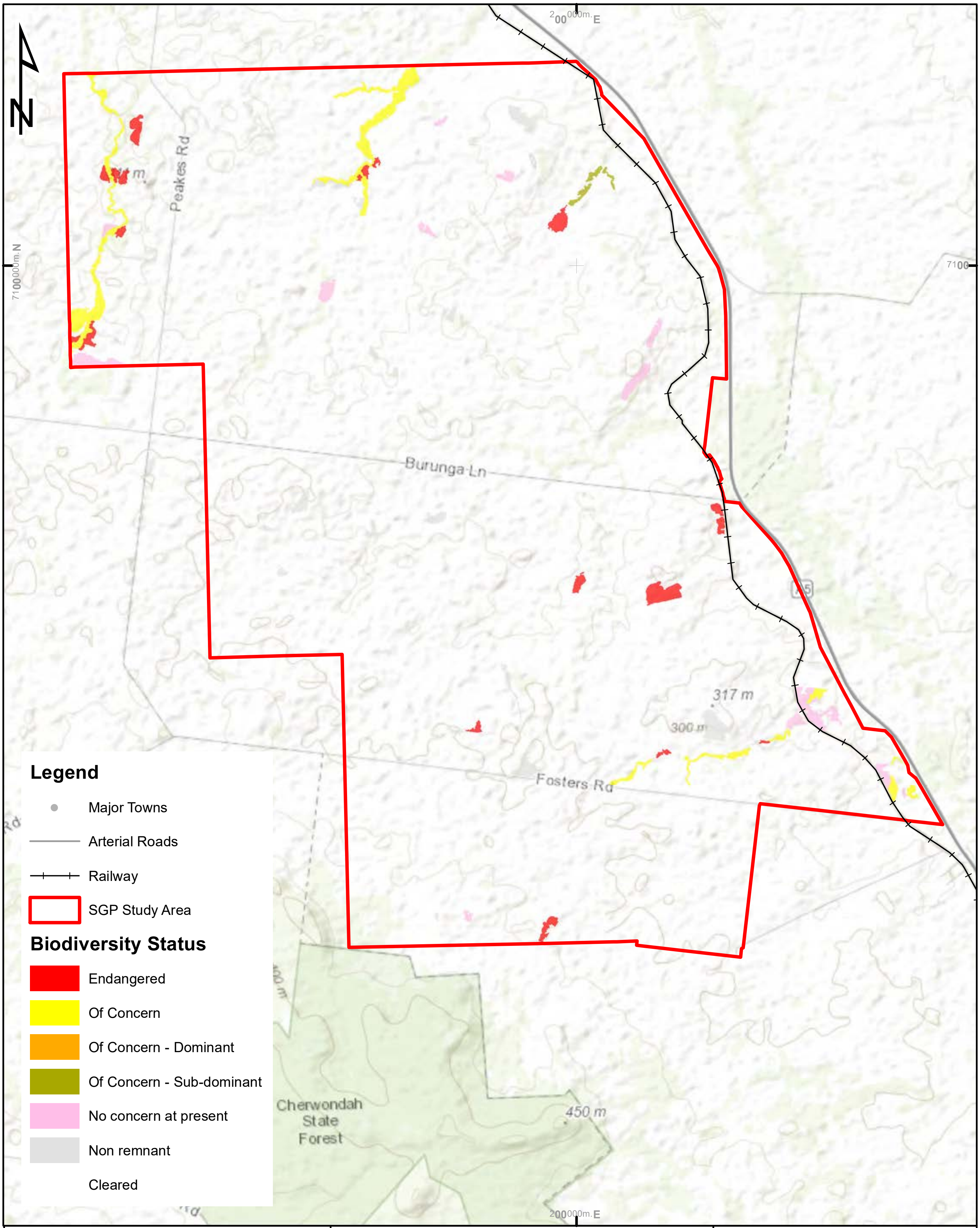

FIGURE 4.8 Biodiversity Status of Regional Ecosystems in the northern region of the SGP Study Area.

Client ARROW ENERGY

0 1 2 3 4
Kilometers

Scale	1:63,440	**Drawn By**	DG	**Date**	25-Jun-17	A4

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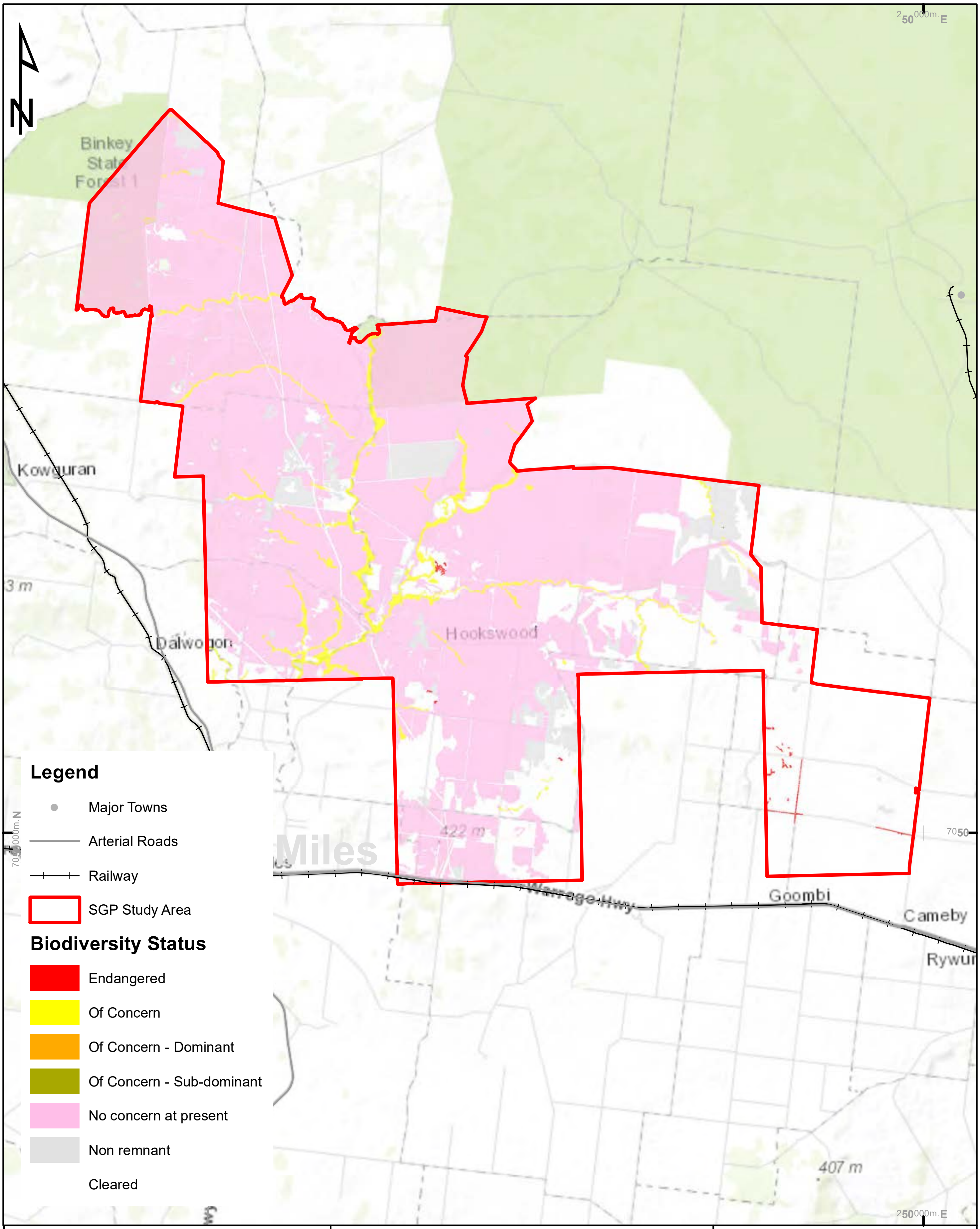

FIGURE 4.9 Biodiversity Status of
Regional Ecosystems in the central region of
the SGP Study Area.

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0 4 8 12 16
Kilometers

Scale 1:226,000 **Drawn By** DG **Date** 25-Jun-17 A4

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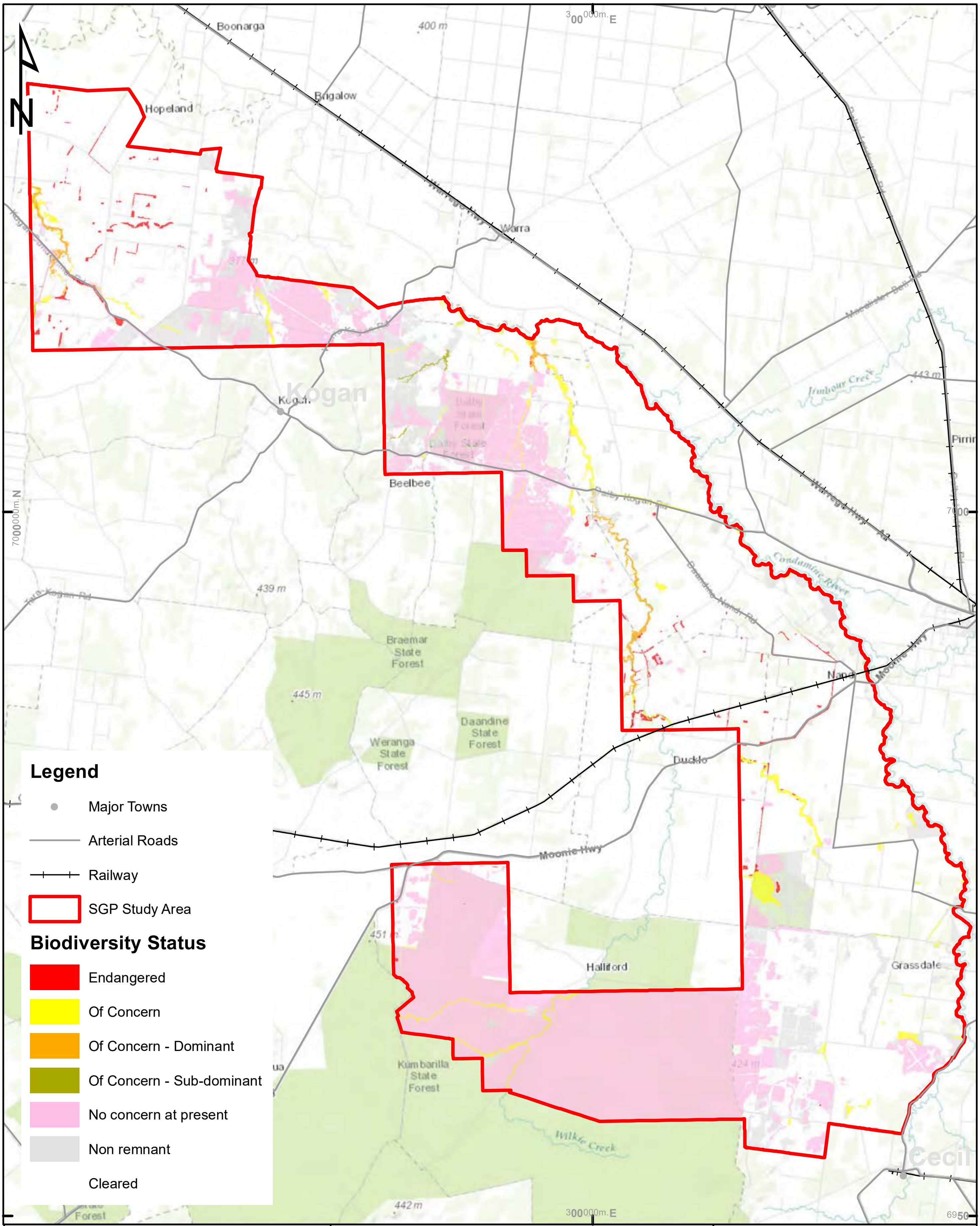

FIGURE 4.10 Biodiversity Status of Regional Ecosystems in the southern region of the SGP Study Area.

Client ARROW ENERGY

0 6 12 18 24
Kilometers

Scale 1:357,316	**Drawn By** DG	**Date** 25-Jun-17	A4

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4.2.2 Flora Diversity

A total of 438 flora species were recorded during the SGP study area flora surveys including:

- 38 exotic species
- 2 Conifers
- 2 ferns
- 90 grasses
- 2 species of grasstree
- A balance of trees, shrubs and forbs across 65 plant families.

The highest floristic diversity was associated with RE 11.5.1 where 100 species were recorded across all survey sites. The high diversity would be in part due to the REs considerable extent and variation in floristic structure.

4.2.3 Threatened Flora Species Likelihood Assessments

Only one threatened flora species, *Philotheca sporadica* (Near Threatened NC Act; Vulnerable EPBC Act) has been recorded during assessments completed by Arrow Energy, including the current 2016 – 2017 survey event. However database records (Herbrecs and Australia's Virtual Herbarium) indicate a number of additional EVNT species have been previously recorded either in or adjacent to the SGP study area. These species include *Crytandra ciliata* (Near Threatened NC Act); *Solanum papaverifolium* (Endangered NC Act), *Fimbristylis vagans* (Endangered NC Act) and *Digitaria porrecta* (Near Threatened NC Act). Some of these records are relatively old and there are no contemporary records despite extensive searches in suitable habitat. *Digitaria porrecta*, for example has not been recorded from within the SGP study area since 1995, and *Fimbristylis vagans* was last recorded from the Lake Broadwater area in 1984.

Figure 4.11 identifies the locations of all EVNT species records contained within 1km of the SGP study area boundary based on Herbarium records and a range of surveys undertaken on behalf of Arrow Energy.

Whilst only five EVNT flora species are considered known or likely to be present within the SGP study area, an additional 31 species are known from the regional area (i.e. within a 50km buffer of the SGP study area boundary). An analysis of the likelihood of these species occurring is provided in Appendix C which identifies an additional 14 species that may possibly occur within the SGP study area (Table 4.3). In general, species with records greater than 25km from the SGP study area were considered unlikely unless large tracts of sparsely surveyed habitat was present.

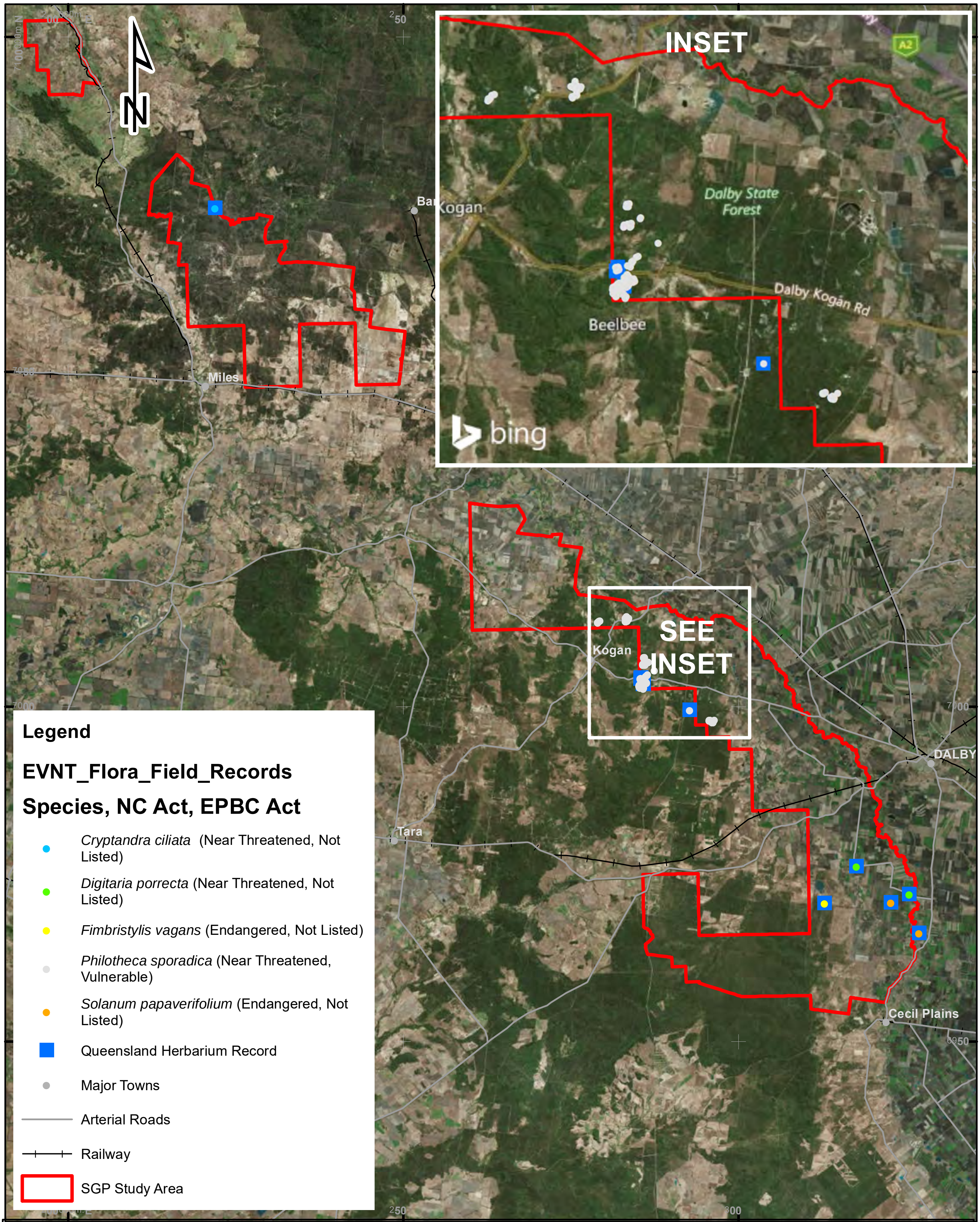

FIGURE 4.11 Survey records of EVNT flora species from within the SGP Study Area.

Client ARROW ENERGY

0 12 24 36 48

Kilometers

Scale 1:750,000 **Drawn By** DG **Date** 24-Jun-17 A4

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Table 4.3. Likelihood assessment for Threatened flora species in the SGP study area.

Scientific Name	**Common Name**	**EPBC Status**	**NC Status**	**Likelihood**
Shrubs and Trees				
Philotheca sporadica	Kogan waxflower	V	NT	Present
Acacia barakulensis	Waaje wattle	-	V	Possible
Acacia curranii	Curly-bark wattle	V	V	Possible
Acacia handonis	Hando's wattle	V	V	Possible
Callitris baileyi	Bailey's cypress	-	NT	Possible
Calytrix gurulmundensis	Gurulmundi fringe myrtle	V	V	Possible
Micromyrtus carinata	Gurulmundi heath myrtle	-	E	Possible
Eucalyptus curtisii	Plunkett mallee	-	NT	Possible
Acacia lauta	Tara wattle	V	V	Unlikely
Acacia wardellii	Wardell's wattle	-	NT	Unlikely
Cadellia pentastylis	Ooline	V	V	Unlikely
Denhamia parviflora	Small-leaved denhamia	V	V	Unlikely
Eucalyptus argophloia	Chinchilla white gum	V	V	Unlikely
Eucalyptus virens	Shiny-leaved ironbark	V	V	Unlikely
Grasses and Sedges				
Digitaria porrecta	Finger panic grass	-	NT	Present
Fimbristylis vagans	NA	-	E	Present
Homopholis belsonii	Belson's panic	V	E	Possible
Cyperus clarus	-	-	V	Unlikely
Herbs and Orchids				
Solanum papaverifolium	-	-	E	Present
Cymbonotus maidenii	-	-	E	Possible
Picris barbarorum	-	-	V	Possible
Rutidosis lanata	-	-	NT	Possible
Solanum stenopterum	-	-	V	Possible
Xerothamnella herbacea	Xerothamnella	E	E	Possible
Cryptandra ciliata	-	-	NT	Likely
Thesium australe	Austral toadflax	V	V	Possible
Pomaderris coomingalensis	-	-	E	Unlikely

E = Endangered; V = Vulnerable; NT = Near Threatened

Further discussion regarding threatened flora taxa considered possible, likely or present from the SGP study area is provided in Appendix E. The appendix includes the criteria used to develop individual species habitat maps in the associated GIS product, and an assessment of the mapping accuracy for predicting the species habitat/extent. Table 4.4 shows the extent of habitat available to each species based on the GIS mapping product.

Table 4.4. The extent of mapped habitat for Threatened flora species present or possibly occurring within the SGP study area.

Scientific Name	**Common Name**	**Status**		**Habitat extent in SGP (ha)***		
		EPBC	**NCA**	**CHK**	**CHP**	**GH**
Acacia barakulensis	Waaje wattle	V	-	0	0	33,811.2
Acacia curranii	Curly-bark wattle	V	V	0	0	33,811.2
Acacia handonis	Hando’s wattle	V	V	0	0	33,811.2
Callitris baileyi	Bailey’s cypress	NT	-	0	0	33,811.2
Cryptandra ciliata	NA	.	-	103.4	-	33,707.8
Calytrix gurulmundensis	Gurulmundi fringe myrtle	V	V	0	0	13,096.5
Cymbonotus maidenii	NA	E	-	0	0	3,677.6
Digitaria porrecta	Finger panic grass	NT	-	99.8	0	3,675.5
Eucalyptus curtisii	Plunkett mallee	NT	-	0	0	24,167.5
Fimbristylis vagans	NA	V	-	5.3	499.1	3,181.7
Homopholis belsonii	Belson’s panic	V	V	0	19.3	1,206.9
Micromyrtus carinata	Gurulmundi heath myrtle	E	-	0	0	6,217.0
Philotheca sporadica	Kogan waxflower	NT	V	1,574.5	2,213.0	20,308.0
Picris barbarorum	NA	V	-	0	0	3,788.9
Rutidosis lanata	NA	-	NT	0	0	3,393.9
Solanum papaverifolium	NA	E	-	2.9	0	3,672.2
Solanum stenopterum	NA	E	-	0	0	2,764.5
Thesium australe	Austral Toadflax	V	V	0	0	526.7

*CHN = Core Habitat Known, CHP = Core Habitat Possible and GH = General Habitat

4.2.4 Exotic Flora Species

Of the 38 exotic species recorded during the assessment, five are listed as Restricted Invasive Plants under Queensland’s Biosecurity Act 2014 meaning that they cannot be given away, sold, or released into the environment without a permit. The majority of these plants are from the Cactus (Cactaceae) family which includes the genera of Opuntia and Harissia. African lovegrass (Eragrostis curvula), whilst not listed as a restricted plant in Queensland is considered a ‘High Priority Weed’ under the Western Downs Regional Council Pest Management Plan (2011 to 2015). The species was also abundant in the study area, particularly in southern portions in the vicinity of Dalby. A summary of significant pest plants recorded during the survey is provided in Table 4.5.

Table 4.5. Summary of declared weeds and weeds of national significance (WONS) known to occur in the study area from database searches and field survey.

Scientific Name **Common Name**	**Category***	**Significantly Infested Res**	**Comments**
Opuntia tomentosa Velvet tree pear	3/WONS	11.3.1, 11.3.4, 11.4.3, 11.3.17, 11.9.5.	Dense infestations of velvet tree pear were universally associated with brigalow habitats wihere it formed up to 15% cover in the taller shrub layers. The plant was also scattered throughout the majority of habitats although infestations considerably less vigorous on soils of lower fertility.
Opuntia stricta Prickly pear	3/WONS	Occurs at low to moderate levels throughout all ecosystems	Scattered individuals occur throughout all habitats although the species in more abundant in regional ecosystems with fertile alluvial soils.
Opuntia aurantiaca Tiger pear	3/WONS	11.3.1, 11.3.2, 11.3.4, 11.3.14, 11.3.17, 11.3.18, 11.3.25, 11.4.3, 11.9.5 and non-remnant habitats	Dense infestations typically recorded adjacent to or within brigalow habitats where it formed up to 10% ground cover in patches. Particularly heavy infestations associated with the riparian margins of Wilkie Creek.
Harrisia martiniii Harrisia cactus	3	Mostly Brigalow habitats including REs 11.3.1 11.3.17, 11.4.3 and 11.9.5.	Most commonly associated with brigalow habitats where it typically formed cover of < 5%. Tends to be less common and in lower abundance than tiger pear in infested habitats.
Bryophyllum delagoensis Mother of millions	3	Generally in riparian ecosystems including REs 11.3.2, 11.3.4, 11.3.25.	Dense infestations of >50% groundcover recorded in REs 11.3.25 and 11.3.17 adjacent to Wilkie Creek and Braemar Creeks. Scattered infestations recorded on drainage lines throughout the SGP study area.
Eragrostis curvula African love grass**	N/A	Mostly non-remnant habitats, particularly roadside margins with sandy soils.	An aggressive coloniser that is most typically associated with roadside margins although extends into remnant woodland habitats in the vicinity of Dalby.

*As per Queensland's Biosecurity Act 2014 / Weed of National Significance; ** Priority plant in the Western Downs Regional Council Pest Management Plan 2011 – 2015.

4.3 TERRESTRIAL FAUNA RESULTS

Terrestrial fauna surveys for this work identified a total of 266 vertebrate species[5] within the SGP study area including 20 amphibians, 55 reptiles, 151 birds and 40 mammals (Appendix F). Based on available database sources and previous works, one species was recorded for the first time within the region of the SGP study area (i.e., the SGP and ~50km buffer), the Pink-tongue Lizard (*Cyclodomorphus gerrardii*). An investigation of previous records (WildNet) revealed three records east of Toowoomba, one due south of the SGP study area (located on the southern side of the Gore Highway) and two within Southwood National Park (approximately 85km west of the SGP study area).

A number of species recorded during the surveys are at, or near, their distributional limit including Green Tree Snake (*Dendrelaphis punctulata*), Cotton Pygmy-goose (*Nettapus coromandelianus*), Yellow-tailed Black Cockatoo (*Calyptorhynchus funereus*), Azure Kingfisher (*Ceyx azureus*), White-naped Honeyeater (*Melithreptus lunatus*), Scarlet Honeyeater (*Myzomela sanguinolenta*), Rufous Fantail (*Rhipidura rufifrons*), Broad-toed Feathertail Glider (*Acrobates frontalis*) and Yellow-footed Antechinus (*Antechinus flavipes*).

Other notable observations include two Amalosia geckos, which while most closely resembling *A. jacovae*, lacked the distinctive toe webbing diagnostic to the species. According to current knowledge, neither *A. rhombifera* or *A. jacovae* occur in the Miles region (Wilson 2015), and the captured individuals had a mix of both characteristics. Subject to further study, these individuals may be assigned to one of these two taxa, extending their current range, or prove to be a new undescribed taxon. One individual was submitted to the Queensland Museum.

Recent taxonomic work on *Carlia pectoralis* (Open-litter Rainbow Skink) found the species to be a composite of three distinct taxa (Hoskin and Couper 2012). Two of these newly described species, *C. rubigo* and *C. pectoralis*, have the potential to occur within the SGP study area. Our field studies assigned most individuals to *C. rubigo*, though several individuals matched the description of *C. pectoralis*. However numerous captured animals had a mix of characters and could not be assigned to either species.

Eleven of the 266 identified species (4%) are non-native introduced species (Table 4.9, Appendix F).

4.3.1 Likely Threatened Terrestrial Fauna Species

Database searches including the EPBC Act Online Protected Matters Search Tool have identified 39 threatened species as occurring, or potentially having habitat, within the SGP study area (Table 4.6). An assessment of these species based on record relevance and habitat suitability (see Appendix C) suggests 11 are present, or have potential to occur.

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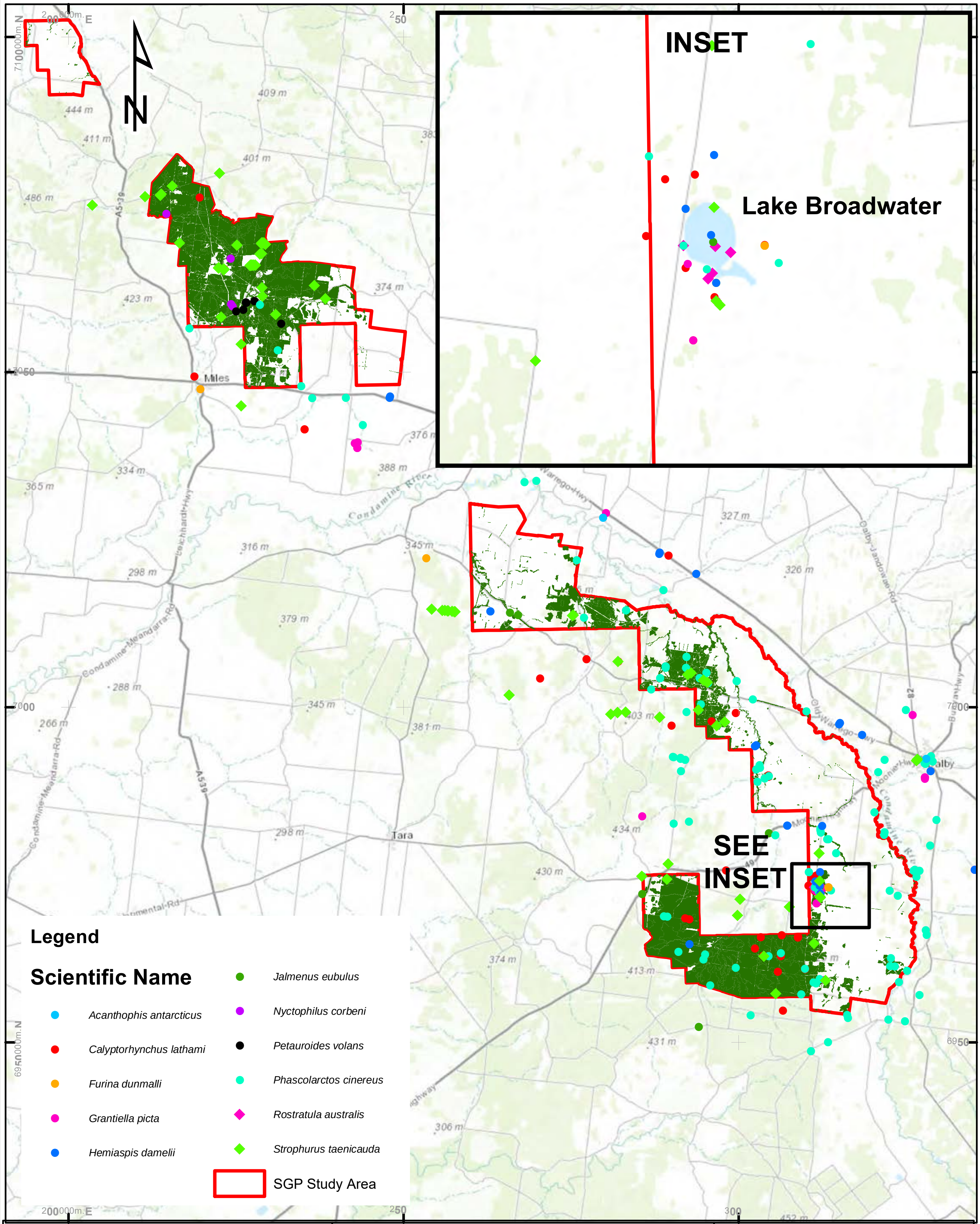
[5] Species totals discussed in this text do not include unidentified taxa (e.g., *Uperoleia* sp.), but do include recognisable taxa of taxonomic uncertainty (e.g., *Amalosia sp. cf. jacovae*).

Table 4.6. Likelihood assessment for Threatened fauna species in the SGP study area.

Scientific Name	Common Name	EPBC Status	NC Status	Likelihood
BUTTERFLIES				
Jalmenus eubulus	Pale Imperial Hairstreak	-	Vul	Likely
REPTILES				
Rheodytes leukops	Fitzroy River turtle	Vul	Vul	Unlikely
Elseya albagula	Southern snapping turtle	CEnd	End	Unlikely
Strophurus taenicauda	Golden-tailed Gecko	-	NT	Present
Delma torquata	Collared Delma	Vul	Vul	Unlikely
Anomalopus mackayi	Long-legged Worm-skink	Vul	End	Unlikely
Egernia rugosa	Yakka Skink	Vul	Vul	Unlikely
Tympanocryptis condaminensis	Condamine earless dragon	End	End	Unlikely
Aspidites ramsayi	Woma	-	NT	Unlikely
Acanthophis antarcticus	Common Death Adder	-	Vul	Possible
Furina dunmalli	Dunmall's Snake	Vul	Vul	Possible
Hemiaspis daemeli	Grey Snake	-	End	Present
Denisonia maculata	Ornamental Snake	Vul	Vul	Unlikely
BIRDS				
Botaurus poiciloptilus	Australasian Bittern	End	LC	Unlikely
Calidris ferruginea	Curlew Sandpiper	C End	End	Transient
Limosa lapponica baueri	Bar-tailed Godwit	Vul	Vul	Unlikely
Rostratula australis	Australian Painted Snipe	End	Vul	Possible
Pedionomus torquatus	Plains Wanderer	C End	Vul	Unlikely
Turnix melanogaster	Black-breasted Button-quail	Vul	Vul	Unlikely
Falco hypoleucos	Grey Falcon	-	Vul	Unlikely
Erythrotriorchis radiatus	Red Goshawk	Vul	End	Unlikely
Geophaps scripta scripta	Squatter Pigeon (southern)	Vul	Vul	Transient
Calyptorhynchus lathami	Glossy Black-Cockatoo	-	Vul	Present
Lophochroa leadbeateri	Major Mitchell Cockatoo	-	Vul	Unlikely
Lathamus discolor	Swift Parrot	End	End	Unlikely
Ninox strenua	Powerful Owl	-	Vul	Unlikely
Grantiella picta	Painted Honeyeater	Vul	Vul	Possible
Anthochaera phrygia	Regent Honeyeater	C End	End	Unlikely
Poephila cincta cincta	Black-throated Finch	End	End	Unlikely
MAMMALS				
Dasyurus hallucatus	Northern Quoll	End	LC	Unlikely
Dasyurus maculata maculata	Spotted-tailed Quoll	End	Vul	Unlikely
Phascolarctos cinereus	Koala	Vul	Vul	Present
Petauroides volans	Greater Glider	Vul	Vul	Present
Petrogale penicillata	Brush-tailed Rock-wallaby	Vul	Vul	Unlikely
Pteropus poliocephalus	Grey-headed Flying-fox	Vul	LC	Unlikely
Macroderma gigas	Ghost Bat	Vul	End	Unlikely
Chalinolobus dwyeri	Large Pied Bat	Vul	Vul	Unlikely
Nyctophilus corbeni	South-eastern Long-eared Bat	Vul	Vul	Present
Pseudomys australis	Plains Rat	Vul	End	Unlikely

The of EVNT records detected during the current surveys are shown in Figure 4.12.



Vegetation_Management_Status

🟩 Remnant Vegetation

FIGURE 4.12 Survey records of EVNT fauna species from within the SGP Study Area Region

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0 12 24 36 48
Kilometers

Scale 1:750,000 **Drawn By** DG **Date** 23-May-17 A4

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Many threatened species considered in the original SGP EIS (3d Environmental 2011) are no longer specially protected including Rough Collared Frog (*Cyclorana verrucosa*), Brigalow Scalyfoot (*Paradelma orientalis*), Grey Goshawk (*Accipiter novaehollandiae*), Black-necked Stork (*Ephippiorhynchus asiaticus*), Square-tailed Kite (*Lophoictinia isura*), Black-chinned Honeyeater (*Melithreptus gularis*), Turquoise Parrot (*Neophema pulchella*), Cotton Pygmy-goose (*Nettapus coromandelianus*), and Little Pied Bat (*Chalinolobus picatus*).

Profiles for Threatened fauna considered to be possible, likely or present from the study area are provided in Appendix G. The profiles include the criteria used to develop individual species habitat maps in the associated GIS package, and an assessment of mapping accuracy. Table 4.7 shows the extent of habitat available to each species based on the GIS mapping product.

Table 4.7. The extent of mapped habitat for Threatened fauna species present or possibly occurring within the SGP study area.

Scientific Name **Common Name**	**Status**		**Habitat extent (ha) in SGP by region***			**Likelihood**
	EPBC	**NCA**	**CHK**	**CHP**	**GH**	
Jalmenus eubulus Pale Imperial Hairstreak	-	Vul	0	869.4	0	Likely
Strophurus taenicauda Golden-tailed Gecko	-	NT	7,160.3	74,649.4	1,341.5	Present
Acanthophis antarcticus Common Death Adder	-	Vul	69.81	72,052.9	1,550.6	Possible
Furina dunmalli Dumnall's Snake	Vul	Vul	297.9	71,463.1	6,504.8	Possible
Hemiaspis daemeli Grey Snake	-	End	939.6	9,280.7	44,189.4	Present
Rostratula australis Australian Painted Snipe	End	Vul	266.5	223.3	0	Possible
Calyptorhynchus lathami Glossy Black Cockatoo	-	Vul	5,165.3	1,852.8	35.1	Present
Grantiella picta Painted Honeyeater	Vul	Vul	696.5	863.6	359	Possible
Phascolarctos cinereus Koala	Vul	Vul	8,187.4	5,015.36	71,949.8	Present
Petauroides volans Greater Glider	Vul	Vul	324.7	3,413.8	1,914.1	Present
Nyctophilus corbeni South-eastern Long-eared Bat	Vul	Vul	3,531.4	55,836.2	26,146.0	Present

*CHN = Core Habitat Known, CHP = Core Habitat Possible and GH = General Habitat

4.3.2 Migratory Fauna Species

Three Migratory species, listed under the EPBC Act, were recorded during the 2016-17 SGP surveys (Table 4.8). Other species have been historically recorded within the SGP study area, predominantly from Lake Broadwater (Figure 4.13) which is likely to be significant habitat for Migratory taxa. A discussion on the likelihood of each species occurring in the SGP study area over Life of Operation (approximately 25 years) is also provided in Table 4.8.

Table 4.8. Migratory species recorded within the SGP study area

Scientific Name **Common Name**	**ESE 2016-17**	**DB Recs**	**Discussion**
Gallinago hardwickii Latham's Snipe		X	The Latham's Snipe frequents Lake Broadwater, with only on other record restricted to a small dam in the southern region of the SGP study area. While it has potential to occur throughout the SGP study area on suitable dams, swamps and flooded paddocks, best habitat is largely limited to Lake Broadwater and Long Swamp. These two locations should be considered 'Important Habitat' as defined in Department of Environment, Water, Heritage and Arts 2009).
Limosa lapponica Bar-tailed Godwit		X	The Bar-tailed Godwit has been recorded twice from Lake Broadwater in 1985 and 1987. It is a vagrant species unlikely to occur within the SGP study area during Life of Operation. Lake Broadwater represents the only area of suitable habitat within the SGP study area.
Limosa limosa Black-tailed Godwit		X	The Black-tailed Godwit has been recorded once from Lake Broadwater in 1995. It is a vagrant species unlikely to occur within the SGP study area during Life of Operation. Lake Broadwater represents the only area of suitable habitat within the SGP study area.
Numenius phaeopus Whimbrel		X	The Whimbrel has been recorded only once from Lake Broadwater in 1990. It is a vagrant species unlikely to occur within the SGP study area during Life of Operation. Lake Broadwater represents the only area of suitable habitat within the SGP study area.
Tringa nebularia Common Greenshank		X	Common Greenshank is only known at Lake Broadwater where the most recent observation occurred in 2007. It is a vagrant which has a very low probability of occurring within the SGP study area during Life of Operation. The only area of suitable habitat occurs at Lake Broadwater.
Calidris ferruginea Curlew Sandpiper		X	The Curlew Sandpiper has been recorded on seven occasions within the SGP study area, all but one at Lake Broadwater. The most recent record (2007) is from an artificial dam approximately 6.5km SSE of Lake Broadwater. All other records predate 1995. It is likely the species will appear at Lake Broadwater during SGP operations, but is unlikely elsewhere. These vagrant individuals will not represent a significant population.
Plegadis falcinellus Glossy Ibis		X	The Glossy Ibis has been frequently recorded at Lake Broadwater. Lake Broadwater and Long Swamp represent the best areas of habitat within the SGP study area, and at these locations the species is expected to occur over Life of Operation. Alternative habitat is scarce, but the species could possibly occur in other wetlands or flooded paddocks.
Tringa stagnatilis Marsh Sandpiper		X	Marsh Sandpipers have been recorded semi-frequently at Lake Broadwater where it was last observed in 2007. It is possible this species could occur within Lake Broadwater during Life of Operation, but is unlikely to occur elsewhere due to lack of suitable habitat.

Scientific Name **Common Name**	**ESE 2016-17**	**DB Recs**	**Discussion**
Myiagra cyanoleuca Satin Flycatcher		X	A single Satin Flycatcher has been recorded within the central region of the SGP study area in 1997. It is a vagrant species and is unlikely to occur over Life of Operation.
Calidris acuminata Sharp-tailed Sandpiper		X	Sharp-tailed Sandpipers are recorded semi-frequently at Lake Broadwater where it was last observed in 2009. This species could occur at Lake Broadwater or possible Long Swamp during Life of Operation. While habitat elsewhere is limited, there is some potential for the species to occur in smaller farm dams, wetlands and flooded paddocks.
Tringa glareola Wood Sandpiper		X	The Wood Sandpiper has been recorded once from Lake Broadwater in 1995. It is a vagrant species that is unlikely to occur during Life of Operation or away from the Lake.
Gelochelidon nilotica Gull-billed Tern		X	Gull-billed Terns have been recorded on only nine occasions within the SGP study area, most recently in 2013. In all but two occasions the species has been recorded at Lake Broadwater. There is some possibility the species could sporadically appear on isolated waterbodies, but on balance it is only likely to occur infrequently at Lake Broadwater.
Chlidonias leucopterus White-winged Black Tern		X	The White-winged Black Tern has been recorded once from Lake Broadwater in 1995. It is a vagrant species that is unlikely to occur during Life of Operation or away from either Lake Broadwater or Long Swamp. It typically only occurs around larger waterbodies, wetlands or swamps.
Hirundapus caudacutus White-throated Needletail	X	X	Recorded at seven separate locations during the 2016-17 ESE surveys, all within the central region. These records represent large foraging flocks moving across the region. Records are also present in databases. Being aerial in nature, this species can occur over both natural and modified landscapes (including urban cities), though large stands of forest may be important for roosting. The species is likely to frequently occur throughout the SGP study area.
Apus pacificus For-tailed Swift	X	X	Recorded at fourteen separate locations during the 2016-17 ESE surveys. Known from an additional 14 records in databases. Strictly aerial in nature, they can occur over modified landscapes (including tilled crops and urbanisation) though large tracts of woodland may be a key habitat requirement (Department of Environment 2015). They will occur throughout the SGP study area.
Rhipidura rufifrons Rufous Fantail	X	X	Recorded at four locations during the current surveys, all within or adjacent Dalby State Forest. The species has also been recorded at six other locations in databases, also only within the southern region of the SGP study area. Habitats within the SGP study area are marginal, the species prefers rainforest or wet sclerophyll forests. These records approximate the limit of the species western extent (only four records further west, all <100km of the SGP study area), and therefore their populations could be considered 'Important' as defined under the MNES impact assessment guidelines (Department of Environment 2013).

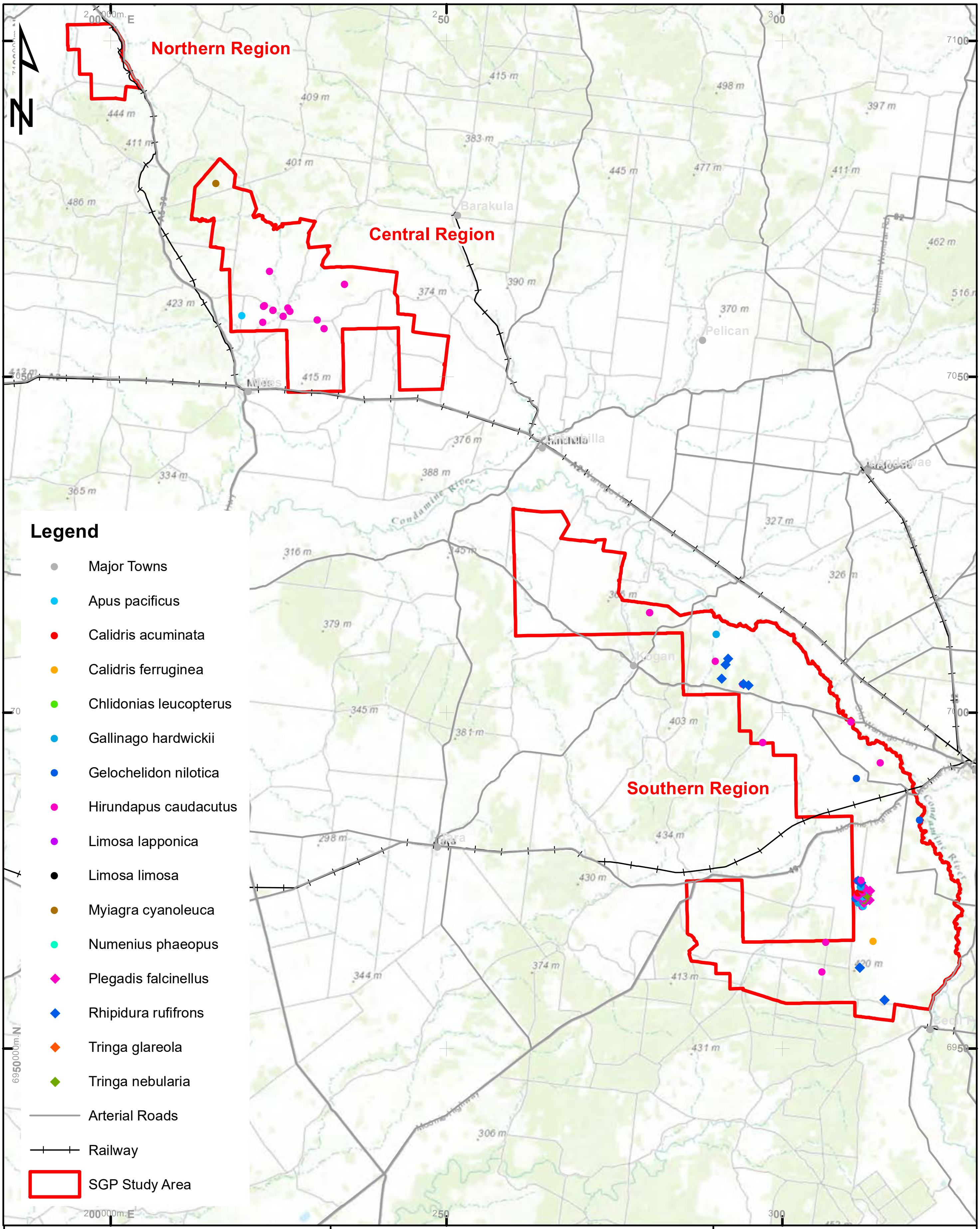

FIGURE 4.13 Migratory species records within the SGP Study Area

Client ARROW ENERGY

0 12 24 36 48
Kilometers

Scale 1:750,000 **Drawn By** DG **Date** 24-Jun-17 A4

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& Mapping Specialists

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4.3.3 Exotic Pest Species

Feral pest species known to occur within the SGP study area are discussed in Table 4.9.

Table 4.9. Exotic pest species known from the SGP study area

Scientific Name **Common Name**	**Recorded during ESE surveys**	**Discussion**
Sus scrofa Feral Pig	Y	While only a handful of individuals were observed, feral pig evidence was commonly encountered. Evidence of pig activity was at its highest in locations with water or damp soils (e.g., creeklines and gullies), particularly in the larger tracks of forest. They are likely to be throughout the SGP study area. Predation, habitat destruction, competition and disease transmission by Feral Pigs is a Key Threatening Process under the EPBC Act.
Rhinella marina Cane Toad	Y	Cane Toads are common in the northern portion of the SGP study area, being frequently recorded north of the Dalby-Kogan Rd. South of this road they become increasingly less abundant, only one individual was recorded south of the Moonie Highway. A similar pattern is apparent in database records. The biological effects, including lethal toxic ingestion, caused by Cane Toads is a Key Threatening Process under the EPBC Act.
Canus lupus familiaris/dingo Dog/dingo	Y	Dogs/dingos and their signs were frequently observed during the survey and the species is likely to be widespread throughout the SGP study area. Highest densities may occur within larger tracts of vegetation away from grazing land where they are more likely to be actively hunted and controlled.
Felis catus Feral Cat	Y	Feral Cats were noted at 12 locations during the surveys and will be abundant and widespread within the SGP study area. Feral Cats pose a significant threat to biodiversity and predation by Feral Cats is a Key Threatening Process under the EPBC Act.
Oryctolagus cuniculus European Rabbit	Y	Rabbits are uncommon within the SGP study area. They were recorded four times during these surveys, and have only been recorded at two other locations within databases.
Lepus europeaus Brown Hare	N	Brown Hares are infrequently encountered within the SGP study area. Individuals were observed on only two occasions during these surveys, and the species has been recorded only eight times within the SGP study area in other databases.
Sturnus vulgaris Common Starling	N	Common Starlings are abundant in modified land along the Condamine River. They are largely absent from the heavily wooded areas covering most of the SGP study area.
Sturnus tristis Common Myna	Y	Within the SGP study area Common Mynas have a similar distribution to Common Starlings, being abundant in modified lands along the Condamine River and rare elsewhere.
Columba livia Rock Dove	Y	Rock Doves have not been frequently recorded within the SGP study area. They are usually more abundant around larger urban centres, but can be found in surrounding farmlands. They have only been noted from the southern region of the SGP study area, and in most cases in modified land along the Condamine River.

Scientific Name **Common Name**	**Recorded during ESE surveys**	**Discussion**
Mus musculus House Mouse	Y	House Mice have been recorded throughout the SGP study area. While they are likely to be most abundant in modified agricultural areas and adjacent remnant vegetation, they can occur from within large tracts of native vegetation.
Streptopelia chinensis Spotted Dove	N	Rare recorded from the SGP study area; all historic records (4) noted from Lake Broadwater between 2003 and 2009.
Rattus rattus Black Rat	N	Likely to be more abundant than suggested by the few database records. Likely to be largely restricted to around human dwellings and occupied centres.
Vulpes vulpes Red Fox	Y	Records of the Red Fox are restricted to the southern region of the SGP study area where grazing land is widespread. While they will have lower abundance in large continuous tracts of vegetation, they are likely to occur throughout the SGP study area. Red Foxes pose a significant threat to biodiversity and predation by European Red Fox is a listed Threatened Process under the EPBC Act.
Passer domesticus House Sparrow	N	House Sparrows will be largely restricted to urban towns. Currently they occur infrequently in the SGP study area, and are most likely to turn up in the southern region along the Condamine River where large-scale land clearing has occurred.
Unidentified Deer Species	Y	An unidentified species of deer was briefly observed during the March surveys north of Kogan. While unmistakably a deer, the species could not be identified. This is the first deer record within the region (i.e., SGP study area + 50km buffer).

5.0 HABITAT CONDITION

5.1 CONDITION OF WETLANDS INCLUDING LONG SWAMP

A relatively complex system of floodplain wetlands occurs in the southern region of the SGP study area, generally associated with sinuous overflows of the Condamine River and its larger tributaries. The southern region also contains Lake Broadwater, a seasonal water feature that is recognised nationally for its natural values, being significant at a national and state level. The lake is listed on the Directory of Important Wetlands and is recognised as being a rare example of a semi-permanent freshwater lake in the bioregional area (Blackman *et al*. 1999, EHP 2006) The Lake is fringed by an open forest of River Red Gum (*Eucalyptus camaldulensis*) (RE 11.3.27d) which is broadest (approx. 200m) around the north-eastern portion of the lake. Habitats surrounding the lake are generally in good condition.

The numerous flood plain wetlands are almost universally heavily infested with Lippia (*Phyla canescens*) during seasonal drying periods. This severely limits the ability of native aquatic species to re-colonise these areas during wetter, more favourable seasons.

Long Swamp is a sinuous hydrological feature (overland flow path) that flows across the Condamine Alluvium in a north-westerly direction to the east and north of Lake Broadwater, before joining with Wilkie Creek to the west. The feature occupies a broad depression on the alluvium with the central portion of the depression formed by heavy clay. Surface water is present seasonally and following dry spells the associated vertosol soils form deep hummocks and cracks. There was no flow, nor any significant pooled water within Long swamp during the field visits, despite heavy recent rains. These observations together with the observations of deep, open cracks in the central swamp channel soil surface confirmed that the feature is only active during significant flooding.

At Long Swamp the vegetation is predominantly native, although exotic groundcovers predominant in some localities. The canopy is formed by tall, broadly spaced River Red Gum (*Eucalyptus camaldulensis*) at approximately 15 - 30% cover with Poplar Box (*Eucalyptus populnea*) forming on the swampy margins. The canopy is significantly stressed in some areas with signs of senescence and foliage loss. The noted senescence is possibly due to historic groundwater drawdown for irrigation (Kath *et al.* 2014; 3d Environmental, 2017) although may have been further compounded by surface water extraction.

Four secondary vegetation survey sites were completed within Long Swamp during the dry season survey (DS21, DS22, DS26, DS31 completed when the swamp was dry). At these locations exotic vegetation cover contributed an average of 15% to the total groundcover, and formed 39% of the total living groundcover. Common native species included Nardoo (*Marsilea drummondii*), Water Chestnut (*Eleocharis dulcis*) and scattered native grasses including *Panicum decompositum*. Lippia (*Phylla canescens*) was the most abundant exotic forb blanketing the clay soils, particularly where grazing pressure is most intense. It should be noted that groundcover composition will vary seasonally with native aquatic sedges, particularly Water Chestnut, becoming dominant during periods of standing surface water.

Photo 2. Long Swamp with characteristic Red Gum showing moderates signs of stress as suggested by foliage loss.

5.2 GENERAL HABITAT CONDITION

The SGP study area incorporates a number of landscapes, ranging from the broad river flood plains centred on the Condamine River and its associated tributaries, rolling hills on fine grained sedimentary rocks in the Wandoan (northern) area, rangeland woodlands formed on skeletal rocky soils, and ironstone jump ups and extensive tracts of ironbark dominant woodland associated with older Tertiary / Cainozoic plains. The impacts of land use vary across the landscape dependant largely on the fertility of the underlying substrate.

The productivity of the alluvial clay soils on the Condamine River floodplain, collectively referred to as the Condamine River Alluvium (CRA), has resulted in heavy utilisation of these areas for agricultural purposes, predominantly tilled cropping. Floodplain vegetation is generally restricted to the immediate river channel and associated flood pockets, with scattered areas on crown or council owned land and as isolated fragments adjacent to floodplain overflows and swamps. Long-term abstraction of groundwater associated with the CRA, has lowered groundwater levels by up to 25m in some localities (Kath *et. al.* 2014). It is understood that Arrow is currently investigating the presence and connectivity of perched aquifers and deeper aquifers in this area. The loss of water from the rooting zone of deeper rooted species such as River Red Gum (*Eucalyptus camaldulensis*) and Poplar Box (*Eucalyptus populnea*) has resulted in severe loss of canopy vigour and dieback in some localities. It is expected that based on historic groundwater levels (take from Arrow well baseline assessments), maximum tree rooting depth would not have exceeded 15m across the dominant portion of the CRA. The reduction of canopy vigour has resulted in increased light penetration, coupled with the impact of grazing, which has resulted in pervasive displacement of native groundcovers by exotic species such as Green Panic (*Megathyrsus maximum var. trichoglume*) and Lippia (*Phylla canescens*).

Brigalow communities (RE 11.3.1, RE 11.4.3 and RE 11.9.5) and Brigalow/Eucalypt associations (RE 11.3.17) have been cleared to the margins of adjacent vegetation types and generally exist as small unviable remnants, slivers along the margins of riparian forest types, or as secondary forests with limited structural complexity or floristic diversity. Native ground covers, although naturally sparse in these communities are often displaced by exotic species including Prickly Pear (*Opuntia stricta*), Mother of Millions (*Bryophyllum delagoense*) and Harrisia Cactus (*Harrisia martinii*). Dense infestations of velvet tree pear are typical in brigalow habitats forming up to 20% cover in the taller shrub layer of many occurrences. Despite their extent, brigalow patches can still have significant value for several threatened fauna species including the Pale Imperial Hairstreak (*Jalmenus eubulus*) and Painted Honeyeater (*Grantiella picta*).

Although ecosystem types on soils of low fertility, typically those REs associated with land zones 5 and 7, form the largest and most continuous tracts of vegetation in the study area, these ecosystems have invariably been heavily utilised for their timber resources with varying degrees of impact. In particular, habitats dominated by the Narrow-leaf Ironbark species *Eucalyptus crebra, E. elegans* and *E. woollsiana* (RE 11.5.1, 11.5.4, 11.7.4 and 11.5.20) have been logged to a degree that all mature canopy trees have been removed. The remaining vegetation comprises of secondary growth with a thickened shrub layer forming the canopy. Examination of 1981 aerial photography for the SGP study area demonstrates closely spaced rip-lines through large areas of remnant vegetation indicating the intensity of historical timber extraction practices.

The impact of logging is also evident in the majority of state forests within the SGP study area including Braemar SF, Kumbarilla SF to the west of Dalby and Barakula SF to the north of Chinchilla. However from general observation these logging regimes have been less severe than those applied on freehold land.

A number of ecosystems appear more resilient to landscape-wide processes of degradation. In particular *Eucalyptus fibrosa subsp. nubila* forest communities (RE11.7.7) have, in general, a better-preserved canopy structure, a greater number of mature canopy trees, and fewer large canopy gaps. This preservation is likely to be due to the quality and usefulness of the timber resource rather than an inherent ability to recover from disturbance.

While, on balance, the State Forests have retained greater conservation value than vegetation on freehold land, the future of these areas may be affected by changes to fire regime. Within the last 10 years, three extremely hot fires have affected large expanses of State Forest within the SGP study area, and in the case of Kumbarilla State Forest on more than one occasion (see Section 2.4). These hot fires can cause significant damage to the canopy and vegetation composition (by removing fire-sensitive species). It is likely the vegetation will take many decades to fully recovery after a significant wildfire. The frequency and intensity of wildfires are predicted to increase due to climate change (Williams *et al.* 2001), possibly leading to possible broad-scale vegetation changes.

In the northern portion of the SGP study area surrounding Wandoan, the arable clay soils and favourable nature of the gently undulating landscape has promoted widespread land clearing for an intensive cattle grazing land use. Only scattered vestiges of remnant vegetation remain including degraded patches of brigalow and riparian remnants adjacent to drainage lines. These patches have invariably suffered from canopy disturbance and invasion of exotic groundcovers, most notably Buffel Grass (*Cenchrus ciliaris*) and Green Panic (*Megathyrsus maximus var. trichoglume*).

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Appendix A.

GIS Package Contents

Contents of the associated Geodatabase package are outlined in the below table.

Geodatabase Dataset	**Contents**	**Notes**
Vegetation		
Arrow_Vegetation	RE mapping, TEC mapping and Threatened species habitat mapping (Core Habitat Possible, General Habitat).	Primary vegetation mapping database which identifies vegetation type in terms of Regional Ecosystem, Threatened Ecological Community and Conservation Status under relevant state and federal legislation. Provides the basis for mapping of EVNT fauna habitats based on vegetation type.
Core Habitat		
Core_Habitat_Flora	Core Habitat Known for all possible, likely or Present flora species	Overlaps the Threatened species mapping in Arrow_Vegetation dataset but takes priority.
Core_Habitat_Fauna	Core Habitat Known for all possible, likely or Present fauna species	Overlaps the Threatened species mapping in Arrow_Vegetation dataset but takes priority.
Ecological Survey Sites		
Flora_Survey_Sites	Compilation of all Secondary, Tertiary, Quaternary and Observation sites collected in floristic ecology surveys commissioned by Arrow Energy since 2009.	Included records from Surat Gas Pipeline Assessments, EIS and Supplementary EIS assessments as well as survey points from the recent 2016 – 2017 surveys.
ESE_Survey_Sites	Location of fauna survey methods completed during current surveys (2016-17)	SGP advanced exploration project works
Daandine_Trapping_Surveys	Location of fauna survey methods completed during Daandine fauna assessments (2014)	Ecosmart Ecology 2014.
SREIS_Trapping _Surveys	Location of fauna survey methods completed during Surat Gas Project supplementary EIS (2013).	3D Environmental (2013)
EVNT_Flora_and_Fauna_Field_Records		
EVNT_Fauna_Field_Records	Terrestrial fauna survey results collected during the current work	Error vetted. Includes geo-referenced sightings and opportunistic records without coordinates. Where opportunistic records have been recorded without specific dates the first day of the survey has been attributed.

Geodatabase Dataset	**Contents**	**Notes**
EVNT_Flora_Field_Records	Terrestrial flora survey results for both recent and historical collections in the SGP study area.	Includes EVNT records for all Arrow commissioned survey works from 2009 onwards plus Queensland Herbarium records within the SGP study area.
Herbrecs_SGP_25km_Buffer	Queensland Herbarium database records for EVNT flora species recorded within a 25+km buffer surrounding the SGP assessment area	Queensland Herbarium records within both the SGP and adjacent areas.
Additional Datasets		
ESE+DB_Recs_SGP	All coordinate based fauna records from both database sources and this work within the SGP.	No error vetting and duplicate records likely. Includes only geo-references sightings
SGP_EVNT_Recs	All known Threatened fauna species records within the SGP + 10km buffer	

Appendix B.

Fauna Survey Effort Compared to EPBC Survey Guidelines

The table below details the recommended survey effort for EPBC threatened taxa compared to survey effort achieved during this work. Note that the recommended EPBC survey effort is based on small project sites.

	Guideline Requirements							**Adjusted for Habitat Extent**			
Scientific Name **Common Name**	**Survey Period**	**Techniques**	**Value**	**Effort**	**Min Duration**	**Area unit**	**Notes**	**Possible BVG's**	**Extent (ha)**	**Required effort (approx)**	**ESE Effort**
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

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)**	
	-	Hair-tubes	primary	40 tubes	14 nights	5ha	small sites. No guideline for larger sites			3,211,488 trap nights	NIL
	-	Camera trap	primary	10 nights	14 nights	1ha				4,014,360 trap nights	460 camera nights

Appendix C.
Threatened Species Likelihood Assessments

The table below lists flora and fauna species that either known from within 50 km of the SGP or have been identified in the EPBC online Protected Matters search. The Likelihood assessment has been based on the SGP having a Life of Operation of approximately 25 years. Mobile fauna species which could occur within the SGP over this timeframe, but are unlikely to represent a permanent population or a population relying on the SGP for its long-term viability (vagrants) are assessed as 'Transient'.

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
FLORA						
Philotheca sporadica Kogan Waxflower	NT	Vul	Based on field survey observation, the species is universally restricted to open scalds and low *Eucalyptus exserta* dominant woodlands associated with RE11.7.4.	The extent of habitat including known, core habitat possible and general habitat has been provided within the attached GIS package	There are 11 known populations, seven occur on road verges, seven extend onto freehold land and one population is within Braemar State Forest (Halford 1995c in TSSC 2008j). The extent of known populations and habitat has been expanded considerably as a result of the current assessment.	Present
Acacia barakulensis Waaje Wattle	Vul	-	HERBRECS specimen records indicate species is associated with woodland and shrubland habitats formed by *Eucalyptus tenuipes, Corymbia trachyphloia, Calytrix gurulmundensis*, and *Triodia mitchellii*. Habitat is consistent with RE 11.7.4, 11.7.5, 11.7.6, and 11.7.7.	The extent of habitat including core habitat possible and general habitat has been provided within the attached GIS package. The species is considered to possibly occur based on suitability of habitat in the SGP and contiguity of adjacent habitats	Herbrecs identifies 5 confirmed populations 28 km to the north-east of the SGP study area within Barakula State Forest.	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Acacia curranii Curly Bark Wattle	Vul	Vul	Plants are known to occur in shrubby heaths, dry sclerophyll forests and semi-arid woodlands where they can occur as widely scattered thickets in very species-rich heathy scrub with emergent eucalypts (Pickard 1995c, Threatened Species Scientific Committee 2008). Curly-bark wattle grows on sandy clay soils that are poorly drained on weathered sandstone (Pickard 1995c).	The extent of habitat including core habitat possible and general habitat has been provided within the attached GIS package. The species is considered to possibly occur based on suitability of habitat in the SGP and contiguity of adjacent habitats	Sixteen local populations are recorded in Herbrecs with the nearest population 11 km west of the SGP study area with Gurulmundi State Forest (excluding low precision records).	Possible
Acacia handonis Hando 's Wattle	Vul	Vul	Hando's wattle has only been collected on rocky ridges and slopes on sandstone-derived geology in eucalypt woodland and open forest. The vegetation it grows within is a shrubby woodland of *Eucalyptus fibrosa subsp. nubila, Eucalyptus watsoniana subsp. watsoniana, Lysicarpus angustifolius*, and Allocasuarina inophloia (Halford 1995). This is consistent with RE11.7.7	The extent of habitat including core habitat possible and general habitat has been provided within the attached GIS package. The species is considered to possibly occur based on suitability of habitat in the SGP and contiguity of adjacent habitats	Seventeen local populations are recorded in Herbrecs with the nearest population 35 km east of the SGP study area within Barakula SF (54 km west-north-west of Miles)	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Callitris bayleyii Bailey's Callitris	NT	-	A 3D Environmental survey record associated with the Surat EIS (3D Environmental 2011) confirms its presence in low open forest (11-15m) of *Eucalyptus exserta, E. crebra* and *Callitris glaucophylla* with a mid-dense shrubby understorey dominated by *Micromyrtus sessilis with Acacia crassa, Alphitonia excelsa*, and *Petalostigma pubescens*. Habitat typical of RE11.7.4	Extensive tracts of suitable habitat occur in the central portion of the SGP area. The extent of habitat including core habitat possible and general habitat has been provided within the attached GIS package.	Nearest local record is 2.6 km west of the SGP study area (40 km north of Miles) in Gurulmundi State Forest.	Possible
Calytrix gurulmundensis Gurulmundi Fringe Myrtle	Vul	Vul	Gurulmundi fringe myrtle has been recorded growing in patches of shrubland on very shallow soils (EPA 2002). Soils are lateritic sandstone ridges, which contain yellow sandy-clay that retains moisture (Williams 1979). Vegetation is predominately eucalypt, acacia, casuarina dense shrublands with spinifex, and spinifex grassland with scattered shrubs. This habitat description is consistent with RE 11.7.5 (shrubland on natural scalds on deeply weathered coarse-grained sedimentary rocks).	Suitable habitats include patches of RE11.7.5 and RE11.7.4 in to the west and north-west of the central assessment area. The extent of habitat including core habitat possible and general habitat has been provided within the attached GIS package.	Nearest local record is 12 km west of the SGP study area (30 km north of Miles) within Gurulmundi State Forest. A population also exists in Waaje Scientific Reserve 36 km east of Wandoan.	Possible
Micromyrtus carinata	E	-	Herbrecs records indicate suitable habitat in heathland and low woodland typical of REs 11.7.4 and 11.7.5.	Estimated extent of suitable habitat within the SGP provided in GIS package.	Nearest Herbarium Record is 10km north-west of Miles and 4 km west of the SGP study area on the Wyona Property.	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Eucalyptus curtisii Plunkett Mallee	NT	-	Lateritic sandstone and sandstone rises/ridges and slopes often with *Eucalyptus exserta, E. fibrosa* subsp. *nubila, Corymbia trachyphloia,* and *Callitris glaucophylla.* Typical habitats include RE11.7.7, 11.7.5 and 11.7.5.	Has potential to occur throughout the SGP study area in suitable habitats. Estimated extent of suitable habitat within the SGP provided in GIS package.	Numerous local records mostly west of the SGP study area with the nearest record 2.5 km west of the SGP study area and 35km north of Miles	Possible
Acacia lauta Tara Wattle	Vul	Vul	Associated with sandy soils hosting ironbark woodland. Known populations have been mapped within REs 11.7.7, 11.7.4 and 11.7.5. These REs provide a representative mix of shrubland and woodland of which ironbark (*Eucalyptus crebra, Eucalyptus sideroxylon or Eucalyptus fibrosa)* forms a dominant to sub-dominant component (TSSC 2008o).	Populations are localised to the area surrounding Tara and Inglewood. Due to a lack of survey record following comprehensive survey, this species is considered unlikely to occur.	Nearest record is 20km west of the Kumbarilla State Forest in the vicinity of Tara (64 km west of Dalby).	Unlikely
Acacia wardellii	NT	-	The species inhabits gravelly soils on shallow weathered sandstone in eucalypt woodland (Pedley, 1978). Herbrecs data (EHP 2013) indicates typical habitats including RE 11.7.4, RE 11.7.7 and RE 11.7.5.	Potential habitats include REs 11.7.4 and 11.7.7 to in the vicinity of Kogan although extensive ground survey in this locality suggest a new population within the SGP is unlikely.	Three populations recorded all approximately 16 km west of the SGP study area and 25 km west of Chinchilla. Greater than 30km west of the nearest suitable habitat near Kogan.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Cadellia pentastylis Ooline	Vul	Vul	Ooline grows in semi-evergreen vine thickets, brigalow and occasionally in adjacent eucalypt woodland, where it maybe locally dominant in the canopy layer or occur as an emergent (TSSC 2008e) and also residual trees in cleared paddocks. Substrates include clay plains, sandstone and residual ridges (Eddie 2007).	Although Ooline occupies a range of substrates, local records are located in sandstone ravines in Gurulmundi State Forest. There are no known similar habitats in the SGP study area.	Nearest local record is 23 km west of the SGP study area and 50 km NE of Miles, No other local records.	Unlikely
Denhamia parviflora Small-leaved Denhamia	Vul	Vul	Small-leaved Denhamia grows in semi-evergreen vine thickets, vine scrubs and brigalow (*Acacia harpophylla*) softwood communities on fertile, red brown sandy clay loam hillslopes and crests (DNR 2000).	Suitable habitat and substrate within the assessment area is extremely limited.	2 pre-1985 records located to the east of Chinchilla, approximately 20 km east of the SGP study area.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Eucalyptus argophloia Chinchilla white gum	Vul	Vul	The existing natural population exists largely in highly disturbed regrowth vegetation with associated tree species including brigalow (*Acacia harpophylla*), grey box (*Eucalyptus molluccana/ Eucalyptus microcarpa*) white cypress pine (*Callitris glauca*) and poplar box (*Eucalyptus populnea*). The tree is associated with red loams, grey brown clays and clay loams of moderate to high fertility (Boland et al. 2006). According to TSSC (2008p), no known populations occur in vegetation classified as remnant under the VM Act.	Suitable red high fertility loamy substrates have not been identified in the assessment area.	Nine records located east of the SGP study area with the nearest population 25 km from the SGP boundary and 18 km north-west of Chinchilla	Unlikely
Eucalyptus virens Shiny-leaved Ironbark	Vul	Vul	The species is known to inhabit plateaus and sandstone escarpments and sandy soils which form low rises. Based on Herbrecs data (EHP 2013), populations are mapped as occurring in association with REs11.7.7, 11.7.4. 11.7.5, 11.7.6 and11.5.1, all associated with residual soils.	Suitable habitat present although extensive field survey did not identify any new populations.	Extremely localised population with 2 records from the vicinity of Tara, 9 km west of the SGP study area (64 km west of Dalby).	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Digitaria porrecta Finger Panic Grass	NT	-	Finger panic grass grows in grasslands, woodlands and open forests with a grassy understory, on black soil plains of the Darling Downs, and lighter textured soils to the west (Goodland 2000; Fensham 1998). Fensham (1998) found it is most abundant in grassland, but is "relatively unspecific" in its habitat preference. It is not restricted to high quality native grasslands, but also grows along roadsides and can be found in highly disturbed sites.	The most suitable habitats are associated with derived grassland habitats, typically associated with roadside easements between Chinchilla and Cecil Plains.	Two records within the SGP study area , both in non-remnant derived grasslands adjacent to roadside easements between Dalby and Cecil Plains. Both records collected in 1995. A further 15 records within 25 km east of the SGP study area boundary.	Present
Fimbristylis vagans	E	-	A sedge to 80cm tall that that fringes ephemeral watercourses and lagoons on alluvium.	A large number of potential habitats associated with swamps and drainage lines.	A single record from the SGP study area associated with the swampy inlet of Lake Broadwater. Has not been recorded or collected since 1984.	Present
Homopholis belsonii	E	V	Belson's panic prefers moderate to highly fertile soils, especially those derived from basalt and fertile alluvial flats. It is generally associated with poplar box and brigalow woodlands on light red/brown earths (Fensham and Fairfax 1997, Goodland 2000). It is most likely to be associated with RE11.3.1, 11.3.17, 11.4.3, 11.9.5, 11.9.10.	Regional ecosystems associated with heavy clay, typically brigalow. Scattered remnants of REs 11.3.1, 11.3.17, 11.4.3, 11.9.5, 11.9.10 occur throughout the SGP EIS Area.	A considerable number of records to the east of Dalby with the nearest 12 km from the eastern boundary of the SGP study area. Two records within 8 km of the boundary of the northern study region within 10 km of Wandoan.	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Cyperus clarus	V	-	Known from heavy soils with records from remnant and disturbed *Eucalyptus orgadophila* woodland on basaltic soils and grassland on heavy alluvium.	Limited suitable remnant habitat in the assessment area and the species is not known to be associated with non-remnant habitats.	A single 1995 herbarium record exists in the Jandowae area, 18 km east of the SGP study area and 25 km north of Dalby.	Unlikely
Solanum papaverifolium	E	-	Occurs in wetter (swampy) areas of grasslands or open eucalypt woodland on heavy alluvial soils (Goodland 2000). The species is often recorded in non-remnant habitat.	Suitable habitat occurs within derived grassland and associated woodlands typically associated with roadside reserves.	Two records contained within the SGP study area to the south of Dalby with an large number of herbarium records to the east of the SGP study area between Chinchilla and Dalby.	Present
Cymbonotus maidenii	E	-	The species is associated with a range of remnant and non-remnant habits with records occurring on disturbed roadside drains, native and derived grasslands. It is typically associated with heavy brown to grey cracking clay soils (Holland & Funk 2006).	Suitable habitat occurs within derived grassland habitats to the south of Dalby.	Five Herbrecs specimens recorded within 10 m of the eastern boundary of the SGP study area, mostly in the Cecil Plains / Millmerran Area including collections on road reserves on the Cecil Plains - Millmerran Road.	Possible
Picris barbarorum	V	-	Known from native grassland (12.3.21) of Dichanthium sericeum in stock routes, road reserves adjacent to disturbed areas such as cultivated paddocks and road and rail lines on black clay soil.	Potential habitat associated with derived grassland in road reserves to the north and south of Dalby.	Four herbarium records within 5km of the SGP study area with the nearest less than 2 km from the assessment area boundary, 14km north-west of Dalby.	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Rutidosis lanata	NT	-	Mainly found in roadside vegetation of Acacia and Eucalypt woodland/open forest on red sandy ridges and clay flats between 280-320m altitude adjacent to cleared or partly cleared grazing and cropping land (DNR 2000).	Most likely to be recorded within REs 11.3.4, 11.3.2 and 11.3.3 in the vicinity of Chinchilla although may occur in these habitats throughout the entire project area.	Eight Herbarium records within 20 km from the SGP study area, all recorded in the Miles / Chinchilla area.	Possible
Solanum stenopterum	V	-	Occurs in disturbed grassland, *Casuarina cristata* forest or *Eucalyptus populnea* woodland on clay soils (Bean 2004).	Derived grassland, Brigalow and grassy woodlands of *Eucalyptus populnea* between Dalby and Cecil Plains.	Known to occur in non-remnant grassland approximately 7.5km south of Dalby; 3.5 km east of Cecil Plains in a roadside gravel pit; and approximately 6 km south east of Cecil Plains in remnant Eucalyptus populnea woodland on alluvium (11.3.2). All herbarium records outside SGP study area.	Possible
Xerothamnella herbacea	E	E	Occurs in remnant and disturbed brigalow (*Acacia harpophylla*) and belah (*Casuarina cristata*) dominated communities in shaded situations, often in leaf litter (TSSC 2008n).	Numerous brigalow habitats (RE11.3.1, 11.4.3, 11.9.5), both remnant and disturbed have potential to host this species.	Two herbarium records to within 20km of the SGP Boundary, 20km to the east and north of Chincilla.	Possible
Cryptandra ciliata	NT	-	Suitable habitat in eucalypt dominated woodland, lancewood (Acacia shirleyi) woodland and Triodia grassland on rocky on low lateritic and sandstone ridges. Habitat in the PDA is consistent with RE 11.7.5, 11.7.4, 11.7.6, 11.5.1, 11.5.4, 11.5.21.	Woodlands in the Chinchilla / Miles region in the Central assessment area provide for potential habitat for the species.	Three herbarium records within 5km of the assessment area boundary with a single record within 1km of the eastern boundary, 30km to the north of Miles.	Possible

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Pomaderris coomingalensis	E	-	Occurs in Eucalyptus and Callitris woodland in shallow sandy soil or Eucalyptus woodland on hard sandstone jump ups. Herbarium records (DERM 2011) include woodland of narrow leaved ironbark (*Eucalyptus crebra*) and *E. fibrosa subsp nubila*.	Extensive areas of potential habitat in the Kogan / Kumbarilla areas in RE11.5.1, 11.7.4 and 11.7.7.	A single record to then west of Kumbarilla State forest, 10km from the west of the SGP study area. Not recorded in field surveys despite extensive survey effort in suitable habitat	Unlikely
Thesium australe Austral toadflax	V	V	Austral toadflax has been collected within popular box (*Eucalyptus populnea*) woodland on alluvial flats (RE 11.3.2) north-west of Dalby, within the project development area.	Most likely to occur on habitats formed on heavy clay associated with the Condamine Alluvium. RE11.3.2 provides the most suitable habitat within the assessment area.	Two herbarium records within 10km of the SGP study area, with the nearest record 2.7k east of the eastern SGP study area boundary, 25km north west of Dalby.	Possible
FAUNA						
Jalmenus eubulus Pale imperial hairstreak	Vul	-	Restricted to Brigalow (*Acacia harpophylla*)-dominated woodlands and open-forests, particularly those areas with Belah (*Casuarina cristata*), emergent eucalypts such as *Eucalyptus populnea* and understorey shrubs (Breitfuss and Hill 2003; Eastwood et al. 2008).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Three records are located within the SGP, the most recent of which is nearly 20 years old. An additional five records are within 10km of the SGP boundary. The species requires targeted surveys to detect, even during suitable conditions. Current number of records are likely to underestimate abundance and distribution	Likely
Rheodytes leukops Fitzroy River turtle	Vul	Vul	Reliant on faster flowing riffle habitats and generally does not move far from them within its home range (Tucker et al. 2001)	No suitable habitat within the SGP.	Only found in the Fitzroy River catchment. No records within 50km of the SGP boundary.	Unlikely

Scientific Name **Common Name**	**Status$^{\#}$**					**Likelihood Assessment**
	NCA	**EPBC**	**Typical Habitat**	**Habitat within the SGP**	**Local Records**	
Elseya albagula Southern snapping turtle	End	CE	Restricted to clear, flowing, well-oxygenated waters with the Fitzroy, Mary and Burnett Rivers and associated smaller drainages (Todd et al. 2013).	No suitable habitat within the SGP.	No records within 50km of the SGP boundary and not known to occur outside the Fitzroy, Mary and Burnett River catchments.	Unlikely
Strophurus taenicauda Golden-tailed gecko	NT	-	Found mainly in association with brigalow (Acacia harpophylla), cypress (Callitris spp.) and ironbark (Eucalyptus spp.).	Recorded during surveys. Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present
Delma torquata Collared delma	Vul	Vul	Rocky areas associated with dry open forest, and brigalow	Some suitable habitat for the species exists within the SGP, however, rarely recorded within the Brigalow Belt.	No records within 50km of the SGP boundary.	Unlikely
Anomalopus mackayi Long-legged worm-skink	Vul	End	Open grasslands with cracking black soil.	Marginal habitat (derived grasslands) for the species exists within the SGP, particularly in the southern region.	No records within the SGP; one record within 10km of the SGP. Most recent records (<20 years old) centred around Oakey and the Dalby. Never recorded west of the Condamine River.	Unlikely
Egernia rugosa Yakka skink	Vul	Vul	Usually occurs on well-drained, coarse, gritty soils in the vicinity of low ranges, foothills and undulating terrain (Wilson and Swan 2008; Richardson 2006), but can also be found on loam and clay soils (Eddie 2012).	Some suitable habitat for the species exists within the SGP, though the bulk is marginal or unsuitable.	Limited records within the region, one old historic record from within 25km of the SG, and anecdotally said to have been recently recorded somewhere in Barakula SF.	Unlikely
Tympanocryptis condaminensis Condamine Earless Dragon	End	End	Open grasslands and cropland with cracking black soil	Marginal habitat (derived grasslands) for the species exists within the SGP, particularly in the southern region.	Closest record 20km from SGP. No records known west of the Condamine River.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Aspidites ramsayi Woma	NT	-	Open habitats, brigalow and mulga woodlands, spinifex deserts	Some suitable habitat for the species exists within the SGP.	No records of the species within 50 km of the SGP. SGP outside species typical range.	Unlikely
Acanthophis antarcticus Common Death Adder	Vul	-	Found in a wide variety of habitats, including rainforest, open woodland, shrubland and heath (Wilson and Swan 2003).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Two records of the species are located within 5km of the SGP boundary, including one from 2015.	Possible
Furina dunmalli Dunmall's snake	Vul	Vul	Wide range of habitats, including forests and woodlands dominated by brigalow (*Acacia harpophylla*) and other Acacia spp., cypress (*Callitris* spp.) or bulloak (*Allocasuarina luehmannii*) on black alluvial cracking clay and clay loams (Covacevich *et al*. 1988; Stephenson and Schmida 2008).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Two old records (i.e. >20 years) exist in the southern portion of the SGP. An additional two records are located within 8km outside the SGP area, with the most recent record from 2000.	Possible
Hemiaspis damelii Grey snake	End	-	Inhabits dry eucalypt forest and occasionally pasture, favouring areas of cracking, flood-prone soils along floodplains and near watercourses within the Brigalow Belt (Wilson 2005).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Denisonia maculata Ornamental Snake	Vul	Vul	Found in Brigalow (*Acacia harpophylla*), Gidgee (*A. cambagei*), Blackwood (*A. argyrodendron*) or Coolibah (*Eucalyptus coolabah*)-dominated vegetation communities; can occur in regrowth. Typically associated with black soils (particularly gilgai).	Some suitable habitat for the species exists within the SGP, though suitable remnant habitat is typically fragmented and isolated.	No records within 50km of the SGP boundary. SGP considered outside species typically range.	Unlikely
Botaurus poiciloptilus Australasian Bittern	LC	End	Freshwater wetlands with dense vegetation, particularly reeds and sedges.	There are scattered areas of suitable habitat (i.e. ephemeral waterbodies with dense fringing vegetation in the western portion of Lake Broadwater and Long Swamp). However, these areas are marginal for the species.	Three records exist within 50km of the project area, with the most recent being in 1999. This species is highly vagrant and would be a very rare visitor to the SGP area.	Unlikely
Calidris ferruginea Curlew Sandpiper	End	CE	Saline and freshwater wetlands, saltmarshes, estuaries, mudflats. Prefers areas with exposed mud for foraging.	Estimated extent of suitable habitat within the SGP provided in GIS package.	Four records known from the southern section of the SGP, three at Lake Broadwater. While it is likely to occur at Lake Broadwater, the species has a low probability of occur at other locations within the SGP during Life of Operation.	Transient
Limosa lapponica baureri Bar-tailed Godwit	Vul	Vul	Saline and freshwater wetlands, saltmarshes, estuaries, mudflats. Prefers areas with exposed mud for foraging, usually within proximity to the coast.	Only likely at Lake Broadwater.	With the exception of two pre-1900 records, this species has been recorded on only three occasions between 1980 and 1987. All records are from Lake Broadwater	Unlikely/ Transient

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Rostratula australis Australian Painted Snipe	Vul	End	Found in a wide range of habitats including ephemeral swamps, dams, rice paddocks, waterlogged grasslands, roadside drains and even brackish waterways (Marchant and Higgins 1993).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Six records known from the southern section of the SGP, in the vicinity of Lake Broadwater. The species could occur with the SGP Life of Operation, though most likely restricted to these two areas.	Possible
Pedionomus torquatus Plains-wanderer	Vul	Vul	Open grasslands with patches of bare ground, low sparse shrublands	There is little suitable habitat within the SGP.	Outside of known range and all records are old (ie. >40 years).	Unlikely
Turnix melanogaster Black-breasted button-quail	Vul	Vul	Leaf litter in drier rainforests, vine thickets, lantana on rainforest edges, hoop pine plantation	There is no suitable habitat within the SGP.	Known from state forests north of, but connected to, Barakula State Forest. No known record from the SGP.	Unlikely
Falco hypoleucos Grey Falcon	NT	-	Lightly treed inland plains, gibber deserts, pastoral lands	Open areas of grazing land and derived grasslands might be considered marginal habitat.	Rarely recorded within the Brigalow Belt. The species does not occur with any frequency in the Project Area.	Unlikely
Erythrotriorchis radiata Red goshawk	End	Vul	Open forests, woodlands, wetlands, rainforest fringes	Suitable habitat for the species exists within the SGP.	One record from within the southern portion of the SGP and an addition three records within 20km of the SGP boundary. All records are old (i.e. >30 years) and the species rarely recorded in the Brigalow Belt.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Geophaps scripta scripta Squatter Pigeon	Vul	Vul	Occurs mainly in dry grassy eucalypt woodlands and open forests and also inhabits cypress pine (Callitris spp.) and Acacia dominated woodlands (Frith 1982)	Suitable habitat for the species exists within the SGP.	Two records exist within the SGP in the central region of the SGP, the most recent in 2012. Despite suitable habitat being present, this species is likely to vagrant, with individuals not representing a resident or seasonal population. May sporadically occur in the northern and central regions of the SGP during Life of Operation.	Transient
Calyptorhynchus lathami Glossy black-cockatoo	Vul	-	Inhabits woodlands and forests that have abundant Allocasuarina species and abundant large hollows suitable for nesting. Many populations are restricted to remnant vegetation within hills and gullies surrounded by agricultural land (Higgins 1999).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present
Lophochroa leadbeateri Major Mitchell's cockatoo	Vul	-	Sparsely timbered open grasslands, *Callitris* and *Casuarina* woodlands, mulga woodlands, trees in proximity to watercourses	Some areas of habitat SGP are marginal. Large areas are unsuitable.	Two records exist within the project site in the Lake Broadwater area. However, these records are more than 30 years old and indicate the species does not occur in the area with any frequency.	Unlikely
Lathamus discolour Swift parrot	End	CE	Flowering trees in forests and woodlands	Suitable habitat for the species exists within the SGP.	Records known from outside the SGP and are more than 50 years old. Any possible current or future occurrence would be of vagrant individuals.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Ninox strenua Powerful owl	Vul	-	Eucalypt forests on ranges with densely vegetated gullies, drier and lower elevation forest with sufficient prey and large hollows	Suitable habitat for the species exists within the SGP.	No records within the SGP and all records are old (i.e. >20 years). Rarely recorded within the Brigalow Belt.	Unlikely
Anthochaera phrygia Regent Honeyeater	End	CE	Forests and woodlands of ironbark, box, swamp mahoghany and river oak.	Suitable habitat for the species exists within the SGP.	Only two records exist within 10km of the SGP. Vagrant within the southern Brigalow Belt.	Unlikely
Grantiella picta Painted honeyeater	Vul	Vul	Found mainly in dry open woodlands and forests, particularly box-ironbark woodlands. It may also occur in riparian forest, on plains with scattered eucalypts and in remnant trees on farmland and their occurrence is strongly associated with mistletoe.	Estimated extent of suitable habitat within the SGP provided in GIS package.	Three records within the SGP in the southern portion near Lake Broadwater, and several records located within 10km of the SGP boundary, including records from the past few years. Likely to occur within the SGP infrequently.	Possible
Poephila cincta cincta Black-throated finch	End	End	Grassy scrublands, woodlands, dunes, Pandanus near water	Most areas of open woodland or grassland are heavily grassed and dominated by exotic grasses. Some areas of derived grassland may be suitable.	No longer occurs within local area or region. One record exists of the species within 10 km of the Project Area, however, this record is more than 50 years old.	Unlikely
Dasyurus hallucatus Northern Quoll	LC	End	Most common in rocky eucalypt woodland and open forest within 200 kilometres of the coast.	Some suitable habitat for the species exists within the SGP	No records within 50km of the SGP.	Unlikely

Scientific Name **Common Name**	**Status[#]**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Dasyurus maculatus maculatus Spotted-tailed quoll	Vul	End	Inhabits a variety of forested habitats including subtropical and temperate rainforests, vine thickets, wet and dry sclerophyll forests, woodland and coastal scrub.	Some suitable habitat for the species exists within the SGP	Three records within the SGP and several within 20km of the SGP boundary, however, all records are old (i.e. >20 years), with the exception of a confirmed sighting of an injured animal near Tara within the past 5 years. This was likely a transient individual. The current status of this species in the Brigalow Belt is uncertain, and transient individuals may occur throughout the SGP, although this would a rare occasion.	Unlikely
Petauroides volans Greater Glider	Vul	Vul	Mainly restricted to eucalypt forests and woodlands where they typically occur in highest abundance in taller, montane, moist eucalypt forests with larger, relatively old trees and abundant hollows (Eyre 2004). In areas west of the Great Dividing Range, they are found in low woodlands (McKay 2008).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Phascolarctos cinereus Koala	Vul	Vul	Found in a diversity of habitats including temperate, sub-tropical and tropical forest, woodland and semi-arid communities, and sclerophyll forest, on foothills, plains and in coastal areas (Dyck & Stratham 2008). On the western side of the Great Dividing Range at the western edges of their range, the species is often associated with riparian vegetation although are not restricted to them (Melzer et al. 2000; Sullivan et al. 2003).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present
Petrogale penicillata Brush-tailed Rock-wallaby	Vul	Vul	Inhabits rock piles and cliff lines in vegetation ranging from rainforest to dry sclerophyll forests.	No suitable habitat for the species exists within the SGP	No records within 50km of the SGP.	Unlikely
Pteropus poliocephalus Grey-headed flying-fox	LC	Vul	Foraging habitat includes rainforests, open eucalypt forests, woodlands, Melaleuca swamps and Banksia woodlands. Roosts are commonly within dense vegetation close to water, primarily rainforest patches, stands of Melaleuca, mangroves or riparian vegetation (Nelson 1965).	Suitable foraging habitat for the species exists within the SGP.	Three records within 50km of SGP, including records from 2011. Individuals are known to occasionally use a seasonal flying-fox camp along Myall Creek in Dalby. The species is a typically a vagrant west of the Great Dividing Range and would be a rare visitor to the SGP.	Unlikely
Macroderma gigas Ghost Bat	End	Vul	Habitats used for foraging vary from dry open woodlands to tropical rainforests (Wilmer 2012).	Suitable foraging habitat for the species exists within the SGP.	One very old record (i.e. >200 years) outside of the SGP. Presumed locally extinct in the area.	Unlikely

Scientific Name **Common Name**	**Status#**		**Typical Habitat**	**Habitat within the SGP**	**Local Records**	**Likelihood Assessment**
	NCA	**EPBC**				
Chalinolobus dwyeri Large-eared Pied Bat	Vul	Vul	Often observed along ecotones on rainforest edges or in association with sandstone escarpments (DoE 2017).	No suitable habitat for the species exists within the SGP.	No records within 50km of the SGP.	Unlikely
Nyctophilus corbeni South-eastern long-eared bat	Vul	Vul	Found more commonly in box/ironbark/cypress pine woodland on sandy soils. It also occurs in bulloak (*Allocasuarina luehmannii*), brigalow (*Acacia harpophylla*) and belah (*Casuarina cristata*) communities (Turbill and Ellis 2006; Churchill 2008).	Estimated extent of suitable habitat within the SGP provided in GIS package.	Recorded during surveys.	Present
Pseudomys australis Plains Rat	End	Vul	Cracking clay depressions and small drainage lines on arid gibber plains, and vast, cracking clay plains (Van Dyck et al 2013).	No suitable habitat for the species exists within the SGP	One very old record (i.e. >100 years) within 10km outside of the SGP. Presumed locally extinct in the area.	Unlikely

LC = Least Concern, NT = Near Threatened, Vul = Vulnerable, E = Endangered, CE = Critically Endangered, Mig = Migratory

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Appendix D.
Threatened Ecological Communities and Regional Ecosystem Descriptions

THREATENED ECOLOGICAL COMMUNITIES

Brigalow Dominant and Co-dominant

Status

Endangered EPBC Act: Component Regional Ecosystem 11.3.1, 11.4.3/11.4.3a, 11.9.5 Endangered under the VM Act and Biodiversity Act.

Total number of survey sites:

70 Sites in Total (RE11.3.1- 11 Secondary, 23 Quaternary; RE11.4.3 - 8 Secondary, 19 Quaternary; 11.9.5 – 2 Secondary, 7 Quaternary).

Within the SGP assessment area, the Brigalow Dominant and Co-dominant Ecological Community comprises the following REs:

- RE11.3.1 (*Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains)
- RE11.4.3/ 11.4.3a *Acacia harpophylla* and/or *Casuarina cristata* shrubby open forest on Cainozoic clay plains)
- RE11.9.5 (*Acacia harpophylla* and/or *Casuarina cristata* open forest on fine-grained sedimentary rocks)

Other relevant habitats included in the ecological community include Brigalow regrowth >15 yrs old which have similarly been mapped under the Brigalow ecological community.

Regional Ecosystem 11.3.1

The ecosystem has been highly fragmented throughout its range, generally existing as linear remnants within roadside reserves and stock routes. The most extensive occurrences are located on the floodplain of the Condamine River and Wilkie Creek to the west of Dalby with scattered occurrences occurring throughout the broader project development area. Typical canopy heights range from 15 to 23 m in better preserved examples where projected canopy covers range 30 to 60%. Whilst *Acacia harpophylla* generally forms the dominant canopy, *Casuarina cristata* predominates in some locations. Typical sub-canopy trees include *Acacia harpophylla,* and *Casuarina cristata* with shrubby layers often dominated by *Geijera parviflora, Pittosporum angustifolium, Melaleuca bracteata, Alectryon oleofolious* subsp*. elongatus, Alectryon diversifolius, Elaeodendron australe* var*. integrifolium, Ehretia membranifolium,* and *Optuntia stricta*.* Ground cover percentage is variable with typical species being *Paspalidium caespitosum, Ancistrachne uncinulata, Aristida* spp., *Enychleana tomentosa, Rhagodia spinescens, Einadia hastata,* and *Solanum parvifolium,* although *Harissia martinii** and *Bryophyllum delagoense** may be typically abundant.

Community condition is typically poor, a testament to edge effects created by massive fragmentation. The class 2 declared weed species prickly pear (*Opuntia stricta),* velvet pear (*Opuntia tomentosa)* and harissa cactus (*Harissia martini)* are highly prominent in shrub and ground layers and frequent canopy gaps, caused by canopy dieback and senescence in the absence of recruitment is a compounding problem.

Tall brigalow woodland (RE11.3.1) on the alluvial plain of Wilkie Creek (Site AS138).

Regional Ecosystem 11.4.3

The distinction between RE11.3.1 and RE11.4.3 is based largely on landscape position rather than any recognisable floristic expression. RE11.3.1 by definition, occupies alluvial landforms, and as such is associated with flood plains, river terraces and associated drainage depressions and swamps. The heavy clay soils associated with land zone (LZ) 4 are raised above the influence of current river systems and in the majority cases, this provides the only basis for distinction. Both ecosystems occupy heavy clay soils with shrink and swell properties (vertosols) and gilgai micro-topography.

The productivity of the associated soil types has resulted in extensive fragmentation of this ecosystem and remaining occurrences are generally highly fragmented and isolated. Intact examples are generally associated with with stock routes where the remnants, although linear, are generally continuous with adjacent ecosystems. The Chinchilla Sporting Shooters Club (which is located on the Chinchilla Sands Local Fossil Fauna Site) hosts one of the better preserved and more extensive examples observed with the project development area. In this location *Acacia harpopylla* forms the dominant canopy to 25 m, mixed to varying degrees with *Casuarina cristata* with a predominant canopy cover ranging from 30% to 60% dependant largely on habitat condition. The sub-canopy is typically formed by *Acacia harpophylla* and *Casuarina cristata* mixed with a range of vine thicket shrubs and trees including *Geijera parviflora, Ehretia membranifolia, Alectryon oleofolia* subsp*. elongatus* and *Carissa ovata.*

The classification also includes RE11.4.3a, a wetland community formed by *Eucalyptus woollsiana* with a sub-canopy formed by *Melaleuca bracteata* (Site AQ163). A relatively extensive area is mapped within PL 253 (in the Linc-Energy operational area) although this area was assessed remotely and requires ground truthing to confirm the true nature of the habitat for confirmation.

The community is degraded throughout much of its range with sub-canopy layers often dominated by *Opuntia spp.* and *Harissia martini.* Canopy dieback, although a natural feature of the brigalow community, is severe in some locations. Excessive light penetration through a dramatically reduced canopy cover has further promoted the invasion of exotic species into the ground cover and shrub layers.

Well-developed woodland of Acacia harpophylla and Casuarina cristata characteristic of RE11.4.3.

Regional Ecosystem 11.9.5

This ecosystem was sampled in one locality to the west of Wandoan where it formed an open forest of *Acacia harpophlla* mixing with *Casuarina cristata* and emergent of *Brachychiton rupestris*. The canopy typically form 60% cover and canopy heights reaching 23m. Shrub layers are typically mid-dense and predominantly occupied by *geijera parviflora, Eremophila mitchellii* and *Santalum lanceolatum*. RE11.9.5 forms small scattered remnants throughout the rolling sedimentary landscapes of the Wandoan region in the northern portion of the SGP assessment area.

Fragmented patch of RE11.9.5 in the Wandoan area.

Weeping Myall Woodlands

Status

Endangered EPBC Act (Not Represented in VM Act)

Total Number of Survey Sites

2 Secondary

In Queensland, the Weeping Myall Woodlands TEC is known to occur as small patches within REs 11.3.2 and 11.3.28 (DEWHA, 2009a), although the latter ecosystem is not known to occur in the project development area. The best-preserved examples are typically associated with road reserves and stock routes although the community is not considered to form woodland communities of sufficient extent to be consistently separated as an ecosystem. As such, the community is not recognised as an individual ecosystem within the framework of Queensland's VM Act. The patchy nature of the community also makes delineation difficult, hence the ecological community may be easily overlooked. Based on descriptions provided by DEWHA (2009a) and TSSC (2008t), the following applies to the Weeping Myall Woodlands TEC:

- The Weeping Myall Woodlands TEC range from open woodlands to woodlands, generally 4 to 12m high. The overstorey is dominated by weeping myall (*Acacia pendula*) trees and in some cases this species may be the only tree canopy species. Other common names for weeping myall include myall, boree, balaar, nilyah, bastard gidgee, and silver leaf boree.

- Other woodland species may also form part of the overstorey of the ecological community. These include: western rosewood (*Alectryon oleifolius* subsp. *elongatus*); poplar box (*Eucalyptus populnea*); or black box (*Eucalyptus largiflorens*). Grey mistletoe (*Amyema quandang*) commonly occurs on the branches of weeping myall trees throughout the ecological community's range.
- The Weeping Myall Woodlands ecological community can naturally occur either as a grassy or a shrubby woodland. However, the understorey often includes an open layer of shrubs over a ground layer which includes a diversity of grasses and forbs. The ground layers can vary in species composition and cover depending on past and current grazing regimes, and the occurrence of recent rain.

The following condition thresholds for the Weeping Myall Ecological Community apply based on DEWHA (2009):

- The patch of woodland must be at least 0.5 ha (5000 m^2) in size.
- The overstorey must have at least 5 per cent tree canopy cover or at least 25 dead or defoliated mature weeping myall trees per hectare.
- The tree canopy must be dominated (at least 50 per cent of trees present) by living, dead or defoliated weeping myall trees.
- The patch has more than two layers of regenerating weeping myall present.

A single occurrence of the Weeping Myall Ecological Community was observed in the Theten area although the habitat was was not recorded within any other location within the SGP assessment area. The observed community formed a low open woodland with canopy heights ranging from 6 m to 10 m with a lower shrub layer at 3m to 6m, merging with a lower shrub layer. The projected canopy cover of the community was formed by 55 % cover of weeping myall (*Acacia pendula)* with scattered eucalypts including poplar box (*Eucalyptus populnea)* forming less than four % of the upper strata. Ground cover is formed by predominantly native graminoids and soils were moist, becoming saturated in depressions. The community was fringed by regrowth woodland of Poplar Box and Queensland Blue Gum (*Eucalyptus tereticornis)* although there is no clear indication that the ecological community originally occurred within RE 11.3.2. The extent of the ecological community at this location was 0.85 ha, well within patch size thresholds. Regional distribution mapping provided by DEWHA (2009) indicates the greatest likelihood for occurence of the Weeping Myall TC is in a band that stretches from Roma to Blackall, west of the project development area meaning that any occurrences are highly significant, representing the eastern limits of the ecological community distribution.

The Weeping Myall TEC in the Theten area (survey site GB82).

Coolibah – Black Box Woodland

Status

Endangered EPBC Act: Component Regional Ecosystems 11.3.3 (Of Concern VM Act and Biodiversity Status)

Total number of survey sites across project area

3 Sites in Total (3 Secondary).

The Coolibah – Black Box Woodlands TEC represents occurrences of one type of eucalypt woodland where *Eucalyptus coolabah* subsp. *coolabah* (coolibah) and/or *Eucalyptus largiflorens* (black box) are the dominant canopy species and where the understory tends to be grassy (TSSC 2011a). The condition thresholds to identify the ecological community are provided below (from TSSC 2011b):

- Patch size: The minimum patch size is 5 ha which may include areas of native vegetation that may be naturally open or contain regrowth.
- The crown cover of trees must be > 8 %.
- Coolibah and coolibah and/or black box in the tree canopy must be present in the patch that are either mature trees with a DBH > 30cm; are coppiced trees with a main stem > 20cm or; hollow bearing trees.
- The ecological community must have a ground-cover in which 10% or more contains native graminoids, herbs or shrubs.

Whilst RE11.3.3 is mapped relatively broadly in certified regional ecosystem mapping (Version 8.0, 2017) in the Chinchilla region, and Eucalyptus coolibah occurs as a component tree in riparian habitats of the Condamine River, the majority of these patches are considered too small or degraded to provide representation of the TEC. A few minor occurrences are however identified on the Theten property and the adjacent habitats of Wilkie Creek where they occupy a combined area of 23 ha with the largest patch covering an area of 10ha. Typical canopy heights range from 10 – 15m and up to 40 % projected canopy cover. Ground layers are dominated by native species (> 60 %) including a range of native graminoids and forbs (*Eleacharis spp. Walwhelleya subxerophila* and *Marsilea drummondii* predominate). Exotic species, which form < 20% of the ground cover are dominated by lippia *(Phyla canescens).* The habitat typically occupies broad drainage depressions and overflow channels on major watercourses.

Coolibah / Black Box Woodland Ecological Community (RE11.3.3) on Theten (survey site GB74 _ 2433)

OTHER ENDANGERED / OF CONCERN REGIONAL ECOSYSTEMS

Regional Ecosystem 11.3.17

Eucalyptus populnea woodland with Acacia harpophylla and/or Casuarina cristata on alluvial plains

Status

VMA Status: Endangered

Biodiversity Status: Endangered

Total number of survey sites across project area

15 Sites in Total (1 Secondary and 14 Quaternary / Observation).

This community occurs on alluvial plains, typically near watercourses with the largest representations in the southern survey area in the Lake Broadwater Region. The habitat is also mapped in the northern assessment area near Wandoan. In a typical occurences, the canopy is dominated by Poplar Box (*Eucalyptus populnea*) and ranges between 16-26m in height with a mean PPC of 40%. Additional trees in the canopy layer are Belah (*Casuarina cristata*), Brigalow (*Acacia harpophylla)* and occasional Grey Box (*Eucalyptus woollsiana*). The second tree layer is well developed and comprises the above canopy species together with Western Rosewood (*Alectryon oleofolius*), Weeping Pittosporum (*Pittosporum angustifolium*) Sally Wattle (*Acacia salicina*), *Casuarina cristata* and other associated species including *Callitris glaucophylla, Alectryon oleofolius* subsp*. elongatus*, *Melaleuca bracteata,* and *Alphitonia excelsa.* The shrub layer is typically dominated by a sparse cover of *Geijera parviflora, Citurs glauca, Capparis mitchellii,* and *Elaeodendron australe* var*. integrifolium*. Exotic ground covers, in particular Lippia (*Phyla canescens**) in the south and Buffel Grass (*Cenchrus ciliaris*Green Panic (*Megathyrsus maximus var. trichoglume)* contribute to approximately 50% of the overall cover, with scattered infestations of Harissa Cactus (*Harissia martini**), Noogoora Bur (*Xanthium occidentale**), and Mayne's Pest (*Verbena aristigera**), African Love Grass (*Eragrostis curvula**), Paspalum (*Pasplalum dilatatum**), and Giant Panic (*Magathrysus maximus* var. *maximus**). Native grasses and sedges dominate the cover.

Degraded patch of RE11.3.17 in the Wandoan region (Site DS155_300).

Regional Ecosystem 11.3.2

Eucalyptus populnea woodland on alluvial plains.

Status

VMA Status:	Of concern
Biodiversity Status:	Of concern

Total number of survey sites across project area

54 Sites in Total (9 Secondary and 45 Quaternary / Observation).

This community is consistently dominated by poplar box (*Eucalyptus populnea*) with a canopy height ranging between 10-16m and a mean crown cover of 41%. Associated canopy trees may include Queensland Blue Gum (*Eucalyptus tereticornis*) and Moreton Bay Ash (*Corymbia tessellaris*). A sparse second tree layer comprises the above canopy species. The shrub layer is generally poorly developed with scattered poplar box saplings and occasional shrubs of velvet pear (*Opuntia tomentosa**).

The groundcover is often weedy, affected by infestations of Buffel Grass (*Cenchrus* ciliaris), African Love Grass (*Eragrostis curvula**), Lippia (*Phyla canescens*), Mayne's pest (*Verbena aristigera**), Harissa Cactus (*Harissia martini**) and Mother of Millions (*Bryophyllum* *delagoense)* in some localities, which contribute to a mean exotic cover of 35% across all survey sites. Dominant graminoid species include *Aristida caput-medusae, Aristida acuta, Chloris truncata, Dichanthium sericeum* subsp*. sericeum, Digitaria brownii, Eulalia aurea,* and *Paspalidium* sp., with common native herbs of *Chrysocephalum apiculatum, Cheilanthes sieberi, Cyanthillium cinereum, Desmodium campylocaulon, Rostellularia adscendens,* and *Wahlenbergia communis*.

There is often some evidence of selective thinning of the canopy species, although large mature trees remain throughout with evidence of canopy recruitment in the shrub layers in most habitats.

Well preserved representation of RE11.3.2 in the Central Assessment Area (Site DS132_275).

Regional Ecosystem 11.3.4

Eucalyptus tereticornis and/or Eucalyptus spp. tall woodland on alluvial plains.

Status

VMA Status: Of concern

Biodiversity Status: Of concern

Total number of survey sites across project area

52 Sites in Total (12 Secondary and 40 Quaternary / Observation).

This ecosystem occurs on seasonally flooded alluvial plains associated with both minor and major drainage lines. The canopy height ranges between 14-24m and a mean crown cover of 28 - 45%. A typical representation is dominated by Queensland blue gum *(Eucalyptus tereticornis)* and rough-barked apple *(Angophora floribunda)* mixed with other species including Moreton Bay Ash (*Corymbia tessellaris)* and occasional Poplar Box (*Eucalyptus populnea)*. The relative proportions of these tree varies with rough-barked apple dominant in some habitats, particularly along the frontage of Wambo Creek.

The second tree layer is sparse and comprises the above canopy species together with *Acacia salicinia* and kurrajong (*Brachychiton populnea*). The shrub layer ranges between 1-4 m in height with a mean cover of 22%. Dominant species are Moon Wattle (*Acacia semilunata*) in the northern area with frequent Yellow Tea Tree (*Leptospermum polygalifolium*), Black Wattle (*Acacia leiocalyx),* Glory Wattle *(Acacia spectabilis),* Wilga *(Geijera parviflora),* and Paper Bark *(Melaleuca decora).*

The ground layer is variable ranging from good condition in the habitats surrounding Miles to highly degraded in habitats associated with the Condamine River Flood Plain in the Dalby region. Typical native groundcover species include *Lomandra longifolia, Aristida caput-medusae, Aristida acuta, Chloris truncata, Dichanthium sericeum* subsp*. sericeum, Digitaria brownii, Eulalia aurea, Gahnia aspera, Heteropogon contortus, Juncus continuus.,* and *Paspalidium* sp., with common native herbs including *Chrysocephalum apiculatum, Cheilanthes sieberi, Cyanthillium cinereum, Desmodium campylocaulon, Dianella longifolia* var*. longifolia, Rostellularia adscendens,* and *Wahlenbergia communis*. Exotic species associated with this regional ecosystem include Green Panic (*Panicum maximum var. trichoglume)* limited to scattered occurrences Mayne's Pest (*Verbena aristigera**), Buffel Grass (*Pennisetum ciliare**) and Liverseed Grass (*Urochloa mosambicensis**).

There is some evidence of selective thinning in many locations and canopy recruitment is lacking in some habitats along the Condamine River where grazing pressure is particularly high. Heavily grazed fringe of RE11.3.4 along the Condamine River

Heavily grazed fringe of RE11.3.4 along the Condamine River

Regional Ecosystem 11.3.25

Eucalyptus camaldulensis or Eucalyptus tereticornis open-forest to woodland. Occurs on fringing levees and banks of major rivers and drainage lines of alluvial plains.

Status

VMA Status: Least concern

Biodiversity Status: Of concern

Total number of survey sites across project area

130 Sites in Total (17 Secondary, 4 Tertiary and 109 Quaternary / Observation).

Maximum development of RE11.3.25 is associated with the riparian margins of the lines of Condamine River and larger tributaries such as Wilkie Creek. The ecosystem however occurs broadly throughout the SGP assessment areas where it fringes both major and minor drainage lines. At its maximum development, canopy heights range from 23 - 33 metres and a mean crown cover of 46%. Dominant canopy trees are River Red Gum (*Eucalyptus camaldulensis* and Queensland Blue Gum *(Eucalyptus tereticornis),* Rough Barked Apple (*Angophora floribunda*) and Moreton Bay Ash (*Corymbia tessellaris*). A sparse sub-canopy is dominated by the above species with occasional willow wattle (*Acacia salicina*) and cooba (*Acacia* *stenophylla*). Shrub cover is very sparse (0-5% cover) with scattered willow wattle, cooba and prickly mimosa (*Acacia farnesiana**). The sparse ground cover which averages at 23% is attributed to scouring of groundcover species from recent flood events. Mean cover is dominated by exotic species with grasses such as Green Panic (*Megathyrsus maximus var. trichoglume**), Purple Top Rhodes (*Chloris virgata**), and Couch Grass (*Cynodon dactylon**). Saltwater Couch (*Sporobolus virginicus)* was also a dominant cover on some sections of Wilkie Creek, being an indication of salinity. Natives such as Mat rush (*Lomandra longifolia*) and Blady Grass (*Imperata cylindrica*) characterise the native component of the groundcover in most habitats examined.

Weedy representation of RE11.3.25 on the Condamine River.

Regional Ecosystem 11.3.27

Palustrine wetland (vegetated swamp).

Status

VMA Status:	Least concern
Biodiversity Status:	Of concern

Total number of survey sites across project area

28 Sites in Total (7 Secondary, 21 Quaternary / Observation).

Floodplain wetlands are generally associated with the flood overflow channels characteristic of the flood plains of major river systems throughout the SGP assessment area. The wetlands play an important hydrological role, facilitating nutrient exchange between aquatic and terrestrial ecosystems during periods of seasonal overbank flow. The Condamine River floodplain hosts a complex wetland system with RE11.3.27 forming mosaics with RE11.3.25, 11.3.2 and 11.3.4 throughout its entire length with a variety of wetland types recognised.

Lake Broadwater, mapped as RE11.3.27a (Freshwater Lake) is a seasonal water feature that is recognised nationally for its natural values, being significant at a national and state level. The lake is listed on the Directory of Important Wetlands and is recognised as being a rare example of a semi-permanent freshwater lake in the bioregional area (Blackman *et al.* 1999).

Long Swamp, a similar vegetated wetland ecosystem that discharges on a seasonal basis into Wilkie Creek. Representation of the feature as RE11.3.2 in Certified RE Mapping (DERM 2009b) is incorrect with field survey confirming features typical of RE11.3.27d (palustrine wetland). Long Swamp is heavily utilised for irrigation purposes which has undoubtedly affected hydrological function, species composition of the ground layers, the vigour of the canopy trees and reduced its overall biodiversity values. Long Swamp is a sinuous hydrological feature (overland flow path) that flows across the Condamine Alluvium in a north-westerly direction to the east and north of Lake Broadwater, before joining with Wilkie Creek to the west. The feature occupies a broad depression on the alluvium with the central portion of the depression formed by heavy clay. Surface water is present seasonally and following dry spells the associated vertosol soils form deep hummocks and cracks. There was no flow, nor any significant pooled water within Long swamp during the field visits, despite heavy recent rains. These observations together with the observations of deep, open cracks in the central swamp channel soil surface confirmed that the feature is only active during flooding.

Vegetation is predominantly native with although exotic groundcovers predominant in some localities. The canopy is formed by tall, broadly spaced River Red Gum (*Eucalyptus camaldulensis)* at approximately 15 - 30% cover with Poplar Box (*Eucalyptus populnea)* forming on the swampy margins. The canopy is significantly stressed in some areas with signs of senescence and foliage loss in the Red Gums which predominate the canopy. The noted senescence can largely be attributed to historic groundwater drawdown in shallow sandy alluvial aquifers, compounded by surface water extraction for irrigation (Kath et al 2014; 3D Environmental 2016).

Of the four secondary vegetation survey sites completed during the dry season survey (DS21, DS22, DS26, DS31 completed when the swamp was dry), exotic vegetation cover contributed on average to 15% to the total groundcover, and formed 39% of the total living groundcover mixing with native species including Nardoo (*Marsilea drummondii),* Water Chestnut (*Eleocharis dulcis)* and scattered native grasses including *Panicum decompositum*. Lippia (*Phylla canescens)* was the most abundant exotic forb blanketing the clay soils, particularly where grazing pressure is most intense. It should be noted that groundcover composition will vary seasonally with native aquatic sedges, particularly Water Chestnut becoming dominant during periods of standing surface water.

Long Swamp with characteristic River Red Gum (*Eucalyptus camaldulensis)* showing moderates signs of stress as suggested by foliage loss.

The most extensive of the wetland types is RE11.3.27c which forms by the extensive floodplain system of channel overflows and anabranches that are seasonally activated during periods of overbank flow. The regional ecosystem sub-type is associated with the alluvial depressions along the Condamine River floodplain. It is a palustrine wetland ecosystem with an overstorey of scattered River Red Gum over a sedgeland groundcover with semi-permanent water. The composition of the ground cover is simple and limited to Water Chestnut (*Eleocharis plana),* Juncus (*Juncus continuus)* with scattered native herbs such as Lesser joyweed (*Alternanthera denticulata*) and Eclipta (*Eclipta prostrata*). Infestations of Lippia (*Phyla canescens*) occur throughout the ecosystem, although are generally only evident when wetlands are dry.

Overflow channel of the Condamine River providing representation of RE11.3.27c. The system was seasonally dry and ground cover was dominated by a dense infestation of Lippia.

Regional Ecosystem 11.9.7

Acacia harpophylla, Eucalyptus populnea open forest on fine-grained sedimentary rocks

Status

VMA Status: Of Concern

Biodiversity Status: Endangered

Total number of survey sites across project area

1 Quaternary

A single small polygon of 1.5ha is located in the northern assessment area, representing a remnant sliver that runs along a footslope, contiguous with remnant riparian vegetation on a creek line. The canopy has been fragmented with a cover of up to 30% and canopy heights range from 18 to 23m. The sub-canopy and shrub layers are sparse, typically < 5% cover formed by Wilga (*Geijera parviflora*) and Sandalwood (*Santalum lanceolatum*). Whilst the habitat has been subject to heavy grazing, the ground covers are predominantly native and are formed by *Themeda triandra, Dicanthium sericeum, Paspalideum caespitosum, and Chloris ventricosa.*

Regional Ecosystem 11.9.10

Acacia harpophylla, Eucalyptus populnea open forest on fine-grained sedimentary rocks

Status

VMA Status: Of Concern

Biodiversity Status: Endangered

Total number of survey sites across project area

3 Sites in Total (3 Quaternary)

Small scattered remnants are located in the northern assessment area with the fragmented landscapes surrounding Wandoan where patch sizes are typically 1 to 2ha. The ecosystem exists in small remnants that are isolated from larger patches of remnant vegetation. Canopy heights are generally in the range of 9 to 16m with up to 35 % projected canopy cover formed by *Eucalyptus populnea* and a sub-canopy of *Acacia harpophylla, Casuarina cristata* and occasional *Callitris glaucophylla*. Shrub layers are sparse (10 – 20%) dominated by *Geijera parviflora, Eremophila mitchellii* and *Atalaya hemiglauca.* Ground covers are formed by a mix of native and exotic species including *Paspalidium caespitosum, Sporobolus creber, Aristida ramosa, Capparis lasiantha, Sclerolaena sp., Enchylaena tomentosa, Sida sp., Nyssanthes diffusa, Senecio brigalowensis, Salsola australis, Bothriochloa decipiens, Enteropogon acicularis, Aristida calycina, Enteropogon ramosus, Sporobolus caroli* and patches of Buffel Grass (*Cenchrus ciliaris).*

Regional ecosystem 11.9.10 at Site Q69_631 near Wandoan.

LEAST CONCERN REGIONAL ECOSYSTEMS

Regional Ecosystem 11.3.14

Eucalyptus tereticornis and/or Eucalyptus spp. tall woodland on alluvial plains.

<u>Status</u>

VMA Status: Least Concern

Biodiversity Status: No Concern at Present

<u>Total number of survey sites across project area</u>

31 Sites in Total (8 Secondary, 1 Tertiary and 22 Quaternary / Observation).

This ecosystem is associated with both shallow alluvial depressions and sandy rises on flood plains where it is characterised by mix of eucalyptus species including River Red Gum (*Eucalyptus camaldulensis),* Rough Barked Apple (*Angophora floribunda),* Smooth Barked Apple (*Angophora leiocarpa)* and an often dense to mid-dense sub-canopy of *Callitris glaucophylla*. Sub-canopy is variable although habitats on sandy substrates are often characterised by a mid-dense sub-canopy of *Callitris glaucophylla* and Black Wattle (*Acacia leiocalyx).* The canopy height ranges between 18-26m and canopy cover that ranges from 40 to 65%. Ground covers are generally intact, formed by dense swards of Blady Grass (*Imperata* *cylindrica),* Reed Grass (*Arundinella nepalensis), Heteropogon contortus* and often dense cover of Mat-rush (*Lomandra longifolia).*

RE11.3.14 associated with a sandy rise above the Condamine River Flood Plain (AS12_2346)

Regional Ecosystem 11.3.18

Eucalyptus populnea, Callitris glaucophylla, Allocasuarina luehmannii shrubby woodland on alluvium

Status

VMA Status: Least Concern

Biodiversity Status: No Concern at Present

Total number of survey sites across project area

13 Sites in Total (2 Secondary, 11 Quaternary / Observation).

Regional ecosystem RE 11.3.18 is restricted to the southern assessment area where it occupies sandy alluvial associated with largely with ephemeral watercourses. Canopy heights range from 12 – 23m with typical canopy cover of 35 – 45%. The dominant canopy tree is Poplar Box (*Eucalyptus populnea)* with occasional Moreton Bay Ash (*Corymbia tessellaris),* Rough Barked Apple (*Angophora floribunda)* and Narrow leafed Ironbark (*Eucalyptus crebra).* The sub-canopy and shrub layer is universally occupied by a dense to mid-dense sub-canopy of White Cypress (*Callitris glaucophylla)* and less abundant Bulloke (*Allocasuarina leuhmannii)* with Sally Wattle (*Acacia salicinia)* and Black Wattle (*Acacia leiocalyx)* generally associated. Ground cover is typically native, often with dense mats of Matrush (*Lomandra longifolia)* and native grasses including *Chrysopogon fallax,* Kangaroo Grass (*Themeda triandra), Chloris truncata,* Black Spear Grass (*Heteropogon contortus)* and *Aristida caput-medusae* in areas of poorer soil. African Love Grass (*Eragrostis curvula)* is prominent in some occurrences south of Dalby and Mother of Millions forms a dense infestation in habitats associated with Braemar Creek.

RE11.3.18 at site on a broad drainage channel in the Tipton Area (GB101_2402)

Regional Ecosystem 11.3.26

Eucalyptus moluccana or E. microcarpa woodland to open forest on margins of alluvial plains.

Status

VMA Status: Least Concern

Biodiversity Status: No Concern at Present

Total number of survey sites across project area

8 Sites in Total (3 Secondary, 5 Quaternary / Observation).

Small areas (25ha in total) occur in the southern and central assessment areas on broad loamy flats formed from alluvial outwash. Canopy heights range from 12 – 22m with typical canopy cover ranging from 25 to 55%. The dominant canopy tree is Grey Box (*Eucalyptus woollsiana)* occasionally with scattered Poplar Box (*Eucalyptus populnea)* in the sub-canopy. Shrub layers are typically sparse formed by Grey Box, *Acacia semilunata* and Bulloke (*Allocasuarina leuhmannii).* The ground layer is also sparse with up to 40% living cover of *Eragrostis bimaculate, Aristida caput-medusae, Gahnia aspera,* Variable Sword Sedge (*Lepidosperma laterale)* and the low shrub *Dodonaea macrossanii*. Regional Ecosystem 11.3.26 provides habitat for the Endangered sedge *Fimbristylis vagans* in the Lake Broadwater area.

Regional Ecosystem 11.5.1

Eucalyptus crebra, Callitris glaucophylla, Angophora leiocarpa, Allocasuarina luehmannii woodland on Cainozoic sand plains/remnant surfaces.

Status

VMA Status: Least concern

Biodiversity Status: No concern at present

Total number of survey sites across project area

542 Sites in Total (30 Secondary, 2 Tertiary, 510 Quaternary / Observation).

Regional Ecosystem 11.5.1, including sub-type 11.5.1a is the most extensive habitat type in the SGP assessment area. The ecosystem occurs on loamy to sandy clay soils which are associated with extensive areas of broad, flat to gently undulating plains. The typical canopy height ranges between 10-22m and a mean crown cover of 37%. It is dominated by Narrow Leaf Ironbark *(Eucalyptus crebra / Eucalyptus elegans)* with associated Smooth Barked Apple *(Angophora leiocarpa),* White Cypress *(Callitris glaucophylla)* and Poplar Box *(Eucalyptus populnea).* Where Poplar Box is dominant, the ecosystem is mapped as RE11.5.1a. A sparse second tree layer has an average height of 8.5m and is dominated by White Cypress (*Callitris glaucophylla*) and Bulloke (*Alloacasuarina Luehmannii)* with less frequent narrow leaf ironbark.

A diverse upper shrub layer ranges between 5-30% in cover with a mean height of 4%. Bulloke and White Cypress predominate across all sites surveyed. Other typical species are Moon Wattle (*Acacia semilunata*), *Acacia ixiophylla, Melaleuca decora, Acacia apprepta, Acacia crassa* subsp. *crassa*, *Acacia leiocalyx*, *Acacia spectabilis*, *Petalostigma pubescens, Alphitonia excelsa,* *Grevillea striata,* and *Ozanthamnus diosmifolius.* The lower shrub layer averaging at 2m in height and 18.5 % in cover, is similarly diverse comprising species which include *Leucopogon* sp*., Callitris glaucophylla*, *Acacia crassa* subsp*. crassa* and *Allocasuarina Luehmannii.*

Diversity of the the ground layer varies dependent on disturbance history and grazing regimes although in tends to be relatively diverse. Dominant species include *Aristida caput-medusae, Fimbristylis dichotoma, Chrysopogon fallax, Cyanthillium cinereum, Dodonaea macrossanii, Panicum decompositum, and Themeda triandra.* Frequent species include *Aristida calycina, Commelina lanceolata, Eragrostis sororia, Goodenia* sp. and *Lomandra multiforla*. Naturalised species are limited to scattered occurrences of *Melinus repens*, Opuntia stricta**, *Opuntia tomentosa**, *Paspalum dilatatum** and *Pennisetum ciliare*.*

Most occurrences have been moderately to heavily logged with selective targeting of the Narrow Leaf Ironbark.

Typical occurrence of RE11.5.1 in Kumbarilla State Forest. Habitat in this location is in good condition.

Regional Ecosystem 11.5.4

Eucalyptus chloroclada, Callitris glaucophylla, C. endlicheri, Angophora leiocarpa woodland on Cainozoic sand plains and/or remnant surfaces

Status

VMA Status: Least concern

Biodiversity Status: No concern at present

Total number of survey sites across project area

55 Sites in Total (2 Secondary, 53 Quaternary / Observation).

Regional Ecosystem 11.5.4 shares floristic similarities with RE11.5.1 merging in regard to floristic attributes and landform associations. The ecosystem tends to occur on sandier soils than RE11.5.1, often occupying low sandy rises. The canopy height tends to vary with examples of lower stature ranging in height between 10-22m with some taller representations in Kumbarilla State Forest attaining heights of up to 30m. Crown cover values range from Canopy cover also tends to vary ranging from 30 to 60%. Smooth Bark Apple (*Angophora leiocarpa)* and Dirty Gum (*Eucalyptus chloroclada)* are the dominant species with Narrow Leaf Ironbark *(Eucalyptus crebra)* generally present*. A sparse to mid-dense second tree layer has an average height of 8.5m and is generally present attaining heights of 12m and dominated by Smooth Barked Apple, Dirty Gum and White Cypress (Callitris glaucophylla),* Budgeroo (*Lysicarpus angustifolius),* Stringy Bark She-oak (*Allocasuarina inophloia), Melaleuca decora* with less frequent Bulloke *(Alloacasuarina Luehmannii).*

Shrub layers are generally dominated by White Cypress, Budgeroo, Stringy Bark She-oak, *Acacia ixiophylla, Melaleuca decora, Acacia crassa subsp. crassa, Acacia leiocalyx, Acacia spectabilis, Petalostigma pubescens, Alphitonia excelsa* and *Acacia semilunata* in the northern occurrences.

Ground cover tends to be sparse to mid-dense (15 to 40% living cover) with dominant species include *Aristida caput-medusae, Ancistrachne uncinellata, Gahnia aspera, Lomandra multflora, Aristida ramosa, Aristida salicinia* and Grass Tree (*Xanthorrhoea johnsonii*) in some localities.

Representative structure of RE11.5.4 in Kumbarilla State Forest with sparse canopy cover.

Regional Ecosystem 11.5.20

Eucalyptus moluccana and/or E. microcarpa/ E. pilligaensis +/- E. crebra woodland on Cainozoic sand plains.

Status

VMA Status:	Least concern
Biodiversity Status:	No concern at present

Total number of survey sites across project area

80 Sites in Total (8 Secondary, 72 Quaternary / Observation).

Regional ecosystem 11.5.20 is represented most abundantly in the southern assessment area, particularly Kumbarilla State Forest by a woodland of 16-23m in height. Grey Box (*Eucalyptus woollsiana*) is the dominant species, occasionally with associated narrow leaf ironbark (*E. crebra*). Canopy species also occur in the second tree layer with bull oak (*Allocasuarina Luehmannii*) and psydrax (*Psydrax* sp.).

A typically sparse native groundcover (15 – 25% cover) is dominated by Many-Headed Wire Grass (*Aristida caput-medusae),* Barbed Wire Grass *(Aristida calycina),* Love Grass (*Eragrostis* *lacunaria*), barbed wire grass *(Cymbopogon refractus),* Paspalidium *(Paspalidium distans),* and Windmill Grass (*Chloris truncata*) and *Gahnia aspera*.

This ecosystem has almost universally been subject to heavy logging regimes greatly simplified the original habitat structure.

Regional ecosystem 11.5.20 in the Kumbarilla State Forest with heavily modified structure through timber extraction and Grazing.

Regional Ecosystem 11.5.21

Corymbia bloxsomei +/- Callitris glaucophylla +/- Eucalyptus crebra +/- Angophora leiocarpa woodland on Cainozoic sand plains/remnant surfaces.

Status

VMA Status:	Least concern
Biodiversity Status:	No concern at present

Total number of survey sites across project area

62 Sites in Total (7 Secondary, 1 Tertiary, 54 Quaternary / Observation).

This woodland ecosystem generally occupies sandier localities on Tertiary age plains. The canopy height ranges between 14-23m and a mean crown cover of 32%. It is dominated by yellow bloodwood *(Corymbia bloxsomei)* in association with smooth barked apple *(Angophora* *leiocarpa),* narrow leaf ironbark *(Eucalyptus crebra),* Queensland blue gum *(Eucalyptus tereticornis),* and white cypress *(Callitris glaucophylla).*

The second tree layer is poorly formed and often absent with white cypress, bull oak (*Allocasuarina luehmanii*) and occasional narrow leaf ironbark. The shrub layer ranges between 1-5 m in height with a very sparse cover average of 11%. Characteristic species are *Acacia spectabilis*, *Callitris glaucophylla*, *Allocasuarina Luehmannii*. Others include *Acacia amblygona, Acacia ixiophylla, Eucalyptus crebra, Hakea purpuea, Leptospermum polygalifolium, Leucopogon sp., Micromyrtus sessilis, Opuntia tomentosa *,* and *Xylomelum cunninghamianum.*

The ground layer is in good condition with a mean PFC of 62%, and comprises native species which include *Triodia scariosa, Aristida caput-medusae, Brachyscome sp., Cheilanthes sieberi, Chrysocephalum apiculatum, Cymbopogon refractus, Dianella brevipedunculata, Eragrostis sp., Eulaia aurea, Fimbristylis dichotoma, Homoranthus melanostictus, Lomandra leucocephala subsp. leucocephala, Murdannia graminea, Pimelea novae-hollandaei, Pleurocarpaea sp., Tricoryne elatior and Xanthorrhoea johnsonii* which forms a dominant cover in some localities.

The habitat is generally well preserved with limited disturbance evident in most representations.

Regional ecosystem 11.5.21 in Barakula State Forest, central assessment area.

Regional Ecosystem 11.7.2

Acacia spp. woodland on Cainozoic lateritic duricrust. Scarp retreat zone

Status

VMA Status: Least concern

Biodiversity Status: No concern at present

Total number of survey sites across project area

25 Sites in Total (5 Secondary, 20 Quaternary / Observation).

Regional ecosystem 11.7.2 occupies areas of extremely shallow soil, typically growing on rudosols formed on indurated sandstones in the central assessment area. The habitat is dominated by Lancewood (*Acacia shirleyi)* although have other species scattered throughout its canopy including *Eucalyptus fibrosa subsp. nubile,* Narrow Leaf Ironbark (*Eucalyptus crebra*) and Queensland Peppermint (*Eucalyptus exserta).* Canopy heights range from 14-23m and crown cover varies between 30 to 80%.

The second tree layer is often absent or sparse Lancewood. The upper shrub layer is formed by Lancewood, *Alphitonia excelsa, Ehretia membranifolia,* Bitter Bark (*Alstonia constricta)* while the lower layer consists of *Dodonaea biloba, D. macrossanii, Prostanthera cryptandroides subsp. euphrasioides. Leucopogon sp., Dodonaea triangularis* and *Acacia triptera.*

The ground layer generally retains near natural condition with up to 70% cover of wiry grasses include *Ancistrachne uncinellata* and *Thyridolepis mitchelliana.* The habitat is generally well preserved although clearing and timber harvesting affects some localities.

Tall straight stand of Lancewood characteristic of RE11.7.2

Regional Ecosystem 11.7.4

Eucalyptus decorticans and/or Eucalyptus spp., Corymbia spp., Acacia spp., Lysicarpus angustifolius on lateritic duricrust.

Status

VMA Status: Least concern

Biodiversity Status: No concern at present

Total number of survey sites across project area

538 Sites in Total (20 Secondary, 4 Tertiary, 514 Quaternary / Observation).

An extensive habitat type within the central and southern assessment areas. This woodland ecosystem is restricted to low hills and rises where soils are shallow and gravelly ridges. Characteristic species in the canopy are Queensland peppermint (*Eucalyptus exserta),* Brown Bloodwood (*Eucalyptus trachyphloia)* and Smooth Barked Apple *(Angophora leiocarpa)* with less frequent White Cypress *(Callitris glaucophylla),* Narrow Leaf Ironbark *(Eucalyptus crebra)* and Lancewood (*Acacia shirleyi*). The canopy height ranges from 11 – 18m and average crown cover is around 40%.

A well-developed second tree layer has an average cover of around 50% and comprises Queensland Peppermint, Miles Mulga (*Acacia apprepta),* White Cypress, False Mahogany *(Eucalyptus rubiginosa),* Stringy Bark Sheoak (*Allocasuarina inophloia)* and Budgeroo *(Lysicarpus angustifolius).* Tall shrubs of *Acacia crassa* subsp*. crassa, Acacia julifera*, and *Acacia semilunata* dominate a sparse upper shrub layer. A distinct yet very sparse lower shrub layer features a range of low shrubs in particular *Leucopogon* sp., *Westringea cheellii, Acacia conferta,* and *Micromyrtus sessilis.*

The ground layer is mid dense and diverse with 42 species recorded. The native graminoids, include *Ancistrachne uncinellata, Thyridolepis mitchelliana, Aristida calycina, Aristida caput-medusae, Eragrostis sororia, Panicum decompositum, Scleria sphacelata* and *Triodia scariosa* occupy the predominant living groundcover with the remainder of cover comprising perennial native herbs such as *Brunoniella acaulis, Cheilanthes sieberi, Goodenia sp*. and *Pleurocarpaea sp.* The woodland ecosystem generally retains good condition although some timber extraction is evident and severe fire damage is evident in Kumbarilla State Forest and some portions of the central assessment area to the north-west of Miles.

Typical structure of RE11.7.4 in the central assessment area (Site AG313_129).

Regional Ecosystem 11.7.5

Shrubland on natural scalds on deeply weathered coarse-grained sedimentary rocks.

Status

VMA Status:	Least concern
Biodiversity Status:	No concern at present

Total number of survey sites across project area

15 Sites in Total (2 Secondary, 13 Quaternary / Observation).

This shrubland ecosystem is restricted to shallow sandy soils on the surface of lateritic duricrust. Although most commonly found around Barakula State Forest in the central assessment area, small patches also occur in the south within Kumbarilla State Forest. The habitat is typified by a mid-dense upper shrub layer of Broombush (*Melaleuca uncinata*) or *Melaleuca nodosa* forms the ecological dominant layer with scattered Miles Mulga (*Acacia apprepta),* micromyrtus *(Micromyrtus sessilis),* Budgeroo (*Lysicarpus angustifolius)* and emergent White Cypress *(Callitris glaucophylla)* and Yellowjacket (*Corymbia bloxomeii).* A distinct lower shrub layer is also dominated by Broombush and Micromyrtus in association with dodder laurel *(Cassytha* *pubsecens), Leucopogon sp. (GBS3/7), Hakea purpurea, Pimelea nova-anglica,* and *Callitris glaucophylla.*

In comparison to woodland habitats this shrubland ecosystem is depauperate in species. Low species diversity is reflected in the ground layer that supports a limited number of grasses including Spinifex (*Triodia scariosa*), *Aristida leichardtiana, Aristida ramose, Panicum decompositum, Panicum queenslandicum, Paspalidium distans* and the herbs *Cheilanthes sieberi, Drosera indica, Cassytha filiformis,* and *Boronia bipinnata.*

Recently burnt heath in Kumbarilla State Forest with dominant *Melaleuca uncinnata.*

Regional Ecosystem 11.7.6

Corymbia citriodora or *Eucalyptus crebra* woodland on Cainozoic lateritic duricrust.

<u>Status</u>

VMA Status:	Least concern
Biodiversity Status:	No concern at present

<u>Total number of survey sites across project area</u>

17 Sites in Total (5 Secondary, 12 Quaternary / Observation).

Regional ecosystem 11.7.6 is largely restricted to the central assessment area to the north of Miles. This woodland to open forest ecosystem typically occurs on hills and ridge crests hills with associated shallow gravelly soils. Spotted Gum *(Corymbia citriodora)* characterises the habitat and forms a relatively tall, continuous canopy cover up to 25m tall and cover ranging from 40 to 70%. Associated species include Narrow Leaf Ironbark *(Eucalyptus crebra)* Brown Bloodwood (*Eucalyptus trachyphloia)* and Smooth Barked Apple *(Angophora leiocarpa)* with less frequent White Cypress *(Callitris glaucophylla),* and Lancewood (*Acacia shirleyi*) although these are more commonly associated with a sparse sub-canopy layer forming 15 to 25% cover.

Tall shrubs of *Acacia crassa subsp. crassa, Alphitonia excelsa, Acacia semilunata, Acacia conferta* and *Allocasuarina leuhmanni* dominate a sparse shrub layer. Lower shrub layers are also sparse and are formed by *Dodonaea macrossanii, Mirbellia pungens, Acacia melliodora, Prostranthera sp., Westringea cheellii, Acacia conferta, Callitrix tetragona* and *Leucopogon muticus*.

The ground layer is mid dense and generally diverse with native covers including *Arundinella nepalensis, Ancistrachne uncinellata, Thyridolepis mitchelliana, Gahnia aspera, Lomandra leucocephala, Lomandra multiflora, Aristida calycina, Aristida caput-medusae, Eragrostis sororia, Panicum decompositum, Scleria sphacelata* and *Triodia scariosa*.

A heavily logged representation of RE11.7.6 in the central assessment area.

Regional Ecosystem 11.7.7

Eucalyptus fibrosa subsp. nubila +/- Corymbia spp. +/- Eucalyptus spp. on lateritic duricrust.

Status

VMA Status: Least concern

Biodiversity Status: No concern at present

Total number of survey sites across project area

212 Sites in Total (16 Secondary, 2 Tertiary, 194 Quaternary / Observation).

This widespread and relatively abundant woodland and open forest ecosystem occurs on low hills and ranges formed from deeply weathered sediments. Soils are shallow with sandy and gravelly surface horizons. Blue Leaved Ironbark (*Eucalyptus fibrosa* subsp*. nubila)* forms a distinct canopy which ranges between 11 and 25m in height. The canopy may also include Narrow Leaf Ironbark (*E. crebra* and *E. elegans*), Queensland peppermint (*E. exserta*) and white cypress (*Callitris glaucophylla*). These species also characterize a distinct yet discontinuous second tree layer. *Eucalyptus elegans* dominates the canopy in restricted locations although *Eucalyptus fibrosa* is always present.

Scattered tall shrubs such as *Acacia semilunata, Acacia conferta* and *Callitris glaucophylla* form a sparse to very sparse upper shrub layer. The lower shrub layer is similarly sparse and poorly formed and also comprises *Leucopogon* sp., *Acacia ixiophylla, Acacia muelleriana, Hakea purpurea* and *Westringea cheelii*.

The native species dominated ground layer is mid dense with grasses such as *Eulalea aurea, Paspalidium* sp., *Chloris truncata* and *Gahnia aspera* forming the majority of the cover. Characteristic native herbs and low herbaceous shrubs are *Dodonaea macrossanii, Dianella longifolia var. longifolia, Cheilanthes sieberi, Boronia bipinnata*, and *Brunoniella acaulis*.

Regional Ecosystem 11.7.7 on Girraween, central assessment area.

Regional Ecosystem 11.9.2

Eucalyptus melanophloia +/- E. orgadophila woodland on fine-grained sedimentary rocks

Status

VMA Status: Of Concern

Biodiversity Status: Endangered

Total number of survey sites across project area

1 Quaternary Site

Only a few, scattered remnants of this regional ecosystem are mapped in the northern assessment area to the north of Miles. The habitat is invariably dominated by a sparse canopy layer of Silver Leaf Ironbark (*Eucalyptus melanophloia)* with a mid-dense sub-canopy and shrub layer of White Cypress Pine. Canopy heights generally do not exceed 10m which is in part testament to a repetitive and heavy disturbance regime. There is limited canopy recruitment in these fragments and a significant portion of the original Silver Leaf Ironbark canopy layer is suffering from dieback and senescence. Ground covers are universally displaced by exotic Buffel Grass (*Cenchrus ciliaris).*

An extremely degraded patch of Callitris regrowth with scattered Silver Leaf Ironbark. The habitat in non-remnant in this location although remnants of the original ecosystem (RE11.9.2) are preserved in the vicinity.

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Appendix E.

Present, Likely or Possible Threatened Flora Species Profiles and Mapping Criteria

TREES AND SHRUBS

Kogan Waxflower (*Philotheca sporadica*)

Status

Near Threatened (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

Philotheca sporadica is a Queensland and bioregional endemic known from south-east Queensland, from just north of Tara, to approximately 12 km east of Kogan (TSSC 2008j). Of the 11 known populations, seven occur on road verges, seven extend onto freehold land and one population is within Braemar State Forest (Halford 1995c in TSSC 2008j).

The majority of records are in low open forest and woodland of *Acacia burrowii, Eucalyptus exserta, Eucalyptus crebra, Eucalyptus fibrosa subsp. nubila* and *Callitris glaucophylla* (Halford 1995 in TSSC 2008j), and also on residual hills which are remnants of laterised Cretaceous sandstones, where the soils are shallow, uniform sandy loams to clay loams of extremely low fertility and poor condition (TSSC 2008j). Field survey indicates that the species occurs almost exclusively within RE 11.7.4 (*Eucalyptus decorticans and/or Eucalyptus spp., Corymbia spp., Acacia spp., Lysicarpus angustifolius* on *lateritic duricrust*) and possibly RE11.7.5 with a few individual plants overlapping with RE11.7.7. The species has a tendency to form dense, locally restricted populations, particularly on scalded areas with limited soil

Known Threats to the Species

This species is threatened by clearing, particularly localised populations that might be impacted by well pads and linear infrastructure.

Records Relevant to the SGP

Six localised populations are identified within the assessment area to the east of Kogan, both within both private land and State Forest. Populations may cover extensive areas although the margins of populations are generally discrete.

Rule(s) for Habitat Mapping:

1. The species will most likely occur within a 25km wide buffer surrounding Kogan although cannot be discounted as occurring within suitable habitats throughout the SGP assessment area.
2. REs 11.7.4 and 11.7.7 are classified as "Core habitat Possible" within 25km from Kogan.
3. Regrowth habits (non-remnant) derived from RE11.7.4 within 25km from Kogan are classified as "General Habitat'.
4. All "Core Habitat Possible" and "General Habitat" within 1km of a recent (1980+), accurate (± 100m) record is reclassified as "Core Habitat Known".
5. The remaining areas of RE11.7.4 throughout the SGP assessment area are classified as "General Habitat"
6. All other areas are classified as "Absence Suspected".

Mapping Confidence

The detailed ground surveys undertaken throughout habitats for this species in the SGP area and highly localised populations gives habitat mapping is presented with high confidence.

Photograph: David Stanton

Waaje Wattle (Acacia barakulensis)

Status

Vulnerable (NC Act)

Distribution and Habitat

Waaje Wattle is a Queensland and bioregional endemic that is Restricted to Barakula State Forest north of Chinchilla where it grows on sandy soils in eucalypt communities in the Waaje Wildflower Area (Lithgow 1997, Chinchilla Field Naturalists Club 1997, Maslin 2001).

HERBRECS specimen records indicate habitat in flat gently undulating plains on the crest of the slope on deep yellow loamy sand soil derived from sandstone or laterite. Vegetation is tall shrubland with *Eucalyptus tenuipes, Corymbia trachyphloia, Calytrix gurulmundensis*, and *Triodia mitchellii* (DEHP 2017). Habitat is consistent with RE 11.7.4, 11.7.5, 11.7.6, and 11.7.7. Survey records identified the species in woodland of narrow leaf ironbark (*Eucalyptus crebra*) + smooth barked apple (*Angophora leioclada*) + white cypress pine (*Callitris* *glaucophylla*) with a subcanopy of white cypress and bulloak (*Allocasuarina luehmanii*) on old loamy plains (RE 11.5.1, 11.5.4, 11.5.21).

Ecology

Similarity to many Acacias, there is a likelihood that Acacia barakulensis will respond to disturbance, or populations rejuvenated by fire. Knowledge of the species biology and response to disturbances such as habitat fragmentation, changed fire regimes and edge effects requires is poorly understood.

Known Threats to the Species

The species may be impacted by habitat clearing or fragmentation that leads to changes in fire frequency and intensity. As known populations are well away from the SGP assessment area impacts are more likely to be generated during forestry operations.

Records Relevant to the SGP

Herbrecs identifies 5 confirmed populations 28 km to the north-east of the SGP area within Barakula State Forest. Due to contiguity of habitats between populations and the SGP assessment area, it is considered possible that the species may occur.

General Rule(s) for Habitat Mapping:

1. The species will only likely occur in the Central assessment area.
2. Within the central area of the SGP, RE's 11.5.1, 11.5.14, 11.5.21, 11.7.4, 11.7.5, 11.7.6 and 11.7.7 are mapped as "General Habitat" due to lack of local records.

Mapping Confidence

Due to the relatively broad habitat tolerances, mapping of general habitat is considered to be of moderate accuracy.

Curly-bark Wattle (*Acacia curranii*)

Status

Vulnerable (NC Act)

Distribution and Habitat

The only known Queensland population occurs in and adjacent to the Gurulmundi State Forest area of the Darling Downs, approximately 65 km north-west of Chinchilla (Pedley 1987; Maslin 2001). The Gurulmundi population is restricted to an area of less than 20 km diameter and represents a highly disjunct northern limit of distribution with southern populations in NSW.

Plants are known to occur in shrubby heaths, dry sclerophyll forests and semi-arid woodlands where they can occur as widely scattered thickets in very species-rich heathy scrub with emergent eucalypts (Pickard 1995c, Threatened Species Scientific Committee 2008a). The Gurlumundi population has been reported as growing in dense "groves" (Pedley 1987). Queensland collections of curly-bark wattle, recorded in Herbrecs, mostly occur within areas mapped by the Queensland Herbarium as Regional Ecosystem 11.7.5; shrubland with *Calytrix* spp., *Hakea* spp., *Kunzea* spp., *Micromyrtus* spp., *Acacia* spp., *Melaleuca* spp. and a spinifex grass layer, on natural scalds on deeply weathered sedimentary rocks.

Ecology

The typical life span of curly-bark wattle is unknown, but it is probably similar to many other shrubby *Acacia* species in being a moderately long-lived shrub of 10 to 30 years. It has been recorded flowering during August and September, with pods maturing several months later (Pedley 1987). As a hard-seeded legume, the soil-stored seed reserves of *A. curranii* are likely to be long lived (i.e. > 10 years). The observed abundant regeneration via seedlings after fire suggests *Acacia curranii* will also germinate seedlings following mechanical disturbance of the topsoil, although repeated soil disturbance would kill the seedlings that germinate after any initial disturbance. The impact of stock grazing is unknown, but damage from grazing by feral goats has been observed (Cohn 1995).

Known Threats to the Species

Grazing, browsing and trampling of adult and seedling plants by feral goats and rabbits (and to less an extent by stock, and macropods). This may be facilitated installation of well ponds which artificially increases watering points for feral animals. Additional threats include clearing of vegetation for road widening, gravel extraction and mining

Records Relevant to the SGP

Sixteen records of the species are confirmed in Herbrecs with the nearest population 11 km west of the SGP area with Gurulmundi State Forest (excluding low precision records).

General Rule(s) for Habitat Mapping:

1. The species will only occur in the central portion of the SGP assessment area to the north of Miles.
2. In the absence of survey records within the SGP area, RE11.7.5, 11.7.4, 11.7.7 in the potential area of occurrences have been allocated as "General Habitat".

3. All other regional ecosystems, regrowth and cleared areas are mapped as "Absence Suspected".

Mapping Confidence

High mapping confidence is applied to be species based on the revised mapping boundaries and detailed on-ground assessment.

Curly-bark wattle (*Acacia curranii).* Photograph M. Fagg, Australian National Botanical Gardens

Hando's Wattle (*Acacia handonis*)

Status

Vulnerable (NC Act); Vulnerable (EPBC Act Act)

Distribution and Habitat

Hando's wattle has an extremely restricted occurrence, being known only from the Barakula State Forest, approximately 40 km north of Chinchilla (Maslin 2001). This population of Hando's wattle was considered to occur in three adjacent areas and was estimated in 1994 to contain around 10 080 individuals over approximately 28 ha (Halford 1995b). The extent of population was considered to have broadened within the Barakula State Forest between the initial collections in 1978 and 1997 (Lithgow, 1997).

Hando's wattle has only been collected on rocky ridges and slopes on sandstone-derived geology in eucalypt woodland and open forest (Maslin 2001). The vegetation it grows within is a shrubby woodland of *Eucalyptus fibrosa* subsp. *nubila*, *Eucalyptus watsoniana* subsp. *watsoniana, Lysicarpus angustifolius,* and *Allocasuarina inophloia* (Halford 1995). The descriptions of the habitat from which it has been collected are consistent with the regional ecosystem mapping for its locations. This is, primarily RE 11.7.7: *Eucalyptus fibrosa* subsp. *nubila* +/- *Corymbia* spp. +/- *Eucalyptus* spp. on lateritic duricrust. One collection is also recorded in RE 11.7.6: *Corymbia citriodora* or *Eucalyptus crebra* woodland on lateritic duricrust.

Ecology

The life span of Hando's wattle plants in the wild is unknown, but they live for about 10 years in cultivation (Hando 2007). Plants have been collected in flower in July, August and September, and with pods in August, September and November. As a hard-seeded legume, the soil-stored seed reserves of Hando's wattle are likely to be long lived (i.e. > 10 years). The response to fire by Hando's wattle has not been well studied. However, it is suggested that it regenerates well from seed following burning (DNR 2000).

Known Threats to the Species

Inappropriate fire regimes, habitat destruction, disturbance from timber harvesting, inappropriate grazing regimes (DNR 2000) are considered the major threats to *Acacia handonis* populations. Halford (1995b) suggested the main threat to Hando's wattle was inappropriate fire regimes. That is, fires that are too frequent, intense fires, or complete fire exclusion.

Records Relevant to the SGP

Seventeen records in Herbrecs with the nearest population 35 km east of the SGP assessment area within Barakula SF.

Rule(s) for Habitat Mapping:

Regional Ecosystems 11.7.4, 11.7.5, 11.7.6, 11.7.7 and 11.5.1 in the Central region of the SGP (North of Miles) should be classed as "General Habitat" on account of the intensive survey undertaken in the assessment area

Mapping Confidence

High mapping confidence is applied to be species based on the revised mapping boundaries and detailed on-ground assessment.

Photograph M. Fagg, Australian National Botanical Gardens.

Bailey's Callitris (*Callitris baileyii*)

Status

Near Threatened (NC Act)

Distribution and Habitat

In Queensland, Baileys Cypress occurs from the state border to Goomeri in the north and west to the Bunya Mountains. The distribution is predominantly within the Southeast

Queensland bioregion extending into the Brigalow Belt near the bioregional boundary (EHP 2017b). The species also occurs in the drier ranges of NSW.

Typical habitat is open woodland and woodland of *Eucalyptus exserta*, *E. crebra* and *Callitris glaucophylla* with a mid-dense shrubby understorey typical of RE11.7.4. Stanley & Ross (1983) describe its habitat as eucalypt woodland, with ironbark, blue gum and spotted gum on rocky slopes, hilly or mountainous areas, in shallow and often clay soils.

Ecology

Little is known concerning the ecology of this species. Male and female flowers occur on the same tree and fruiting has been recorded all year round.

Known Threats to the Species

This species is threatened by direct loss as a result of clearing as well as inappropriate fire regimes.

Records Relevant to the SGP

Nearest local record is 2.6 km west of the SGP assessment area (40 km north of Miles) in Gurulmundi State Forest. The record was collected during SGP EIS studies in 2011.

Rule(s) for Habitat Mapping:

REs 11.5.1, 11.7.4, 11.7.5, 11.7.6 and 11.7.7 in the Gurulmundi area to the north of Chinchilla (-27.75) in the Central Assessment Area should be considered "General Habitat". Any subsequent collections of the species should be buffered by 1km and General Habitat re-assigned to "Core Habitat Known". Other habitats should be assigned to "Absence Suspected".

Mapping Confidence

The general nature of habitat for this species makes preferred habitats relatively easy to predict and habitat mapping for the species is considered to have high to moderate confidence.

Gurulmundi Fringe Myrtle (*Callitrix gurulmundensis)*

Status

Vulnerable (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

The species is endemic to the Gurulmundi and Barakula areas north of Chinchilla (Halford 1996). Gurulmundi fringe myrtle has been recorded growing in patches of shrubland on very shallow soils. Soils are lateritic sandstone ridges, which contain yellow sandy-clay that retains moisture (Williams 1979). Vegetation is predominately eucalypt, acacia, casuarina dense shrublands with spinifex, and spinifex grassland with scattered shrubs. This habitat description is consistent with RE 11.7.5 (shrubland on natural scalds on deeply weathered coarse-grained sedimentary rocks). The coordinates of Gurulmundi fringe myrtle collections derived from Herbrecs place them in areas mapped by as RE11.7.4, 11.7.5, 11.7.6 and 11.7.7.

Ecology

The life span of Gurulmundi fringe myrtle is unknown, but it is likely to live for at least a decade. Flowers have been recorded from June to October (Halford 1996). Plants as small as 15 cm tall have been observed to flower (Williams 1979). Gurulmundi fringe myrtle can be quite common at sites where it grows, being described in several collection labels as abundant or co-dominant at the collection site (AVH 2013a).

Known Threats to the Species

Clearing, disturbance for track creation and maintenance and inappropriate fire regimes are the key threats to habitat for this species. At least one population is identified as having been damaged in the past due to gravel extraction (Williams 1979).

Records Relevant to the SGP

The nearest local record is 12 km west of the SGP assessment area (30 km north of Miles) within Gurulmundi State Forest. A population also exists in Waaje Scientific Reserve 36 km east of Wandoan.

Rule(s) for Habitat Mapping:

REs 11.5.1, 11.7.4, 11.7.5, 11.7.6 and 11.7.7 in the Gurulmundi area to the north of Chinchilla (-27.75) in the Central Assessment Area should be considered "General Habitat". Any subsequent collections of the species should be buffered by 1km and General Habitat re-assigned to "Core Habitat Known". Other habitats should be assigned to "Absence Suspected

Mapping Confidence

High mapping confidence is applied to be species based on the revised mapping boundaries and detailed on-ground assessment that did not locate any additional populations.

Gurulmundi fringe myrtle (*Calytrix gurulmundensis)* foliage and flower. Copyright © Boobook

Gurulmundi Heath-myrtle (*Micromyrtus carinata*)

Status

Endangered (NC Act)

Distribution and Habitat

Endemic to Queensland, *Micromyrtus carinata* is known only from the Gurulmundi State Forest 40 km to the north of Miles with a sub-population also located on the Wyona Property 10km to the north of Miles (Herbrecs).

Herbarium records indicate *Micromyrtus carinata* is associated with landscapes formed on lateritised sediments with an upper soil layer of red to yellow sand (DEHP 2017c). Associated regional ecosystems include inhabits the tops of laterised ridges, on shallow to deep, yellow or red sands. Associated habthitats include heath and shrubland (RE11.7.5) and low woodland dominated by *Eucalyptus exserta, Corymbia trachyphloia* and *Callitris glaucophylla* (RE11.7.4).

Ecology

Little is known regarding the ecology of this species. Bean (1997) suggest that it likely flowers at any time in response to rain although fruits and flowers have been collected between May and October (DEHP 2017c).

Known Threats to the Species

The species is considered to be threatened by mining activity, gravel extraction and inappropriate fire regimes (Bean, 1997, DEHP 2017c).

Records Relevant to the SGP

Nearest Herbarium Record is 10km north-west of Miles and 4 km west of the SGP assessment area on the Wyona Property. The major population of the species occurs in Gurulmundi State Forest 12km west of the SGP assessment area (Herbrecs)

Rule(s) for Habitat Mapping:

REs 11.7.4 and 11.7.5 in the Gurulmundi area to the north of Chinchilla (-27.75) in the Central Assessment Area should be considered "General Habitat". Any subsequent collections of the species should be buffered by 1km and General Habitat re-assigned to "Core Habitat Known". Other habitats should be assigned to "Absence Suspected

Mapping Confidence

High mapping confidence is applied to be species based on the revised mapping boundaries and detailed on-ground assessment that did not locate any additional populations.

Plunkett Mallee (*Eucalyptus curtisii*)

Status

Near Threatened (NC Act)

Distribution and Habitat

The plant is scattered but nowhere common occurring on coastal hinterland to 80 km north and south of Brisbane and inland over 300 km north west to the Dalby and Miles districts (DNR 2000). Occurs in the Burnett, Leichhardt, Moreton and Darling Downs pastoral districts (Bostock and Holland 2016). Conserved in Expedition Range, Robinson Gorge and Isla Gorge National Parks (Brooker and Kleinig 2004).

DEHP (2017d) suggests *Eucalyptus curtisii* has two growth forms that occur in different habitats with a shorter shorter mallee associated with shrublands dominanted by banksia in poorly drained lowland sites with a larger growth occurring as scattered individuals on better drained soils in the more open areas of mixed eucalypt forests. The species is most typically associated with lateritised landscapes within regional ecosystems 11.7.4 and 11.7.5. Commonly associated species include *C. trachyphloia, Eucalyptus exserta* and *Callitris endlicheri* and less commonly associated with *E. fibrosa*.

Ecology

Flowering of *Eucalyptus curtisii* has been recorded between the months of September and November, and fruiting occurs throughout the year (Queensland Herbarium, 2012 cited in DEHP 2017d). Response to fire is not documented.

Known Threats to the Species

Known threatening process related largely to clearing, timber harvesting and inappropriate grazing and fire regimes.

Records Relevant to the SGP

Numerous local records mostly west of the SGP with the nearest record 2.5 km west of the SGP assessment area and 35km north of Miles. A number of records in Kumbarilla State Forest to the south although well outside the SGP assessment area.

Rule(s) for Habitat Mapping:

Eucalyptus curtisii may occur throughout the entire assessment area. Through the assessment area, REs 11.7.2, 11.7.4, 11.7.5, 11.7.6 and 11.7.7 should be classified as "General Habitat" in recognition of the extensive survey effort undertaken. All other REs and non-remnant vegetation should be classified as "Absence Suspected".

Mapping Confidence

Due to the extensive survey effort and known habitat preferences, mapping of *Eucalyptus curtisii* is attributed as having a high degree of confidence.

GRASSES AND SEDGES

Finger Panic Grass (*Digitaria porrecta*)

Status

Near Threatened (NC Act)

Distribution and Habitat

Finger panic grass is known from four disjunct areas extending over 1000 km across NSW and Queensland. The Queensland distribution includes broad populations in the Nebo district; the Central Highlands between Springsure and Rolleston; and from Jandowae south to Warwick. In NSW, it is known from near Inverell, south to the Liverpool Plains near Coonabarabran and Werris Creek (TSSC 2008f).

Finger panic grass grows in grasslands, woodlands and open forests with a grassy understory, on black soil plains of the Darling Downs, and lighter textured soils to the west (Goodland 2000; Fensham 1998). Fensham (1998) found it is most abundant in grassland, but is "relatively unspecific" in its habitat preference. It is not restricted to high quality native grasslands, but also grows along roadsides and can be found in highly disturbed sites (Goodland 2000). Finger panic grass been recorded inside the project development area, within roadside remnant grasslands on dark cracking clay plains (RE11.3.21); poplar box (*E.*

populnea) open forest and woodland with grassy understorey, on dark cracking clay plain (RE11.3.2); and along disturbed railway reserves on dark cracking clay soils (EHP 2013). The primary habitats for this species in the project development area are RE11.3.2, RE 11.3.21 and non-remnant derived grasslands.

Ecology

Finger panic grass is a spreading perennial that can reproduce vegetatively (Halford 1995a). Older clumps are reported to die in the centre, with the outer edges of the clump becoming separate plants. Seeds drop to the ground when mature, but appear to have a six month to one year dormancy prior to germinating (Halford 1995a). This is similar to some other sub - tropical grasses, such as black spear grass, and delays germination until the wet season rains. The species produces fertile material from March to April (TSSC 2008f).

Known Threats to the Species

The grassland habitat for this species has been heavily fragmented by clearing for agriculture, and sowing of exotic pasture grasses that can replace finger panic grass. It is mainly restricted to stock routes and road reserves and threatened by degradation from mechanical disturbance, invasive weeds and inappropriate grazing regimes. Goodland (2000) notes that finger panic grass can withstand disturbance, although populations decline where introduced species (e.g. Rhodes grass) become dominant.

Records Relevant to the SGP

Two records within the SGP assessment area, both in non-remnant derived grasslands adjacent to roadside easements between Dalby and Cecil Plains. Both records collected in 1995. A further 15 records within 25km east of the SGP boundary.

Rule(s) for Habitat Mapping:

1. The species is most likely to occur on heavy clay soils associated with the Condamine Alluvium although may occur throughout the entire assessment area.
2. Regional Ecosystem 11.3.2 should be treated as "General Habitat".
3. Derived native grassland where it is associated with the Condamine Alluvium or other heavy clay soil should be considered "General Habitat".
4. High precision (+/- 500m) species records should be buffered by 1km and all General Habitat upgraded to "Core Habitat Known".
5. All other remnant vegetation in the project development area and all cleared agricultural and grazing land should be treated as "Absence Suspected".

Mapping Confidence

Digitaria porrecta has relatively predictable habitat preferences and with the availability of project scale mapping (1:50 000), it is considered that the habitat mapping has a high level of confidence. It should be noted that no records of the species have been formally documented since 1995 and

Fimbristylis vagans

Status

Endangered (NC Act)

Distribution and Habitat

A little-known Queensland and bioregional endemic restricted to the Darling Downs district between Lake Broadwater and Nudley Creek area (30 km NE of Chinchilla) (DERM 2011). The species occupies habitats that fringe ephemeral watercourses and lagoons on alluvium. Typical regional ecosystems include RE11.3.2, 11.3.4, 11.3.14 and 11.3.26 where they fringe watercourses and wetlands (RE11.3.27). The species is not known to be associated with non-remnant habitats.

Ecology

Species ecology is poorly documented although like most species associated with wetland habitats, is likely to be a seasonally dependent species that flowers and reproduces following rainfall.

Known Threats to the Species

Threats are poorly documented although major threats are likely to be associated with damage created by feral animals, particularly pigs and intensive grazing.

Records Relevant to the SGP

A single herbarium record from the SGP assessment area associated with the swampy inlet of Lake Broadwater. The species has not been recorded or collected since 1984.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire EIS area.
2. "Core Habitat Possible" includes the wetland fringe of Lake Broadwater characterised by RE11.3.27f and wetland habitats of Long Swamp.
3. REs 11.3.2, 11.3.3, 11.3.4, 11.3.25 and 11.3.26 throughout the broader SGP assessment area is classified as "General Habitat".
4. All Core Habitat Possible and General Habitat within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
5. All remaining remnant and non-remnant vegetation is mapped as "Absence Suspected".

Mapping Confidence

Habitat characteristics for this species are well understood and can be matched to regional ecosystem descriptions. The mapping is considered to be highly accurate.

Belson's Panic (Homopholis belsonii)

Status

Endangered (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

In Queensland, major populations occur on the Darling Downs near Oakey, Jondaryan, Bowenville, Dalby, Acland, Sabine, Quinalow, Goombungee, Gurulmundi and Millmerran, and further west between Miles and Roma (Goodland 2000). Also known from the north-western slopes and plains of NSW (TSSC 2008g).

Belson's panic prefers moderate to highly fertile soils, especially those derived from basalt and fertile alluvial flats. It is generally associated with poplar box and brigalow woodlands on light red/brown earths (Fensham and Fairfax 1997, Goodland 2000). Based on Herbrecs specimens, the species is most commonly associated with habitats on heavy clay soils, particularly those dominated by Brigalow including REs 11.3.1, 11.3.17, 11.4.3, 11.9.5 ad 11.9.10. Herbarium records also indicate some potential for the species to overlap with RE11.3.2.

Belson's panic is also capable of growing within disturbed habitats. Of the 22 collections within the study area, 15 (68%) are located in non-remnant areas such as roadside easements. It has been seen growing among fallen timber at the base of trees or shrubs, among branches and the bottom of netting fences (TSSC 2008g).

Ecology

Belson's panic tends to grow in shade under trees, but can grow in cleared regrowth. As a rhizomatous perennial grass, it probably is capable of living for many years, and to have some tolerance to fire and at least low levels of grazing. It is reported to spread out very rapidly (Menkins 1998). Flowers have been recorded between February and May (Sharp and Simon 2002).

Known Threats to the Species

Loss of habitat from vegetation clearing, pasture improvement, and overgrazing is a major threatening process (TSSC 2008g). Belson's panic declines in abundance with grazing pressure and appears to grow best under tree or shrub cover. Roadside populations are threatened by invasion of pasture grasses such as green panic (Megathyrsus maximus var. trichoglume), and road works (Goodland 2000), however it is known to re-colonise disturbed areas if tree cover is available (Menkins 1998 in TSSC 2008g).

Records Relevant to the SGP

A considerable number of records to the east of Dalby with the nearest 12km from the eastern boundary of the SGP assessment area. Two records within 8km of the boundary of the northern assessment area within 10km of Wandoan.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire EIS area although is most likely to occur in Brigalow associated habitats in the northern assessment area.

2. Regional Ecosystems 11.9.5, 11.9.10 and 11.3.17 including derived non-remnant regrowth is mapped as "Core Habitat Possible" in the northern assessment area.
3. REs 11.3.1, 11.3.17, 11.4.3 and 11.9.5 including non-remnant derived regrowth in central and southern portions of the SGP assessment area are classified as "General Habitat"

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

Belson's panic (*Homopholis belsonii)*. Copyright © Boobook

FORBS AND HERBS

Solanum papaverifolium

Status

Endangered (NC Act)

Distribution and Habitat

Recorded in the Darling Downs from between Jimbour and Warwick, where it is known from three locations (Bean 2004). Known from a number of very old records in the Dalby-Cecil Plains area. Goodland (2000) reports two populations west of Dalby on the Warrego Highway before Kogan Rd), and large populations up to 100m extent off Cecil Plains Rd. Known in NSW north from Inverell to Quirindi and Singleton area and west to Narrabrii and Moree (Bean 2004). Occurs in wetter (swampy) areas of grasslands or open eucalypt woodland on heavy alluvial soils (Goodland 2000, Bean 2004).

Ecology

Little is documented on the ecology of the species. It has been observed flowering thoughout the year and populations are most likely rejuvenated following rainfall.

Known Threats to the Species

The species occurs on soils utilised by intensive agriculture and remains on roadside reserves and stock routes. Populations remain threatened by habitat destruction, weed invasion, and roadworks (Goodland 2000, Bean 2004).

Records Relevant to the SGP

Two records are contained within the SGP assessment area to the south of Dalby with an large number of herbarium records to the east of the SGP assessment area between Chinchilla and Dalby.

Rule(s) for Habitat Mapping:

1. The species is most likely to occur on habitat formed by heavy clay soils associated in particular with the Condamine Alluvium.
2. Regional Ecosystems 11.3.2 and Derived Native Grassland (non-remnant) provide the most suitable habitats for the species. Where these habitats occur on the alluvial landforms to the west and south of Dalby, they are mapped as "General Habitat".
3. All General Habitat within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
4. All remaining remnant and non-remnant vegetation is mapped as "Absence Suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

Solanum papaverifolium (Photograph David Stanton).

Solanum stenopterum

Status

Vulnerable (NC Act)

Distribution and Habitat

Recorded in Queensland from Gayndah in the Burnett Pastoral district to Moonie and west to Glenmorgan and Yuleba (Bean 2004, Bostock and Holland 2016). Known in NSW from Ashford (Bean 2004). The species is Known to occur in non-remnant grassland approximately 7.5km south of Dalby; 3.5km east of Cecil Plains in a roadside gravel pit; and approximately 6km south east of Cecil Plains in remnant Eucalyptus populnea woodland on alluvium (11.3.2).

Ecology

Little is documented on the ecology of the species although similar to many solanum species in the Brigalow Belt, likely flowers at multiple times throughout the year in response to rainfall events.

Known Threats to the Species

The species occurs on soils utilised by intensive agriculture and occurs on roadside reserves. Populations remain threatened by habitat destruction from land clearing, agricultural practices, weed invasion, roadworks and roadside maintenance (Bean 2004).

Records Relevant to the SGP

Known to occur in non-remnant grassland approximately 7.5km south of Dalby; 3.5km east of Cecil Plains in a roadside gravel pit; and approximately 6km south east of Cecil Plains in remnant Eucalyptus populnea woodland on alluvium (11.3.2). All herbarium records are outside SGP assessment area.

Rule(s) for Habitat Mapping:

1. REs 11.3.2, 11.3.1 and 11.3.17 to the west and south of Dalby should be classed as "General Habitat" on account of comprehensive surveys.
2. Derived grasslands on alluvium and regrowth vegetation derived from the aforementioned REs

All other remnant vegetation and cleared agricultural land in the project development area should be treated as "Absence Suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

Cymbonotus maidenii

Status

Endangered (NC Act)

Distribution and Habitat

The species occurs in scattered populations throughout central areas of NSW and in southern inland districts as far west as Mitchell (Holland and Funk, 2006).

The species is associated with a range of remnant and non-remnant habits with records occurring on disturbed roadside drains, native and derived grasslands. It is typically associated with heavy brown to grey cracking clay soils (Holland & Funk 2006). Habitats favoured by the species are RE11.3.21 from which it is known to occur. The woodland RE11.3.2 and derived native grassland also present potential habitat for the species. It can however occur in a range of highly disturbed locations and hence its occurrence may not be readily predicted.

Ecology

Other than being a perennial, very little is known about this species although, though as a daisy it is probably fairly short-lived (e.g. living < 5 years). The species is known to flower throughout the year but most prominently in spring, possibly in response to rainfall. The seeds are likely to be wind dispersed, which should assist colonisation. It has the ability to survive along disturbed roadsides in in other highly disturbed habitats.

Known Threats to the Species

The species is threatened by roadside clearing and herbicide drift. It may also be threatened by invasion of exotic species of which lippia (*Phyla canescens)* and green panic (*Megathyrsus maximus var. pubiglumis)* pose the most immediate threat.

Records Relevant to the SGP

Five Herbrecs specimens recorded within 10 km of the eastern boundary of the SGP assessment area, mostly in the Cecil Plains / Millmerran Area including collections on road reserves on the Cecil Plains - Millmerran Road.

Rule(s) for Habitat Mapping:

The species is most likely to occur from the Dalby area (-27.00) south to Millmerran (-27.9) generally on the Condamine Alluvium. RE 11.3.2 and associated derived grasslands occuring between in this area should be treated as "general habitat".

All other remnant vegetation and cleared agricultural land in the project development area should be treated as "absence suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence. There may however be a number of potential habitats adjacent to roadsides that are beyond mapping resolution.

Picris barbarorum

Status

Vulnerable (NC Act)

Distribution and Habitat

Occurs from the Darling Downs and Warrego pastoral districts in southern Queensland (Bostock & Holland 2016), to north of the north-west plains of NSW. Herbrecs data indicates that in the Darling Downs, it has a restricted distribution but may be locally abundant along roadsides. Known to occur from the Jandowae, Macalister, Norwin locailities and along the Warrego highway west of Dalby.

Herbrecs specimens indicate occurrence in native grassland (12.3.21) of Dichanthium sericeum in stock routes, road reserves adjacent to disturbed areas such as cultivated paddocks and road and rail lines on black clay soil (DERM 2011).

Ecology

Very little is known about this species although, though as a daisy it is probably fairly short-lived (e.g. living < 5 years). Flowering period is not documented although it is likely to be re-invigorated in response to rainfall, particularly in the spring period.

Known Threats to the Species

Vouchered records of Plains Picris suggest that the annual herb may be tolerant of light disturbance. Its known occurrence on roadsides suggest it may be impacted by roadworks. In similarity to Picris evae it may well be intolerant of grazing and capable of surviving other forms of disturbance.

Records Relevant to the SGP

Four herbarium records within 5km of the SGP assessment area with the nearest less than 2 km from the assessment area boundary, 14km north-west of Dalby.

Rule(s) for Habitat Mapping:

The following REs and habitats should be classified as "General Habitat" where they area association with the Condamine Alluvium.

1. RE 11.3.2 and derived regrowth vegetation.
2. Non-remnant derived native grasslands

All other remnant vegetation in the SGP Assessment area and cleared agricultural and grazing land should be treated as "absence suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence. There may however be a number of potential habitats adjacent to roadsides that are beyond mapping resolution.

Rutidosis lanata

Status

Vulnerable (NC Act)

Distribution and Habitat

Endemic to south central Queensland from near Jackson to Hannaford on the western Darling Downs (DNR 2000). Mainly found in roadside vegetation of Acacia and Eucalypt woodland/open forest on red sandy ridges and clay flats between 280-320m altitude adjacent to cleared or partly cleared grazing and cropping land (DNR 2000). Based on Herbrecs notes, associated vegetation includes open grassy woodland of *Eucalyptus populnea* with *Eremophila mitchellii; Acacia harpophylla, Casuarina cristata*, and *Eucalyptus woollsiana* woodland on reddish-brown loamy clay; remnant *Acacia harpophylla, Eucalyptus coolabah,* *Eucalyptus populnea* open forest on alluvium clay loam and gentle sedimentary rises; and in cleared areas along powerlines adjoining *Acacia aprepta* thicket.

Ecology

Rutidosis lanata flowers and fruits from October to March and produces a soil-stored seed bank that lasts for less than one year (DEHP 2017e; Pollock, 1997).

Known Threats to the Species

The species and habitat are known to be threatened by clearing with possible threats of inappropriate grazing, road verge maintenance, and habitat disturbance by weeds and introduced pastures (DNR 2000).

Records Relevant to the SGP

Eight Herbarium records within 20km from the the SGP Assessment area, all recorded in the Miles / Chinchilla area.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire project area although is more likely north from Chinchilla based on vouchered herbarium records. Throughout the assessment area, the following REs should be treated as 'General Habitat'; 11.3.4, 11.3.2, 11.3.17, 11.9.5 and 11.9.7.
2. All other remnant vegetation in the project development area, regrowth vegetation and cleared agricultural land should be treated as "Absence Suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

Xerothamnella herbacea

Status

Endangered (NC Act): Endangered (EPBC Act)

Distribution and Habitat

Xerothamnella herbacea is known from seven locations between Goondiwindi and Theodore. Scattered populations occur to the north-east of Chinchilla (between Chinchilla and Boondooma Lake), within Palmgrove and Expedition National Parks to the southwest of Moura. Two isolated population occur between Goondiwindi and Millmerran.

Occurs in remnant and disturbed Brigalow (Acacia harpophylla) and Belah (Casuarina cristata) dominated communities in shaded situations, often in leaf litter (TSSC 2008n). The species is associated with Brigalow dominated communities, preferring shady locations where it grows in leaf litter (TSSC 2008n). The plant often occurs in gilgais in vertic clay soils (vertosols) and is known to occur in non-remnant and highly disturbed habitats. Regional ecosystems associated with this species are typically dominated by Brigalow or Belah and include REs 11.3.1, 11.4.3 and 11.9.5.

Ecology

Little is known in regard to the ecology of *Xerothamnella herbacea* although it can live for a few years and establish vegetatively by rooting from nodes along stems.

Known Threats to the Species

The species is threatened by competition from invasive grasses such as green panic (Megathyrsus maximus var. pubiglumis) and to a lesser extent buffel grass (Cenchrus ciliaris) either by direct competition or by increasing the fuel load and altering fire regimes. Potential threats include road widening and maintenance activities, surface erosion, and grazing and trampling by cattle and native macropods (TSSC 2008n).

Records Relevant to the SGP

Two herbarium records to within 20km of the SGP Boundary, 20km to the east and north of Chinchilla.

Rule(s) for Habitat Mapping:

The species may occur throughout the entire project area where it may be associated with Brigalow dominant habitats. Throughout the assessment area, the following REs and any derived regrowth Brigalow > 15 yrs age should be treated as 'General Habitat'; 11.3.1, 11.4.3 and 11.9.5.

All other remnant vegetation in the project development area, regrowth vegetation and cleared agricultural land should be treated as "Absence Suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

Xerothamnella herbacea. Photograph Copyright © Boobook

Cryptandra ciliata

Status

Near Threatened (NC Act)

Distribution and Habitat

Restricted to the Gurulmundi, Barakula and Cracow areas of south-eastern Queensland (Chinchilla Field Naturalists Club 1997, DNR 2000). Typical habitat is eucalypt dominant woodland, lancewood (*Acacia shirleyi*) woodland and Triodia grassland on rocky on low lateritic and sandstone ridges. Habitat in the PDA is consistent with RE 11.7.5, 11.7.4, 11.7.6, 11.5.1, 11.5.4, 11.5.21.

Ecology

There is little documented information on the ecology of this species.

Known Threats to the Species

DNR (2000) indicate that the species and habitat is possibly threatened by clearing associated with gravel extraction. Other potential threats may include road construction and maintenance, and inappropriate fire regimes.

Records Relevant to the SGP

Three herbarium records within 5km of the assessment area boundary with a single record within 1km of the eastern boundary, 30km to the north of Miles.

Rule(s) for Habitat Mapping:

1. The species is only likely to occur in the central portion of the SGP assessment area where the following REs should be treated as "General Habitat"; 11.5.1, 11.5.4, 11.5.21, 11.7.4, 11.7.5, 11.7.6 and 11.7.7.
2. All General Habitat within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
3. All other remnant vegetation in the project development area, regrowth vegetation and cleared agricultural land should be treated as "Absence Suspected".

Mapping Confidence

Due to the general habitat requirements, intensity of the field survey and detailed mapping revision available, mapping is considered to have a high degree of confidence.

Austral Toadflax (*Thesium australe*)

Status

Vulnerable (NC Act): Vulnerable (EPBC Act)

Distribution and Habitat

Historical collections (including the late 1800's) were made from Tasmania, but it is now considered extinct in that state (DSE, 2003). Austral Toadflax occurs in eastern Victoria, NSW and southern Queensland. The majority of southern Queensland collections are from the Darling Downs and Moreton districts (Bostock and Holland 2016). The Dalby area represents the species western limits on the Darling Downs.

Austral toadflax has been collected within popular box (*Eucalyptus populnea*) woodland on alluvial flats (RE 11.3.2) north-west of Dalby, within the project development area. Other Herbarium collection records of Austral toadflax are from along roadsides, mountain coolibah (*Eucalyptus orgadophila*) grassy open woodlands with kangaroo grass (*Themeda triandra*) and Queensland blue grass (*Dichanthium sericeum*). RE11.3.2 in the Dalby region is considered the most likely habitat in the SGP assessment area.

Ecology

A root parasite of kangaroo grass (Themeda triandra) and other grasses, Austral toadflax lives for at least two years. Flowers have been recorded from spring to autumn with fruit developing in summer. Austral toadflax has been observed to germinate prolifically after fire and also after drought. The species is relatively short lived, persisting up to two years after germination (Department of Sustainability and Environment (DSE) 2003).

Known Threats to the Species

Populations in road reserves are threatened by roadwork and maintenance activities such as spraying, grading, slashing, by inappropriate grazing and burning regimes, and weed infestation (Goodland 2000). The species is known to be susceptible to rabbit, horse and cattle grazing but able to tolerate light, non-continuous cattle grazing. Populations of the species are thought to be declining. Austral toadflax cannot survive beneath a dense shaded canopy (Griffith, 1992), nor is it likely to be capable of surviving dense infestations of exotic grass.

Records Relevant to the SGP

Two herbarium records within 10km of the SGP assessment area, with the nearest record 2.7k east of the eastern SGP assessment area boundary, 25km north west of Dalby.

Rule(s) for Habitat Mapping:

Intact representation of Poplar Box dominant woodland (RE11.3.2) associated with the Condamine River Alluvium (Condamine River Floodplain) should be treated as "General Habitat'. All other REs, non-remnant regrowth and cultivated areas should be treated as "Absense Suspected".

Mapping Confidence

Due to the relatively specific habitat requirements, detailed survey throughout the assessment area and resolution of the revised mapping database, mapping is considered to have a high degree of confidence.

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Appendix F.
Recorded Vertebrate Fauna List

List of Terrestrial Vertebrate Fauna Recorded during the 2016-17 SGP surveys

GROUP		**Status**		**SGP Region**		
Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
AMPHIBIAN						
Crinia parinsignifera	Beeping froglet		LC	X	X	
Pseudophryne major	Great brown broodfrog		LC		X	
Uperoleia laevigata	Eastern toadlet		LC	X		
Uperoleia rugosa	Chubby toadlet		LC	X	X	
Uperoleia sp.			LC	X	X	
Limnodynastes fletcheri	Barking marsh frog		LC		X	
Limnodynastes salmini	Salmon-striped frog		LC		X	
Limnodynastes tasmaniensis	Spotted marsh frog		LC	X	X	
Limnodynastes terraereginae	Scarlet-sided pobblebonk		LC	X	X	
Neobatrachus sudellae	Meeowing frog		LC	X	X	
Notaden bennettii	Holy cross frog		LC		X	
Platyplectrum ornatum	Ornate burrowing frog		LC	X	X	
Cyclorana alboguttata	Greenstripe frog		LC	X	X	
Cyclorana brevipes	Superb collared frog		LC		X	
Cyclorana novaehollandiae	Eastern snapping frog		LC	X	X	
Litoria caerulea	Green tree frog		LC	X	X	
Litoria fallax	Eastern sedge frog		LC	X	X	
Litoria latopalmata	Broad-palmed rocketfrog		LC	X	X	
Litoria peronii	Emerald-spotted treefrog		LC	X	X	
Litoria rubella	Ruddy treefrog		LC	X	X	
Rhinella marina	Cane toad		I	X	X	
Amphibian Total	20			16	20	0
REPTILE						
Underwoodisaurus milii	Thick-tailed gecko		LC	X	X	
Amalosia sp. cf. jacovae			LC		X	
Amalosia sp. cf. rhombifer			LC		X	
Diplodactylus vittatus	Eastern stone gecko		LC	X	X	
Lucasium steindachneri	Box-pattern gecko		LC	X	X	
Nebulifera robusta	Robust velvet gecko		LC	X	X	
Oedura tryoni	Southern spotted velvet gecko		LC		X	
Strophurus taenicauda	Golden-tailed gecko		**NT**	X	X	
Gehyra dubia	Dubious dtella		LC	X	X	X
Heteronotia binoei	Bynoe's gecko		LC	X	X	X
Delma plebeia	Common delma		LC		X	
Lialis burtoni	Burton's legless lizard		LC		X	
Pygopus schraderi	Eastern hooded scaly-foot		LC		X	
Anomalopus leuckartii	Two-clawed Worm-skink		LC		X	
Carlia munda	Striped rainbow skink		LC		X	
Carlia pectoralis	Open-litter rainbow skink		LC	X		

GROUP			**Status**		**SGP Region**		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
	Carlia rubigo	Orange-flanked rainbow skink		LC	X	X	X
	Carlia sp.	Rainbow skink		LC	X	X	
	Carlia vivax	Tussock rainbow-skink		LC	X		
	Cryptoblepharus pulcher	Elegant snake-eyed skink		LC	X	X	X
	Cryptoblepharus sp.			LC	X	X	
	Ctenotus allotropis	Brown-blazed wedgesnout ctenotus		LC	X	X	
	Ctenotus spaldingi	Straight-browed ctenotus		LC	X	X	
	Cyclodomorphus gerrardii	Pink-tongue lizard		LC	X		
	Egernia striolata	Tree skink		LC	X		
	Lerista fragilis	Eastern mulch-slider		LC	X	X	X
	Lerista punctatovittata	Eastern robust slider		LC	X	X	
	Lerista timida	Timid slider		LC	X	X	
	Lygisaurus foliorum	Tree-base litter-skink		LC	X	X	
	Menetia greyii	Common dwarf skink		LC	X	X	
	Menetia sp.			LC	X		
	Morethia boulengeri	South-eastern morethia skink		LC	X	X	X
	Pygmaeascincus timlowi	Dwarf litter-skink		LC	X	X	
	Tiliqua rugosa	Shingleback		LC	X		
	Tiliqua scincoides	Eastern blue-tongue lizard		LC	X		
	Amphibolurus burnsi	Burns' dragon		LC	X		
	Amphibolurus sp.			LC	X		
	Diporiphora australis	Tommy round-head dragon		LC		X	
	Intellagama lesueurii	Eastern water dragon		LC	X	X	
	Pogona barbata	Eastern bearded dragon		LC	X	X	
	Varanus gouldii	Sand monitor		LC	X	X	
	Varanus panoptes	Yellow-spotted monitor		LC	X	X	
	Varanus tristis	Black-headed monitor		LC		X	
	Varanus varius	Lace monitor		LC	X	X	
	Morelia spilota	Carpet python		LC			
	Boiga irregularis	Brown tree snake		LC		X	
	Dendrelaphis punctulata	Common tree snake		LC	X		
	Tropidonophis mairii	Keelback		LC		X	
	Brachyurophis australis	Coral snake		LC		X	
	Cryptophis nigrescens	Eastern small-eyed snake		LC		X	
	Demansia psammophis	Yellow-faced whipsnake		LC	X	X	
	Furina diadema	Red-naped snake		LC	X	X	
	Hemiaspis damelii	Grey snake		**End**	X		
	Hoplocephalus bitorquatus	Pale-headed snake		LC	X	X	
	Parasuta dwyeri	Dwyer's snake		LC	X		
	Pseudechis porphyriacus	Red-bellied black snake		LC	X	X	
	Pseudonaja textilis	Eastern brown snake		LC		X	
	Vermicella annulata	Bandy Bandy		LC	X		
Reptile Total		55			44	44	6

GROUP			**Status**		**SGP Region**		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
BIRD							
	Dromaius novaehollandiae	Emu		LC	X	X	
	Cygnus atratus	Black Swan		LC	X		
	Chenonetta jubata	Australian wood duck		LC	X		X
	Nettapus coromandelianus	Cotton pygmy-goose		LC		X	
	Anas gracilis	Grey teal		LC	X	X	
	Anas superciliosa	Pacific black duck		LC	X	X	X
	Tachybaptus novaehollandiae	Australasian grebe		LC	X	X	
	Columba livia	Rock dove		I			
	Phaps chalcoptera	Common bronzewing		LC	X	X	
	Ocyphaps lophotes	Crested pigeon		LC	X	X	X
	Geopelia striata	Peaceful dove		LC	X	X	
	Geopelia humeralis	Bar-shouldered dove		LC	X	X	
	Podargus strigoides	Tawny frogmouth		LC	X	X	
	Eurostopodus mystacalis	White-throated nightjar		LC	X	X	
	Eurostopodus argus	Spotted nightjar		LC	X	X	
	Aegotheles cristatus	Australian owlet-nightjar		LC	X	X	X
	Hirundapus caudacutus	White-throated needletail	**M**	LC	X	X	
	Apus pacificus	Fork-tailed swift	**M**	LC		X	
	Elanus axillaris	Black shouldered kite		LC	X		
	Microcarbo melanoleucos	Little pied cormorant		LC	X	X	
	Phalacrocorax sulcirostris	Little black cormorant		LC	X		
	Pelecanus conspicillatus	Australian pelican		LC	X		
	Ardea pacifica	White-necked heron		LC	X		
	Egretta novaehollandiae	White-faced heron		LC	X	X	
	Nycticorax caledonicus	Nankeen Night-Heron		LC	X	X	
	Threskiornis molucca	Australian white ibis		LC		X	
	Threskiornis spinicollis	Straw-necked Ibis		LC	X		
	Aviceda subcristata	Pacific baza		LC			
	Haliaeetus leucogaster	White-bellied sea-eagle		LC	X		
	Haliastur sphenurus	Whistling kite		LC	X		
	Accipiter fasciatus	Brown goshawk		LC	X		X
	Accipiter cirrocephalus	Collared sparrowhawk		LC		X	
	Circus approximans	Swamp harrier		LC	X		
	Aquila audax	Wedge-tailed eagle		LC	X		
	Falco cenchroides	Nankeen kestrel		LC	X		
	Falco berigora	Brown falcon		LC	X	X	X
	Falco longipennis	Australian Hobby		LC		X	
	Gallirallus philippensis	Buff-banded Rail		LC		X	
	Gallinula tenebrosa	Dusky moorhen		LC		X	
	Fulica atra	Eurasian coot		LC		X	
	Ardeotis australis	Australian bustard		LC			
	Burhinus grallarius	Bush stone-curlew		LC		X	
	Vanellus miles	Masked lapwing		LC	X		

GROUP			**Status**		**SGP Region**		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
	Dendrocygna arcuata	Wandering whistling duck		LC			
	Turnix varius	Painted button-quail		LC	X	X	
	Calyptorhynchus banksii	Red-tailed Black-cockatoo		LC			
	Calyptorhynchus lathami	Glossy black-cockatoo		**Vul**	X	X	
	Calyptorhynchus funereus	Yellow-tailed Black-cockatoo		LC			
	Eolophus roseicapillus	Galah		LC	X	X	X
	Cacatua sanguinea	Little corella		LC	X		
	Cacatua galerita	Sulphur-crested cockatoo		LC	X	X	X
	Nymphicus hollandicus	Cockatiel		LC	X		
	Trichoglossus haematodus	Rainbow lorikeet		LC	X	X	
	Trichoglossus chlorolepidotus	Scaly-breasted lorikeet		LC	X	X	
	Daphoenositta chrysoptera	Varied sitella		LC	X	X	
	Glossopsitta pusilla	Little lorikeet		LC	X	X	
	Alisterus scapularis	Australian king-parrot		LC	X	X	
	Aprosmictus erythropterus	Red-winged parrot		LC	X	X	X
	Platycercus adscitus	Pale-headed rosella		LC	X	X	X
	Psephotus haematonotus	Red-rumped parrot		LC	X		
	Centropus phasianinus	Pheasant coucal		LC	X	X	
	Eudynamys orientalis	Eastern koel		LC		X	
	Scythrops novaehollandiae	Channel-billed cuckoo		LC		X	
	Chalcites basalis	Horsfield's bronze-cuckoo		LC	X	X	
	Chalcites osculans	Black-eared cuckoo		LC		X	
	Chalcites lucidus	Shining bronze-cuckoo		LC	X	X	
	Chalcites minutillus	Little bronze-cuckoo		LC		X	
	Cacomantis flabelliformis	Fan-tailed cuckoo		LC		X	
	Cacomantis variolosus	Brush cuckoo		LC	X	X	
	Cacomantis pallidus	Pallid cuckoo		LC	X	X	
	Tyto delicatula	Eastern barn owl		LC		X	
	Ninox boobook	Southern boobook		LC	X	X	
	Ceyx azureus	Azure kingfisher		LC		X	
	Dacelo novaeguineae	Laughing kookaburra		LC	X	X	X
	Todiramphus pyrrhopygius	Red-backed Kingfisher		LC	X		
	Todiramphus sanctus	Sacred kingfisher		LC	X	X	
	Merops ornatus	Rainbow bee-eater		LC	X	X	
	Eurystomus orientalis	Dollarbird		LC	X	X	
	Cormobates leucophaea	White-throated treecreeper		LC	X	X	
	Climacteris picumnus	Brown treecreeper		LC	X		
	Malurus cyaneus	Superb fairy-wren		LC	X	X	X
	Malurus melanocephalus	Red-backed fairy-wren		LC		X	X
	Malurus lamberti	Variegated fairy-wren		LC	X	X	X
	Chthonicola sagittata	Speckled warbler		LC	X	X	
	Smicrornis brevirostris	Weebill		LC	X	X	X
	Gerygone fusca	Western gerygone		LC			
	Gerygone olivacea	White-throated gerygone		LC	X	X	X

GROUP			**Status**		**SGP Region**		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
	Acanthiza nana	Yellow thornbill		LC	X	X	X
	Acanthiza chrysorrhoa	Yellow-rumped thornbill		LC		X	X
	Acanthiza uropygialis	Chestnut-rumped Thornbill		LC			X
	Acanthiza reguloides	Buff-rumped thornbill		LC	X	X	
	Acanthiza apicalis	Inland thornbill		LC	X	X	X
	Acanthiza pusilla	Brown thornbill		LC	X	X	
	Pardalotus punctatus	Spotted pardalote		LC	X	X	
	Pardalotus striatus	Striated pardalote		LC	X	X	X
	Lichenostomus chrysops	Yellow-faced honeyeater		LC	X	X	X
	Gavicalis virescens	Singing honeyeater		LC		X	
	Lichenostomus leucotis	White-eared honeyeater		LC	X	X	
	Lichenostomus melanops	Yellow-tufted honeyeater		LC	X		
	Ptilotula fusca	Fuscous honeyeater		LC	X	X	
	Lichenostomus penicillatus	White-plumed honeyeater		LC	X	X	
	Manorina melanocephala	Noisy miner		LC	X	X	X
	Manorina flavigula	Yellow-throated miner		LC	X	X	
	Acanthagenys rufogularis	Spiny-cheeked honeyeater		LC	X	X	X
	Myzomela sanguinolenta	Scarlet honeyeater		LC	X	X	
	Lichmera indistincta	Brown honeyeater		LC	X	X	X
	Melithreptus gularis	Black-chinned honeyeater		LC	X	X	
	Melithreptus brevirostris	Brown-headed Honeyeater		LC	X	X	
	Melithreptus albogularis	White-throated honeyeater		LC	X		
	Melithreptus lunatus	White-naped Honeyeater		LC		X	
	Entomyzon cyanotis	Blue-faced honeyeater		LC	X	X	
	Philemon corniculatus	Noisy friarbird		LC	X	X	
	Philemon citreogularis	Little friarbird		LC	X	X	
	Plectorhyncha lanceolata	Striped honeyeater		LC	X	X	X
	Pomatostomus temporalis	Grey-crowned babbler		LC	X	X	X
	Coracina novaehollandiae	Black-faced cuckoo-shrike		LC	X	X	
	Coracina papuensis	White-bellied cuckoo-shrike		LC	X	X	
	Coracina tenuirostris	Cicadabird		LC	X	X	
	Lalage tricolor	White-winged triller		LC	X	X	
	Pachycephala pectoralis	Golden whistler		LC	X	X	
	Pachycephala rufiventris	Rufous whistler		LC	X	X	X
	Colluricincla harmonica	Grey shrike-thrush		LC	X	X	
	Oriolus sagittatus	Olive-backed oriole		LC	X	X	X
	Artamus leucorynchus	White-breasted woodswallow		LC	X	X	
	Artamus superciliosus	White-browed woodswallow		LC	X	X	
	Artamus cyanopterus	Dusky woodswallow		LC	X	X	
	Artamus minor	Little woodswallow		LC	X		
	Cracticus torquatus	Grey butcherbird		LC	X	X	X
	Cracticus nigrogularis	Pied butcherbird		LC	X	X	
	Cracticus tibicen	Australian magpie		LC	X	X	X
	Strepera graculina	Pied currawong		LC	X	X	

GROUP			Status		SGP Region		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
	Dicrurus bracteatus	Spangled Drongo		LC	X		
	Rhipidura rufifrons	Rufous fantail	**M**	LC	X		
	Rhipidura albiscapa	Grey fantail		LC	X	X	
	Rhipidura leucophrys	Willie wagtail		LC	X	X	X
	Corvus coronoides	Australian raven		LC	X	X	X
	Corvus orru	Torresian crow		LC	X	X	
	Myiagra rubecula	Leaden flycatcher		LC	X	X	
	Myiagra inquieta	Restless flycatcher		LC	X	X	
	Grallina cyanoleuca	Magpie-lark		LC	X	X	X
	Corcorax melanorhamphos	White-winged chough		LC	X	X	
	Struthidea cinerea	Apostlebird		LC	X	X	X
	Microeca fascinans	Jacky winter		LC	X	X	
	Petroica goodenovii	Red-capped robin		LC	X	X	
	Eopsaltria australis	Eastern yellow robin		LC	X	X	
	Zosterops lateralis	Silvereye		LC	X		
	Hirundo neoxena	Welcome Swallow		LC	X		
	Petrochelidon nigricans	Tree martin		LC	X	X	
	Dicaeum hirundinaceum	Mistletoebird		LC	X	X	X
	Taeniopygia bichenovii	Double-barred finch		LC	X	X	X
	Anthus novaeseelandiae	Australian pipit		LC			X
	Sturnus tristis	Common myna		I	X		
Bird Total		151			122	116	38
MAMMAL							
	Tachyglossus aculeatus	Short-beaked echidna		LC	X	X	X
	Antechinus flavipes	Yellow-footed Antechinus		LC	X		
	Planigale maculata	Common planigale		LC	X	X	
	Sminthopsis murina	Common dunnart		LC	X	X	
	Phascolarctos cinereus	Koala	**Vul**	**Vul**	X	X	
	Trichosurus vulpecula	Common brushtail possum		LC	X	X	
	Petaurus breviceps	Sugar glider		LC	X	X	
	Petaurus norfolcensis	Squirrel glider		LC	X	X	
	Petauroides volans	Greater glider	**Vul**	**Vul**	X	X	
	Acrobates frontalis	Broad-toed Feathertail glider		LC		X	
	Aepyprymnus rufescens	Rufous bettong		LC		X	
	Macropus dorsalis	Black-striped wallaby		LC	X	X	
	Macropus giganteus	Eastern grey kangaroo		LC	X	X	
	Macropus robustus	Wallaroo		LC	X		
	Macropus rufogriseus	Red-necked wallaby		LC	X	X	X
	Wallabia bicolor	Swamp wallaby		LC	X	X	
	Saccolaimus flaviventris	Yellow-bellied sheathtail bat		LC	X	X	
	Austronomus australis	White-striped freetail bat		LC	X	X	
	Mormopterus lumsdenae	Northern free-tailed bat		LC	X	X	
	Mormopterus ridei	Ride's free-tailed bat		LC	X	X	

GROUP			**Status**		**SGP Region**		
	Scientific Name	**Common Name**	**EPBC**	**NCA**	**Sth**	**Cnt**	**Nth**
	Mormopterus petersi	Inland free-tailed bat		LC	X	X	
	Mormopterus sp.			LC	X		
	Chalinolobus gouldii	Gould's wattled bat		LC	X	X	
	Chalinolobus picatus	Little pied bat		LC	X	X	
	Nyctophilus geoffroyi	Lesser long-eared bat		LC	X		
	Nyctophilus gouldi	Gould's long-eared bat		LC	X	X	
	Nyctophilus corbeni	South-eastern long-eared bat	**Vul**	**Vul**	X	X	
	Nyctophilus sp.				X	X	
	Scotorepens balstoni	Inland broad-nosed bat		LC	X	X	
	Scotorepens greyii	Little Broad-nosed bat		LC	X	X	
	Vespadelus baverstocki			LC	X	X	
	Vespadelus troughtoni	Eastern cave bat		LC		X	
	Vespadelus vulturnus	Little forest bat		LC	X	X	
	Pseudomys delicatulus	Delicate Mouse		LC		X	
	Rattus tunneyi	Pale field rat		LC	X		
	Mus musculus	House mouse		I		X	
	Canis lupus	Dingo/dog		I	X	X	
	Felis catus	Feral cat		I	X	X	
	Lepus capensis	Brown hare		I	X	X	
	Oryctolagus cuniculus	European rabbit		I	X	X	
	Sus scrofa	Feral pig		I	X	X	
	Vulpes vulpes	Red fox		I	X		
		Unidentified deer species		I	X		
Mammal Total		40			38	35	2
Grand Total		**266**			**220**	**215**	**46**

Appendix G.

Present, Likely or Possible Threatened Fauna Species Profiles and Mapping Criteria Mapping Criteria

BUTTERFLIES

Pale Imperial Hairstreak (*Jalmenus eubulus*)

Status

Vulnerable (NC Act)

Distribution and Habitat

Jalmenus eubulus is restricted to the eastern Brigalow Belt Bioregion. The northern limit of its distribution appears to be around the latitude of Mackay and ranges south to around Boggabilla in northern NSW. The eastern limit of its distribution is roughly designated by the Great Dividing Range, being found near Kroombit Tops, Binjour Plateau, Bunya Mountains and Jondaryan (Eastwood et al. 2008). It may be found as far west as Carnarvon (Sands and New 2002).

The species is restricted to Brigalow (*Acacia harpophylla*)-dominated woodlands and open-forests. Its core habitat is old-growth Brigalow, particularly those areas with Belah (*Casuarina cristata*), emergent eucalypts such as *Eucalyptus populnea* and understorey shrubs and adults are always observed in association with old-growth (remnant) *A. harpophylla* communities (Breitfuss and Hill 2003; Eastwood et al. 2008). Being highly mobile, isolated patches may also provide suitable habitat.

Ecology

Jalmenus eubulus feeds exclusively on Brigalow (*A. harpophylla*) shrubs ranging in height from 0.5 to 5m and (Braby 2000; Breitfuss and Hill 2003; Eastwood et al. 2008). The species has also been documented as feeding on other *Acacia* species (Sands and New 2002), but this has been discarded as erroneous in recent reviews (Eastwood et al. 2008).

It is likely that eggs enter diapause shortly after being laid. Emergence is triggered by summer rainfall, which may fall irregularly throughout the species' range, resulting in apparent different activity patterns between populations and years. Adults have been recorded between October and April, with peak activity in February and March. Peak activity appears to occur approximately two months after the wettest months of the year (December and January) (Eastwood et al. 2008).

Larvae feed singly, or occasionally in small groups of up to three individuals (Braby 2000). As in many lycaenid butterflies, the larvae are always attended by ants of the *Iridomyrmex* group, on which they are likely to be reliant for survival (Braby 2000; Sands and New 2002; Eastwood et al. 2008).

Known Threats to the Species

This species is threatened by clearing of suitably sized stands of old-growth Brigalow woodland (Sands and New 2000).

Records Relevant to the SGP

Three records are located within the SGP, the most recent is nearly 20 years old. An additional five records are within 10km of the SGP boundary. The species requires targeted surveys by experts experienced in butterfly identification. The lack of records is likely to reflect low survey effort as the species is expected to be more widespread and abundant than indicated in databases.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire SGP area.
2. Within the SGP, all areas of remnant Brigalow (11.3.1, 11.3.17, 11.4.3 11.4.3a, 11.9.5) are classed as "Core Habitat Possible".
3. All "Core Habitat Possible" within 2km of a recent (1980+), accurate (± 500m) record is reclassified as "Core Habitat Known".
4. The remaining Regional Ecosystems and non-remnant areas are classed as "Absence Suspected".

Specific Map Modifications

None.

Mapping Confidence

The life-cycle and habitat requirements for the Pale Imperial Hairstreak is well documented and understood. Correlation between important habitat characteristics and Regional Ecosystem descriptions is high. The habitat mapping for this species is expected to be highly accurate.

REPTILES

Golden-tailed Gecko (*Strophurus taenicauda*)

Status

Near Threatened (NC Act)

Distribution and Habitat

Golden-tailed geckoes are distributed from the western slopes of the Great Dividing Range to Carnarvon, and from Emerald in the north to Inglewood/Millmerran in the south. Areas within and surrounding Barakula State Forest may represent a stronghold for this species (Richardson 2006).

This species is a Brigalow Belt endemic. They are found in a wide variety of woodland and forest habitats, mainly in association with brigalow (*Acacia harpophylla*), cypress (*Callitris* spp.) and ironbark (*Eucalyptus* spp.). They can also be common in areas with a shrubby understorey (particularly *Acacia* spp. and *Callitris* spp, including regrowth). Ground cover, tree hollows and loose or peeling bark on standing trees and tree stumps may be important shelter sites for this species (Richardson 2006).

Ecology

During the daytime, golden-tailed geckos shelter under loose bark and in tree hollows (Wilson 2015). They may also bask during the daytime. In Spring/Summer, females lay a clutch of two eggs. Females may lay more than one clutch in a season.

Movement patterns of the species have not been documented. However, individuals have been recorded crossing dual lane roads during warm summer nights.

Known Threats to the Species

Habitat loss and degradation including inappropriate roadside management, inappropriate fire regimes, clearing and thinning of vegetation for agriculture appear to be the species main threats (Richardson 2006). Deaths on roads and predation from introduced carnivores (e.g., foxes and cats) may also affect populations.

Records Relevant to the SGP

The Golden-tailed Gecko have been frequently recorded during these surveys as well during previous ecological works. It is currently known from 82 observations within the SGP, but is likely to be much more widely distributed than indicated by these records. It has been recorded in both the central and southern regions of the SGP, but not the northern region where possible habitat is fragmented and minor in extent. The species has also been regularly recorded in the surrounding area.

General Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire SGP area.
2. Within the SGP, RE's 11.3.1, 11.3.14, 11.3.17, 11.3.18, 11.4.3 11.4.3a, 11.5.1, 11.5.1a, 11.5.4, 11.5.4a, 11.5.20, 11.5.21, 11.7.2, 11.7.4, 11.7.6, 11.7.7, 11.9.2, 11.9.5 are mapped as "Core Habitat Possible".

3. Within the SGP, RE's 11.3.2, 11.3.4, 11.3.26, 11.7.5, 11.7.5b, and 11.7.5x are mapped as "General Habitat".
4. All areas of advanced regrowth (10+) should be treated as remnant vegetation and classed according to the above rules.
5. Core Habitat Possible and General Habitat within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
6. Habitat patches <5ha and not adjacent or near other remnant vegetation (i.e., isolated) are reclassed as "Absence Suspected".
7. "Core Habitat Possible" or "General Habitat" between 5ha and 10ha in size and not adjacent or near other remnant vegetation (i.e., isolated) are reclassed as "General Habitat" and "Absence Suspected" respectively.
8. Remaining regrowth and RE's are classed as "Absence Suspected".
9. Cleared agricultural, grazing land and palustrine and lacustrine wetlands (RE 11.3.3c, 11.3.27c) is classed as "Absence Likely".

Specific Map Modifications

Habitats in the northern section of the SGP (Wondoan) are open and heavily impacted by grazing activities. They generally lack a shrubby understory preferred by this species. All habitats classed as "Core Habitat Possible" or "General Habitat" using the above rules in the northern (Wondoan) section have been reclassified as "Absence Suspected".

Inspections along Wilkie Creek and the Condamine River suggest the bulk of vegetation in this alluvial system lack a suitable shrubby understorey and have been classed as "Absence Suspected".

A small number of small fragments which are unlikely to be valuable for the species based on their landscape position have been manually removed from the mapping product or dropped to a lower mapping category (i.e., Core Habitat Possible to General Habitat).

Mapping Confidence

Golden-tailed Geckos appear to be unevenly distributed throughout suitable habitat. However, they can also inhabit regrowth or cleared habitats with abundant shrubs. As such, the mapped habitat area is likely to have a moderate accuracy.

Common Death Adder (*Acanthophis antarcticus*)

Status

Vulnerable (NC Act)

Distribution and Habitat

This species is widespread throughout Queensland, with the exception of Cape York Peninsula and the Mulga Lands in the south-west (Wilson 2015). Once abundant in the Brigalow Belt, it is now rarely observed and in the southern Brigalow belt the species seems to be particularly aligned with large contiguous tracts of vegetation (e.g. state forests around Inglewood and Southwood National Park may represent strongholds) which maintains a healthy ground strata (and in particular ground debris) (EPA 2008).

It is found in a wide variety of habitats, including rainforest, open woodland, shrubland and heath (Ehmann 1992; Wilson and Swan 2013).

Ecology

The Common Death Adder is a slow-moving, sedentary snake that lies motionless while partially buried in leaf litter, vegetation or soil. Breeding takes place in spring and autumn (Ehmann 1992).

Diet consists of lizards and small mammals, and to a lesser extent, birds and frogs. However, diet changes with age, young animals consuming more reptiles and frogs, whilst adults feed predominantly on small mammals and birds (Shine 1980).

Known Threats to the Species

Threats to this species are poorly known. Land clearing and fragmentation are likely to have extensively affected the occurrence of this species in the Brigalow Belt. Alteration to microhabitats is also likely to detrimentally affected ambush snakes such as death adders, as they require ground cover to ambush their prey. Grazing, agriculture, urbanisation and inappropriate fire regimes modify ground cover considerably, reducing potential ambush sites (Ehmann 1992; Reed and Shine 2002, EPA 2008). Similar patterns of decline have been seen in other ambush snake species (Shine 1994). The species is also at risk from Cane Toad ingestion in areas where toad abundance is high.

Records Relevant to the SGP

Two records of the species are located within 5km of the SGP boundary, including one from 2015. It is possible the species is present within the SGP although this species is very cryptic and difficult to detect, even during suitable conditions.

General Rule(s) for Habitat Mapping:

1. The species could occur throughout the entire EIS area.
2. Vegetation with a combined extent >5,000ha should be classed as "Core Habitat Possible".
3. Core Habitat Possible within 1km of a recent (1980+), accurate (±500m) record is classed as "Core Habitat Known".
4. Vegetation not connected to larger patches, but within close proximity (<500m) can be classed as "General Habitat".
5. Regrowth and cleared areas are mapped as "Absence Suspected".
6. Cleared farmland or tilled crops are classed "Absence Likely".

Specific Map Modifications

Areas along the Kogan-Condamine Rd (in the north-west corner of the southern region) include suitable habitat types (e.g., brigalow communities) but are limited in extent reducing their value for the species. However, this vegetation connects larger remnant patches in the west (just outside the SGP) and has been mapped as "General Habitat".

A number of small linear patches, which are mapped as "Core Habitat Possible" or "General Habitat" using the above guidelines were removed.

Mapping Confidence

Habitat use by Death Adders is difficult to predict; they may occur in any remnant habitat, yet are absent from seemingly good habitats within their range. This may reflect historic land use or events that have affected ground structure. Historical fires, for example, may have reduced ground cover and resulted in local extinctions. Following fire, recolonisation may only occur if remaining patches are large or well connected to nearby populations. Due to these difficulties, the habitat map for this species is considered to have a low accuracy.

Dunmall's Snake (*Furina dunmalli*)

Status

Vulnerable (NC Act); Vulnerable (EPBC Act Act)

Distribution and Habitat

Dunmall's snake (*Furina dunmalli*) is confined to the Brigalow Belt bioregion of south-eastern Queensland and north-eastern New South Wales, occurring north to Clermont and near Rockhampton. Most records are from the Dalby-Tara area of the Darling Downs (Hobson 2012a).

The species has been found in a wide range of habitats, including forests and woodlands dominated by brigalow (*Acacia harpophylla*) and other acacias (*A. burowii*, *A. deanii*, *A. leiocalyx*), cypress (*Callitris* spp.) or bulloak (*Allocasuarina luehmannii*) on black alluvial cracking clay and clay loams (Covacevich *et al*. 1988; Stephenson and Schmida 2008; Brigalow Belt Reptiles Workshop 2010; Hobson 2012a). It also occurs in spotted gum (*Corymbia citriodora*) and ironbark (*Eucalyptus crebra* and *E. melanophloia*) on sandstone-derived soils and there is a record from the edge of dry vine scrub (Stephenson and Schmida 2008; Brigalow Belt Reptiles Workshop 2010). However, preferred habitat appears to be brigalow growing on cracking black clay and clay loams (Cogger et al. 1993), with the majority of records from between 200 to 500 m elevation (Hobson 2012a). The species can, on rare occasions, inexplicably appear in in sub-optimal vegetation. Advanced regrowth habitat should not be excluded, particularly when adjacent or linking areas of suitable habitat. It is unlikely to occur in highly fragmented vegetation, particularly narrow linear strips.

Ecology

Dunmall's snake is a nocturnal, cryptic, secretive species that is possibly genuinely scarce and very rarely encountered (Wilson 2015; Hobson 2012a). The species has been found sheltering under fallen timber and ground litter (Cogger et al. 1993; Brigalow Belt Reptiles Workshop 2010) and may use cracks in alluvial clay soils (Ehmann 1992). Little is known of its ecology, but it reportedly preys on lizards and geckoes (Gow and Swanson 1977; Shine

1981). Nothing is known of its breeding biology other than that it lays eggs (Wilson and Swan 2013).

Known Threats to the Species

Due to the paucity of records and secretive nature of Dunmall's snake, it is not known if the species has declined, although records suggest a decline in eastern parts of its range. Its distribution, however, is confined to the Brigalow Belt bioregion, an area that has been highly modified for agriculture, the timber industry, natural gas and coal extraction, and urban development. Much of its habitat has been cleared or fragmented, particularly in its core area on the Darling Downs (Hobson 2012a). The main threats to the local populations of Dunmall's snake are thought to be:

- Predation by feral animals,
- Pasture improvement practices,
- Livestock grazing,
- Inappropriate roadside management, because much of its core habitat now only exists as linear fragments along roads and in stock routes (Richardson 2006; Hobson 2012a), and
- Increased mortality from vehicle strike.

Other possible threats include loss of fallen timber and ground litter (e.g., fuel reduction burns, firewood collection), weed invasion and drainage of swamps (DoE 2017a).

Records Relevant to the SGP

Two old records (i.e. >20 years) exist in the southern portion of the SGP. An additional two records are located within 8km of the SGP, most recent from 2000. The species is cryptic and difficult to detect, even during suitable conditions.

Rule(s) for Habitat Mapping:

1. The species could occur throughout the entire EIS area.
2. All remnant vegetation >50ha in extent and within 500m of a larger vegetation patch of RE 11.3.1, 11.3.14, 11.3.17, 11.3.18, 11.4.3, 11.4.3a, 11.5.1, 11.5.1a, 11.5.4, 11.5.20, 11.5.21, 11.7.2, 11.7.4, 11.7.6, and 11.7.7 should be classed as "Core Habitat Possible".
3. Smaller vegetation patches of the above RE's may be mapped as "General Habitat" if they are in close proximity to large areas of "Core Habitat Possible".
4. Core Habitat Possible within 1km of a recent (1980+), accurate (±500m) record is classed as "Core Habitat Known".
5. Advanced regrowth of all the above RE's are mapped as "General Habitat" if they are adjacent to or connect large areas of "Core Habitat Possible" or "General Habitat".
6. Remaining regrowth is mapped as "Absence Suspected".

Specific Map Modifications

A number of narrow linear fragments (particularly Brigalow communities) were removed based on their limited extent and surrounding land use (high intensity farming practices).

Mapping Confidence

This species is very poorly understood and records are scarce. Predicting its occurrence is extremely difficult and the mapping is likely to have low accuracy.

Grey Snake (*Hemiaspis damelii*)

Status

Endangered (NC Act)

Distribution and Habitat

Grey snakes occur throughout the Brigalow Belt, from coastal districts near Rockhampton, south-east to the Lockyer Valley in South East Queensland (Wilson 2015).

Grey snakes inhabit dry eucalypt forest and pasture (Covacevich and Wilson 1995), favouring cracking, flood-prone soils along floodplains and near watercourses within the Brigalow Belt (Hobson 2002; Wilson 2015).

Ecology

Grey Snakes are nocturnal frog specialists (Wilson and Swan 2013), sheltering during the day under fallen logs, within soil cracks and down in animal burrows. They are known to give birth to up to 10 live young (Covacevich and Wilson 1995), but little else is known of their breeding biology.

Known Threats to the Species

This species is threatened by habitat loss, habitat degradation and fragmentation. Existing habitats and populations are under threat from agriculture and urban development (Eyre et al. 1997), as well as mining activities and the loss of waterways or wetlands. In addition, ingestion of cane toads and subsequent death from poisoning pose a threat to the species.

Records Relevant to the SGP

The Grey Snake was recorded during these surveys as well during previous ecological works. It is currently known from 16 observations within the SGP and has been recorded in both the central and southern regions of the SGP, but not the northern region where the habitat is fragmented and minor in extent.

Rule(s) for Habitat Mapping:

1. The species could occur throughout the entire EIS area.
2. All remnant vegetation where surface water could collect provides potential habitat for these species. In particular, vegetation on Landzones 3, and 4 should be classed as "Core Habitat Possible". In addition, the following RE's have clay soils, gilgai's or are likely to be subject to temporal ponding and should also be "Core Habitat Possible"; 11.9.5.
3. Derived Grasslands, which occur in alluvial floodplains in the SGP, are mapped as "Core Habitat Possible".

4. Larger contiguous areas of RE's 11.5.1, 11.5.1a, 11.5.20, and 11.5.21, or where these are immediately adjacent Core Habitat Possible, are included as "General Habitat".
5. Artificial waterbodies are mapped as "General Habitat".
6. All remnant vegetation, non-remnant vegetation, regrowth or cleared land within 1km of a recent (1980+), accurate (±500m) record is classed as "Core Habitat Known".
7. Regrowth be classed according to its parent regional ecosystem.
8. Cleared farmland or tilled crops are mapped as "Absence Suspected".

Specific Map Modifications

Field investigations in the northern area (Wondoan) showed riparian habitats in this area were highly fragmented and heavily impacted from cattle grazing leading to loss of soil structure (ie., reduced soil cracks etc). Habitats in this area have been reduced to "General Habitat" in recognition of their reduced value.

Some unsuitable farm dams were removed.

Mapping Confidence

This species may occur in a number of habitats, including artificial grazing land. Predicting its occurrence is therefore difficult based on RE mapping. The habitat map for this species is moderately accurate.

BIRDS

Glossy Black-Cockatoo (*Calyptorhynchus lathami*)

Status

Vulnerable (NC Act)

Distribution and Habitat

Glossy Black-Cockatoos (*Calyptorhynchus lathami*) have a patchy distribution along the east coast and ranges south from near the Paluma Range to Gippsland in Victoria. An isolated population is located on Kangaroo Island in South Australia. They are uncommon and declining, especially in the south-western parts of its range, and are now extinct in mainland South Australia (Garnett *et al.* 2011). There has been concern for the status of Glossy Black-Cockatoos in the Southern Downs due to the loss of feeding and nesting resources (EPA 2003).

Birds inhabit woodlands and forests that contain abundant *Allocasuarina* spp. and abundant large hollows suitable for nesting. Many populations are restricted to remnant vegetation within hills and gullies surrounded by agricultural land (Higgins 1999); however, some populations move through artificial landscapes such as semi-urban parks, gardens and golf courses to access favoured food resources (Higgins 1999, M. Sanders pers. obs.). Groups are never far from waterbodies, which are visited daily. Being highly mobile, birds may travel considerable distances to isolated fragments in search of food. Advanced regrowth may also provide some foraging opportunity.

Ecology

Typically encountered in small family parties, Glossy Black-Cockatoos are dietary specialists, feeding exclusively on the seeds of *Allocasuarina* and *Casuarina* spp. Favoured species include *A. torulosa*, *A. littoralis*, *A. luehmannii*, *A. distyla*, *A. diminuta*, *A. gymnanthera* and *A. verticillata* (Chapman 2007). It is poorly documented, but Glossy Black-Cockatoos also feed on *A. inophloia* in and around the Kumbarilla to Inglewood area (M. Sanders pers. obs.).

Observations of the species feeding on other resources (e.g., *Callitris* and *Banksia* spp.) are likely to represent food switching during periods of poor *Allocasuarina* cone production (Chapman 2007). It is unclear if the use of *A. inophloia* by local populations reflect food switching, or if local populations rely on stands of *A. inophloia*. However, given the abundance of orts (feeding signs) in some locations, and their repeated observation over consecutive years, the latter seems plausible.

Birds show a preference for productive trees (e.g., higher seed/cone weight ratio), notwithstanding the influence of other factors such as distance from water or breeding hollows (Clout 1989; Pepper et al. 2000; Crowley and Garnett 2001; Cameron and Cunningham 2006; Chapman and Paton 2006; Chapman 2007). Stands of *Allocasuarina* spp. are therefore not of uniform value, and the loss of individual stands or trees may have disproportionate impacts.

The production of cones by *Allocasuarina* spp. closely tracks rainfall (Cameron 2006a), and hence the availability of resources for resident Glossy Black-Cockatoos fluctuate between years. While resources may be sufficient to support existing birds, drought is likely to reduce breeding success (Cameron 2009).

Pairs breed during winter, mainly from April to July, although breeding has been recorded as late as August or as early as March (Beruldsen 2003). Nests are located in a large vertical hollow extending one or two meters deep. Hollows may be reused over many years (Beruldsen 2003). Females incubate and care for the young alone, but are regularly attended and fed by the male. Only one egg is produced, which hatches in about 30 days. Once hatched the chick fledges in around 60 days, but remains with its parents and is fed for another three months (Garnett et al. 1999).

Known Threats to the Species

Threats to Glossy Black-Cockatoo populations include:

- Clearing of habitat remains a serious threat. Previous clearing has reduced the species' range in the south and west of the Great Dividing Range (Garnett and Crowley 2000),
- Fire can reduce or remove suitable feed trees from large areas for several years and, if followed by grazing, prevent regeneration of previous habitats.,
- Fragmentation of habitats may also result in an increase in predation of nestlings and eggs or alternatively result in higher competition for hollows (Downes et al. 1997). This threat may be particularly severe where species adapted to altered or open habitats are abundant. These 'edge' species may include Common Brushtail Possum (*Trichosurus vulpecula*), Little Corella (*Cacatua sanguinea*), Galah (*Eolophus roseicapilla*) and Sulphur-crested Cockatoo (*Cacatua galerita*). By out-competing cockatoos for nest hollows, these predators and/or competitors can significantly reduce recruitment of Glossy Black-Cockatoos (Garnett et al. 1999),
- Prolonged and severe drought can significantly reduce *Allocasuarina* cone production, reducing feeding resources and therefore breeding success. Global climate change may therefore negatively impact the species on a broad scale, particularly on the western slopes of the Great Divide (Cameron 2009), and
- The loss of suitable hollow-bearing trees through processes such as fire or logging (Cameron 2006).

Records Relevant to the SGP

The Glossy Black-cockatoo has been frequently recorded during these surveys as well as previous ecological works. It is currently known from 29 observations within the SGP. It has been recorded in both the central and southern regions of the SGP, although it has been more commonly recorded in the southern portion where there is possibly more suitable foraging habitat available.

Rule(s) for Habitat Mapping:

1. The species could occur throughout the entire EIS area.
2. Regional Ecosystems containing *Casuarina cristata* (11.3.1. 11.3.17, 11.4.3, 11.4.3a, 11.9.5) and *Allocasuarina inophloia* (11.5.4) are classed as "Core Habitat Possible". South

of the Warrego Highway areas of RE 11.7.4 may also have *Allocasuarina littoralis* and have been mapped as "Core Habitat Possible".

3. Regrowth of the above RE's, which could contain larger trees with suitable foraging resources, are mapped as "Core Habitat Possible".
4. Core Habitat Possible and General Habitat within 2km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
5. All remaining Regional Ecosystems are classed "Absence Suspected".

Specific Map Modifications

None

Mapping Confidence

Within the SGP Core Habitat Possible accurately predicts the presence of *Allocasuarina* foraging resources, though it is acknowledged that individual trees can be scattered throughout remnant vegetation or modified landscapes. While Core Habitat Possible is abundant in the southern region (Dalby region) of the SGP, it is more scattered in the central region, reducing the likelihood that Glossy Black-cockatoos will occur.

A hot wildfire severely damaged large areas of Glossy Black-cockatoo habitat in Kumbarilla State forest in late 2016. It may take several decades for foraging resources to recover in this area.

General Habitat will be an overestimate as areas of suitable regrowth vegetation (mapped as "General Habitat") will not contain trees of sufficient size to attract foraging birds.

Nests are located in large tree hollows, usually in proximity to foraging resources. Predicting where suitable nest trees might occur is difficult and no attempt has been made to capture possible nest areas in the mapping product.

A supply of water is also important for Glossy Black-cockatoo populations, and suitable locations which may attract birds are likely to be scattered throughout areas of vegetation not mapped.

Painted Honeyeater (*Grantiella picta*)

Status

Vulnerable (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

Endemic to Australia, the Painted Honeyeater (*Grantiella picta*) may be found from the eastern section of the Northern Territory to Victoria and southern regions of South Australia (Pizzey and Knight 2007). Rare in the Northern Territory, they are widespread throughout Queensland, absent only from Cape York and high rainfall areas.

Painted Honeyeaters occur mainly in dry open woodlands and forests, particularly box-ironbark woodlands. They may also be located in riparian forest, on plains with scattered eucalypts, and in remnant trees on farmland. Their occurrence is strongly associated with mistletoe, on which they feed (Higgins et al. 2001) and fragmented or disturbed *Acacia* communities often have the highest density of Mistletoe. More advanced stands of *Acacia* regrowth may also have abundant mistletoe.

Ecology

Painted Honeyeaters feed almost exclusively on mistletoe fruit, but may also collect nectar and invertebrates (Oliver *et al*. 2003). Most foraging is undertaken within the canopy of trees (Higgins *et al.* 2001).

Nesting occurs during spring-summer (Sept.-Feb.), predominantly in the south-east of its range north to and around Brisbane. The breeding season is determined by photoperiod to coincide with warmer summer months, but actual breeding is cued in relation to the progression of mistletoe fruiting. This ensures that breeding is matched by peak resource availability, avoiding temporal variation inherent in unpredictable environments (Barea and Watson 2007).

Small, frail cup-shape nests with narrow sides are constructed in the outer foliage and branchlets of eucalypts, casuarinas and acacias. However, a disproportionately large number of nests are placed in mistletoe clumps in taller trees (Whitemore and Eller 1983; Beruldsen 2003; Barea 2008).

While not well understood, movement patterns are generally described as a north-south migration (Keast 1968). Populations move north during winter and return south of approximately 26^{o} during spring-summer to breed (Higgins *et al.* 2001).

Known Threats to the Species

Large areas of suitable woodland habitat have been extensively cleared throughout this species' range. However, increased mistletoe abundance in degraded woodlands and roadside reserves may have benefited the species and alleviated somewhat the impacts of broad-scale habitat loss (Higgins *et al.* 2001; Bowen et al. 2009).

Records Relevant to the SGP

Three records are located within the SGP in the southern portion near Lake Broadwater where mistletoe is abundant in tall *Eucalyptus* spp., and several records exist within 10km of the SGP boundary, including records from the past few years. Likely to occur within the SGP infrequently, depending on availability and density of mistletoe fruit.

Rule(s) for Habitat Mapping:

1. The species could occur throughout the entire EIS area.
2. RE's 11.3.1, 11.3.17, 11.4.3, 11.4.3a and 11.9.5 (including 'disturbed' communities) are mapped as "Core Habitat Possible".
3. The above RE's and RE's 11.5.20 and 11.5.27 are mapped as "Core Habitat Known" around Lake Broadwater.
4. Regrowth RE 11.3.1, 11.3.17, 11.4.3, 11.4.3a, 11.9.5, and 'Regrowth Brigalow (>15yrs)' are mapped as "General Habitat".

5. All "Core Habitat Possible" within 2km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
6. All remaining regional ecosystems and non-remnant areas are "Absence Suspected"

Specific Map Modifications

A small non-remnant (below patch threshold size) of Weeping Myall (Acacia pendula woodland) was added as "Core Habitat Possible".

Mapping Confidence

The presence of abundant mistletoe can only be accurately determined through field assessment, though it can be predicted to occur with moderate accuracy in areas of Core Habitat Possible. The mapped General habitat, to capture more advanced Acacia regrowth, is likely to over evaluate habitat extent and will have a low accuracy.

Australian Painted Snipe (*Rostratula australis*)

Status

Australian Painted Snipe - Vulnerable (NC Act); Endangered (EPBC Act)

Distribution and Habitat

Most records of the species occur east of a line between Eyre Peninsula and the Gulf of Carpentaria, excluding Cape York Peninsula where they appear to be absent (Marchant and Higgins 1993). However, scattered individuals occur west as far as Western Australia, where they may have once been common in the Kimberley and Swan Coastal Plain (Johnstone and Storr 1998). Recent records mostly centre on the Murray-Darling basin of eastern Queensland and New South Wales (Marchant and Higgins 1993; Rogers et al. 2005). Lake Broadwater is considered to be important habitat for this species within Brigalow Belt South, although there is no known breeding record from this location (EPA 2003).

Birds may be recorded singly or in small groups in freshwater marshes. They are extremely nomadic, coming and going in response to local rainfall and flooding. Although its occurrence in a location is often erratic, with the bird absent some years and common in others (Marchant and Higgins 1993) there is indication of some regular seasonal migration, e.g., to central and north coastal Queensland in autumn and winter (Black et al. 2010). Breeding only occurs in swamps with temporary water regimes and complex shorelines forming islands, shallow water, exposed wet mud and dense low fringing vegetation (Rogers et al. 2005; Geering et al. 2007). During non-breeding periods, they may be found in a wider range of habitats including dams, rice paddocks, waterlogged grasslands, roadside drains and even brackish waterways (Marchant and Higgins 1993).

Ecology

The Australian painted snipe appears to be crepuscular and nocturnal, feeding on mudflats or in shallow water during the morning and evening and throughout the night (Geering et al. 2007). A variety of foods are eaten, including vegetation, seeds, insects, worms, molluscs, crustaceans and other invertebrates including beetles (Marchant and Higgins 1993; Johnstone and Storr 1998).

Nesting occurs in spring and summer in southern Australia and during the wet season in northern Australia (Geering et al. 2007). Nests consist of a simple scrap in the ground lined by dry grasses, fine twigs and other vegetation. These nests are located in specific positions such as on a small island surrounded by shallow water, or occasionally on small mounds of purpose-built vegetation surrounded by water (Beruldsen 2003; Rogers et al. 2005). Breeding occurs only in suitable temporary wetlands with low relief and complex shorelines after an influx of water (Rogers et al. 2005).

Migration patterns are poorly known for the species (Pringle 1987). They are possibly dispersive or migratory. It is possible that such movements are due to local conditions, moving to flooded areas from drying wetlands (Marchant and Higgins 1993).

Known Threats to the Species

Threats to Australian Painted Snipe populations include:

- Loss or alteration of wetland habitats and their water regimes, particularly areas of breeding habitat (Rogers et al. 2005; Garnett et al. 2011).
- Degradation of existing wetlands through weed invasion.
- Trampling of habitat by cattle and feral pigs (*Sus scrofa*) (Rogers et al. 2005; Tzaros et al. 2012).
- Reduced water quality due to a lack of flushing, increased nutrient runoff, pesticide and herbicide runoff, saline discharge and increased erosion and turbidity due to vegetation removal (Tzaros et al. 2012).

Records Relevant to the SGP

Six records for Australian Painted Snipe are known from the southern section of the SGP, all in the vicinity of Lake Broadwater. The species is likely to be a vagrant and rare visitor to the SGP, though there is a low possibility the species might occur at Lake Broadwater and breed in the surrounding habitat during the SGP life of operation..

Rule(s) for Habitat Mapping:

1. Lake Broadwater (RE 11.3.27c and 11.3.27f) is mapped as 'Core Habitat Known'.
2. Long Swamp (RE 11.3.27d and 11.3.27f) is mapped as "Core Habitat Possible'.c
3. All remaining regional ecosystems are "Absence Suspected"

Specific Map Modifications

None

Mapping Confidence

While the Australian Painted Snipe can occur on a variety of wetlands (including minor waterbodies), it is only known to occur within the immediate area of Lake Broadwater. Habitats outside these are likely to be marginal.

MAMMALS

South-eastern long-eared Bat (*Nyctophilus corbeni*)

Status

Vulnerable (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

The south-eastern long-eared bat (*Nyctophilus corbeni*) is largely restricted to the Murray-Darling Basin (Churchill 2008; Turbill et al. 2008), with its stronghold in the Pilliga forests of central New South Wales (Turbill and Ellis 2006). In Queensland, the species is mainly recorded in the southern areas of the Brigalow Belt (Reardon 2012). The distributional limits in Queensland are uncertain. McFarland et al. (1999) states that the species is found north to near Duaringa and Venz et al. (2002) consider that the Dawson River area is at, or close to, its northern range limit. However, Parnaby (2009), in a taxonomic review of Australian greater long-eared bats previously known as *N. timoriensis*, states that the most northerly record of the species is from 80 km west of Taroom. It is unknown if possible misidentifications of the species have resulted in the uncertainty attached to its distribution.

The species is most common in box/ironbark/cypress pine woodland on sandy soils (Turbill and Ellis 2006; Churchill 2008; Turbill et al. 2008), though it also occurs in bulloak (*Allocasuarina luehmannii*), brigalow (*Acacia harpophylla*) and belah (*Casuarina cristata*) communities (Turbill et al. 2008), dry sclerophyll forests with *Corymbia citriodora*, and semi-evergreen vine thickets. The species prefers areas with a distinct canopy and a dense understorey (Churchill 2008). Most records are from large tracts of vegetation, approximately 5000+ ha in size (e.g., Southwood National Park) (EPA 2008), although the species can be occasionally recorded from smaller vegetation tracts of 600 ha (e.g., Erringibba National Park). Field observations and published literature also suggests it may use riparian habitats, though these habitats may be more important for providing roosting sites (hollow-bearing trees) and water.

Ecology

Little is known about the ecology of this species and most of what is known comes from research outside of Queensland (Reardon 2012). Roosting has been recorded in hollows of live trees, cracks in tree limbs, occasionally under exfoliating bark and even within foliage (Churchill 2008; Turbill et al. 2008; Reardon 2012).

With broad, short wings, the south-eastern long-eared bat is highly manoeuvrable and well-adapted to its cluttered habitat. They fly close to vegetation, often through the canopy and can drop suddenly to almost ground level after prey (Churchill 2008). Individuals are known to fly more than seven kilometres between roosts and foraging areas. Roosts may be changed frequently, each used for an average of 1.3 days in one study (Reardon 2012).

Mating occurs in autumn and winter. Females are able to store spermatozoa until ovulation and conception in early spring. Two young are usually born in late October to November and lactation continues until January (Turbill et al. 2008).

Known Threats to the Species

The main threats the south-eastern long-eared bat are:

- Major habitat loss over a large part of its distribution, mostly clearing of brigalow (Reardon 2012),
- Degradation of habitat from grazing,
- Loss of hollows and larger trees from logging and fires (Turbill et al. 2008),
- Increased competition for hollows from other species, and
- Increased exposure to predators (Reardon 2012).

Survey data suggest that large, intact remnants of suitable habitat are required to support populations (Turbill and Ellis 2006; Turbill et al. 2008). With more than 75% of habitat cleared in some parts of its range, land clearing and fragmentation continue to threaten this species (Duncan et al. 1999). Increased competition for hollows is an example of a flow-on impact from fragmentation (Reardon 2012).

Records Relevant to the SGP

The South-eastern Long-eared Bat has been recorded during these surveys as well as during previous ecological works. It is currently known from eight observations within the SGP and has been recorded in both the central and southern regions, although it was captured more frequently in the central region.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire EIS area.
2. Only remnant vegetation which contributes to significantly large contiguous vegetation patches (>500ha) is considered suitable. Within these larger continuous vegetation patches:
   a. RE's 11.3.14, 11.3.25, 11.3.27d, 11.3.27f, 11.5.1, 11.5.1a, 11.5.4, and 11.5.21 are mapped as "Core Habitat Possible", and
   b. RE's 11.3.1, 11.3.14, 11.3.17, 11.3.18, 11.3.2, 11.3.26, 11.4.3, 11.4.3a, 11.5.20, 11.7.2, 11.7.4, 11.7.6, 11.7.7, 11.9.7, and 11.9.5 are mapped as "General Habitat"
3. All "Core Habitat Possible" or "General Habitat" within 2km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
4. All remaining remnant and non-remnant vegetation is mapped as "Absence Suspected".

Specific Map Modifications

None

Mapping Confidence

Identifying suitably large tracts of remnant vegetation within the SGP is relatively easy. Predicting where the species might occur within this vegetation is more complex. While those RE's listed as "Core Habitat Possible" accurately reflect the best areas of habitat, large tracts of "General Habitat" may have suitable structure and provide good habitat for the species. A precautionary approach would be to consider all areas of Core Habitat Possible or General Habitat as suitable.

While several RE's have been excluded as not suitable ("Absence Suspected") in the mapping product, their landscape position often contributes to patch integrity and they may therefore provide an important role in ensure a populations persistence.

Greater Glider (*Petauroides volans*)

Status

Vulnerable (EPBC Act)

Distribution and Habitat

The Greater Glider (*Petauroides volans*) is the largest gliding possum in Australia. Its distribution extends from the Windsor Tableland in north Queensland, south to Wombat State Forest in central Victoria (Woinarski et al. 2014). Inland isolated subpopulations are also known from the Gregory Range (west of Townsville) (Winter et al. 2004), and another in the Einasleigh Uplands bioregion of Queensland (Vanderduys et al. 2012).

The species is predominately restricted to eucalypt forests and woodlands. Greater gliders occur in highest abundance in taller, montane, moist eucalypt forests with larger, relatively old trees and abundant hollows (Andrews et al. 1994; Kavanagh 2000; Eyre 2004; van der Ree *et al*. 2004; Vanderduys et al. 2012). In areas west of the Great Dividing Range, they are found in low woodlands (McKay 2008). The species prefers forests with a diverse range of eucalypt species, due to seasonal variation in its favoured tree species (usually one or two species of eucalypt in any particular area) (Kavanagh 1984). Even in suitable habitat, the distribution may be patchy (Kavanagh 2000).

Ecology

The species is an arboreal nocturnal marsupial which is primarily folivorous, foraging on eucalypt leaves and occasionally flowers (Kehl and Borsboom 1984; Kavanagh and Lambert 1990; van der Ree et al., 2004). It shelters during the day in large tree hollows (Henry 1984; Kehl and Borsboom 1984; Lindenmayer et al., 1991; Smith et al., 2007; Goldingay 2012) and its abundance is often link to hollow density (Andrews et al. 1994; Smith et al. 1994, 1995). Research has shown that in southern Queensland, the species require at least 2–4 live den trees for every 2 ha of suitable forest habitat (Eyre 2002).

Home ranges are usually 1-4ha in size (Henry 1984; Kehl and Borsboom 1984; Comport et al. 1996; Gibbons and Lindenmayer 2002; Pope et al. 2005), however in lower productivity forest and more open woodland habitats home ranges can be up to 16 ha (Eyre 2004; Smith et al. 2007). Males have a larger home range size than females and sexes usually share a den when the breeding season commences (Kavanagh and Wheeler 2004; Pope et al. 2005; McKay 2008).

Females give birth to only one young from March to June. Juveniles emerge from the pouch when three to four months old and become independent at around nine months. However, greater gliders do not reach their sexual maturity and start breeding until their second year (Tyndale-Biscoe and Smith 1969; McKay 2008). It is estimated that the species can live up to 15 years (Harris and Maloney 2010).

Known Threats to the Species

The main threats to the greater glider are:

- Major habitat loss and fragmentation, mostly through clearing, clearfell logging and the loss of senescent trees due to prescribed fire regimes (Eyre 2006; Lindenmayer et al., 2000; Taylor and Goldingay 2009),
- Inappropriate fire regimes (Lindenmayer et al. 2013),
- Effects from climate change such as range contraction (particularly in northern parts of its range) and declines in the health of eucalypt trees (Kearney et al. 2010; Matusick et al. 2013),
- Hyper-predation by owls (McKay 2008; Bilney et al. 2010; Lindenmayer et al. 2011), and
- Increased competition for hollows from other species (e.g. sulphur-crested cockatoos).

Records Relevant to the SGP

The Greater Glider was recorded several times during these surveys and is currently known from 11 observations within the SGP, in both the central and southern regions. Although, it was detected more frequently in the central portion, particularly along riparian areas.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire EIS area. "Core Habitat Possible" includes RE's 11.3.4, 11.3.25 and 11.3.26.
2. Patches of RE 11.3.2, 11.3.3, 11.3.14, 11.3.17, 11.3.18 and 11.3.26 immediately adjacent the above RE's are mapped as "General Habitat".
3. All Core Habitat Possible within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
4. All remaining remnant and non-remnant vegetation is mapped as "Absence Suspected".

Specific Map Modifications

Isolated fragments of Core Habitat Possible or General Habitat were removed as Absence Suspected.

Mapping Confidence

Important habitat characteristics for this species are well understood and can be matched to regional ecosystem descriptions. The mapping is considered to be highly accurate.

Koala (*Phascolarctos cinereus*)

Status

Vulnerable (NC Act); Vulnerable (EPBC Act)

Distribution and Habitat

Endemic to eastern Australia, the Koala is a solitary species that is widespread across coastal and inland areas from Cooktown, Queensland to the Mt. Lofty ranges, South Australia (Martin et al. 2008). Restricted to altitudes below 800m elevation (Munks et al. 1996),

Koalas occur in a diversity of habitats including temperate, sub-tropical and tropical forest, woodland and semi-arid communities, and sclerophyll forest, on foothills, plains and in coastal areas (Martin and Handasyde 1999; Martin et al. 2008). Koalas on the western side of the Great Dividing Range at the western edges of their range are often associated with water courses though are not restricted to them (Melzer et al. 2000; Sullivan et al. 2003). Favoured feed tree species in these areas include *E. camaldulensis, E. coolabah* and *Eucalyptus populnea.*

Koalas have been translocated into a range of areas where they did not occur historically, such as Magnetic, Kangaroo and Phillip Island's.

Ecology

Koalas are well known to have a preference for eucalypt trees as a food source, though not all eucalypts species are equal and diet varies between regions. Although an arboreal species, preferences for individual trees and the distances between feed trees forces individuals to the ground, this is when they are most vulnerable to predation and human-induced mortalities (Hindell et al. 1985; Martin 1985).

Koalas are not strongly territorial and home ranges will overlap. Home ranges vary in size from 1-2 hectares in optimum habitat, and up to 135 hectares in semi-arid regions (Ellis et al. 2002; Martin et al. 2008). Movements are often as short as the distance between feed trees, however dispersing individuals will move over larger distances. Established individuals have been known to make exploratory movements over larger distances before returning to home ranges (Dique 2003).

The breeding season occurs between October and May with females producing up to one offspring per year (Martin et al. 2008). Juveniles become independent from one year of age with males living for over 12 years and females living for over 15 years (Martin and Handasyde 1999). Breeding occurs from two years of age, and is often determined by the establishment of a male hierarchy as males become vocal and fiercely fight for females (Martin et al. 2008).

Known Threats to the Species

Significant threats to Koalas include loss and fragmentation of habitat, vehicle strike, and predation by pet dogs (*Canis lupus familiaris*), whilst wildfire, disease, drought and extreme heat can also be damaging to both individual and population health.

Koalas inhabiting the north-western portion of their range are sparse and insufficiently studied. Although threats are similar to those in areas such as South-east Queensland where more research has been undertaken on Koala populations, it is likely that the severity of some threats is different. In particular, threats such as drought, and extreme heat events, may be more frequent and severe (Munks et al. 1996; Sullivan et al. 2003).

Records Relevant to the SGP

The Koala has been detected numerous times during these surveys as well during previous ecological works. It is currently known from a total of 73 observations within the SGP and has been recorded in both the central and southern regions. However, there are far more records in the southern portion where the Condamine and Wilkie Creek catchments appear to be a stronghold for the species in the southern Brigalow Belt.

Rule(s) for Habitat Mapping:

1. The species may occur throughout the entire EIS area.
2. RE's 11.3.2, 11.3.3, 11.3.4, 11.3.14, 11.3.17, 11.3.18, 11.3.25, 11.3.26, 11.3.27d and 11.3.27f are mapped as "Core Habitat Possible".
3. RE's 11.4.3, 11.4.3a, 11.5.1, 11.5.1a, 11.5.4, 11.5.20, 11.7.2, 11.7.4, 11.7.6, 11.7.7, 11.9.2 and 11.9.7 are mapped as "General Habitat".
4. Regrowth and disturbed vegetation should be mapped as per their parent RE.
5. All Core Habitat Possible and General Habitat within 1km of a recent (1980+), accurate (± 500m) record is classed as "Core Habitat Known".
6. All remaining remnant vegetation is mapped as "Absence Suspected".

Mapping Confidence

Important habitat for this species is reasonably well understood and can be matched to regional ecosystem descriptions. Core Habitat Possible is likely to closely reflect the species distribution, particularly in the southern region of the SGP where the species remains relatively abundant. However, field studies from this work frequently found Koala's in habitats not previously considered high value (mapped as General Habitat), and as such these areas may be more important for the local population than previously understood.

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Appendix H.

Metadata and description of fields for floristic survey database

Appendix F. Metadata and description of fields for floristic survey database.

Metadata Field	Description	Additional Information
Survey Event	The survey program during which the data was collected	Includes data collected during Surat Gas Pipeline Survey, Surat Gas Project EIS and Supplementary EIS, Daandine and Surat Gas Advanced Exploration Surveys.
Survey Event Recorders	Field personnel responsible for recording information	Survey event during which data was collected and personnel responsible for collection of the information.
PP Meander	Timed meander points for Protected Plants within Protected Plant 'High Risk' buffer areas.	Recorded every 5 mins for a 30 minute interval as per the Department of Environment and Heritage Protection (DEHP) (2014). Flora Survey Guidelines – Protected Plants. Department of Environment and Heritage Protection, Queensland Government, Brisbane.
Waypoint Number	Waypoint number from combined survey efforts	Renumbered waypoints based on combined data collected from field personnel.
Ind. Ref. Number	The site number recorded by the individual field personnel. Retained to allow Site Nos to be readily referenced if required by field personnel in the future.	
Survey Type	The intensity of recorded site data as described in Neldner et al (2012)	Secondary: Secondary site data quantifies structural and floristic information for all strata. This includes structural and floristic data for the Emergent (E), Canopy / Sub-canopy (T1, T2), Shrub (S1, S2) and Ground (G) layers. Plot size is a standard 10 x 50 m plot. Ground covers are measured in standard 5 x 1m^2 or 10 x 1m^2 quadrats along a measured centreline. Tertiary: Quantifies structural and floristic information for woody vegetation (T1, T2, S1, S2) in a 10 x 50m plot. Does not record non woody vegetation in ground-covers. Quaternary: Estimates and describes structural and floristic information at a given location. Identifies dominant only and is not plot based. Observation: Provides a description of dominant species and structural formation only. Non-plot based rapid survey effort.
Lat	Latitude in decimal degrees	
Long	Longitude in decimal degrees	
Elevation	Recorded elevation from GPS	
Q Herbarium Mapped RE_2	RE indicated in mapping databases produced by Qld Government agencies (DSITIA).	Most current version is produced by Department of Resources and Mines (Version 8.0, 2014).
RE Ground Truthed	RE recorded at a specific location during field survey.	RE recorded by field ecologists at a specified waypoint. Used to verify RE mapping databases.
VMA Status	Status of RE listed under the VM Act	Categories of Endangered, Of Concern, Least Concern and Non-remnant.
Biodiversity Status	Biodiversity Status of RE	Categories of Endangered, Of Concern, No Concern at Present.
EPBC Status	Status of ecological community listed under the EPBC Act 1999.	Categories of Critically Endangered, Endangered, Vulnerable
Vegetation Structure	Vegetation Structural Formation as defined in Neldner et al 2012.	Categories of Vine forest/ Thicket, Open Forest, Woodland, Open Woodland, Shrubland and Grassland. Further information defined in Neldner et al 2012.
Emergent Height	Height of the Emergent structural layer.	Generally defined as the upper structural layer forming less than 5% total cover (Walker and Hopkins 1990). Neldner et al 2012, define the emergent layer as the upper structural layer that does not form the dominant ecological layer (the layer with the dominant biomass) which typically corresponds with the definition by Walker and Hopkins.
T1 Canopy Height	Measured height of the canopy layer.	Canopy (T1) layer is defined as the upper structural layer that forms the dominant biomass. Often represented as a height interval (e.g. 11 – 13m).

Metadata Field	Description	Additional Information
T1 Canopy Cover	Measured cover of the canopy layer.	Measured by projected canopy cover (PCC) rather than projected foliage cover (PFC). Measured over either a 50 or 100m linear transect.
T1 Count	The number of T1 stems within a standard floristic survey plot.	Standard secondary survey plot is 10 m x 50 m.
T1 Dominant	The dominant species recorded within the T1 structural layer	
T1 Sub-dominant	The sub-dominant species recorded within the T1 structural layer	
T1 Associated	Species associated with the canopy other than dominant and sub-dominant species.	
T2 Canopy Height	Measured height of the sub-canopy layer.	Sub-canopy is the tree layer that lies directly below the canopy (covered by the canopy layer).
T2 Canopy Cover	Measured cover of the canopy layer.	Measured by projected cover of the sub-canopy (PCC).
T2 Count	The number of T2 stems within a standard floristic survey plot.	Standard secondary survey plot is 10 m x 50 m.
T2 Dominant	The dominant species recorded within the T2 structural layer	
T2 Sub-dominant	The sub-dominant species recorded within the T2 structural layer	
T2 Associated	Species associated with the sub-canopy (T2) structural layer other than dominant and sub-dominant species.	
S1 Canopy Height	Measured height of the tallest shrub layer (S1) layer.	Multi-stemmed woody species typically with upper height limits of 8m.
S1 Canopy Cover	Measured cover of the tallest shrub (S1) layer.	
S1 Count	The number of S1 stems within a standard floristic survey plot.	Standard secondary survey plot is 10 m x 50 m.
S1 Dominant	The dominant species recorded within the S1 structural layer	
S1 Sub-dominant	The sub-dominant species recorded within the S1 structural layer	
S1 Associated	Species associated with the tallest shrub layer (S1) other than dominant and sub-dominant species.	
S2 Canopy Height	Measured height of the secondary shrub layer (S2) layer.	Secondary shrub layer falls below the upper (S1) shrub layer. Typical S2 heights range from 0.5 – 2m.
S2 Canopy Cover	Measured cover of the secondary shrub (S2) layer.	
S2 Count	The number of S2 stems within a standard floristic survey plot.	Standard secondary survey plot is 10 m x 50 m.
S2 Dominant	The dominant species recorded within the S2 structural layer	
S2 Sub-dominant	The sub-dominant species recorded within the S2 structural layer	
S2 Associated	Species associated with the secondary (S2) shrub layer other than dominant and sub-dominant species.	

Metadata Field	Description	Additional Information
Ground - % cover live plants.	Total foliage cover of live plants within a standard survey plot. Sometimes represented by an estimate in quaternary plots.	Includes grasses and graminoids, forbs and shrubs <0.5 m, native and exotic species. Excludes leaf litter, timber and bare ground. Measured only in secondary survey plots although estimates can be made in Quaternary survey data. Ground cover measurement is undertaken within 5 or 10 x 1m^2 quadrats (Secondary) and calculated as an average score. Estimates may be made in Quaternary plots.
Ground - % leaf litter	Cover of leaf litter in standard survey plot.	Leaf litter includes dead leaves, bark and other non-specific organic matter.
Ground - % leaf litter	Cover of leaf litter in standard survey plot.	Leaf litter includes dead leaves, twigs, bark and other non-specific organic matter.
Ground - % cover bare ground.	Cover of bare ground in standard survey plot.	Bare ground typically relates to exposed soil and sometimes rock.
Ground - % cover timber.	Cover of timber in standard survey plot.	Timber typical describes woody material (branches) > 5 cm diameter.
Ground - % cover rocks.	Cover of bare rock in standard survey plot.	Exposed rock not covered by soil.
Ground - % Cover Perrenial Native Grass	% cover of perennial native grass measured in a standard secondary plot. Sometimes represented by an estimate in quaternary plots.	% cover of native perennial grasses taken as an average of sampled quadrats (Secondary sites) or an estimate (Quaternary plots). Perennial describes plants that persist throughout seasons although might die back in less favourable growing conditions, resprouting when growth conditions improve (i.e following rain).
Ground - % Cover Native Shrubs < 1m	% cover of shrubs measured within quadrats.	% foliage and branch cover of native shrubs < 1m height taken as an average of sampled quadrats (Secondary sites) or an estimate (Quaternary sites)
Ground - % Cover Native Forbs	% cover of native forbs measured in a standard secondary plot. Sometimes represented by an estimate in quaternary plots.	% cover of native forbs taken as an average of sampled quadrats (secondary sites) or an estimate (quaternary sites). Forbs are herbaceous flowering plants that are not graminoids (grasses and sedges).
Ground - % Cover Exotic Grass	% cover of exotic grass measured in a standard secondary plot. Sometimes represented by an estimate in quaternary plots.	% cover of exotic grasses taken as an average of sampled quadrats (secondary sites) or an estimate (quaternary sites). Perennial describes plants that persist throughout seasons although might die back in less favourable growing conditions, resprouting when growth conditions improve (i.e following rain).
Ground - % Cover Exotic Forbs	% cover of exotic forbs measured in a standard secondary plot. Sometimes represented by an estimate in quaternary plots.	% cover of exotic forbs taken as an average of sampled quadrats (secondary sites) or an estimate (quaternary sites). Exotic forbs are herbaceous flowering plants that are not graminoids (grasses and sedges) and are not native (introduced) to the survey area.
Cryptogams - % Cover	% cover of cryptogams covering soils in the ground layers.	Cryptogams are plants that reproduce by spores without flowers, seeds or leaves. Remnants persist as surface crusts during dry periods.
Grass / Forb dominant	The dominant grass/ forb species measured in ground layers. May be one or several species.	Includes both native and exotic species.
Grass / Forb sub-dominant	The sub-dominant grass / forb species measured in ground layers. May be one or several species.	Includes both native and exotic species.
Total spp. No	Total number of species recorded within a standard secondary survey plot.	Includes all woody and non-woody species although excludes cryptogams.
Harissia cactus % cover	Measured ground cover of Harrisia cactus (Harrisia martini), a declared Class 2 exotic pest.	
Opuntia % cover	Measured ground cover of Opuntia spp., a declared Class 2 exotic pest.	

Metadata Field	Description	Additional Information
Bryophyllum. % cover	Measured ground cover of exotic Sporobolus spp. (Sporobolus fertilis, Sporobolus pyramidalis, Sporobolus jacquemontii).	
Geology/ Soil	Field description of landform, soil and geology at a given survey site.	
Notes	Additional relevant information used to describe site characteristics.	
Philotheca S1 Cover	Measured crown cover of *Cerbera dumicola* in the S1 shrub layer in a standard Secondary site.	Philotheca sporadica is the only threatened species recorded during Arrow Surat Gas Project studies.
Philotheca Stems / ha	Stem counts for *Philotheca sporadica* in standard Secondary site in the shrub layer	
Date of Survey	Time and date of field recording	
Altitude	Altitude of survey location taken as metres above sea level, recorded on GPS.	
Photo number.	Photo number for individual survey locations.	Photo points collected by field recorders according to site location.
Additional Information	Reference to additional structural / floristic data	Reference to structural and floristic information specifically relating to native grassland assessments. Held separately from structural summary table. Includes floristic collection numbers.
Seasonal Effort	Relates to wet or dry season survey	Dry season survey undertaken from June to December and wet season typically from January to May.

Appendix D – DES Streamlined Model Conditions Risk Assessment

Environmental Aspect			Environmental							Assessment of				Controls		Assessment of			
Petroleum Lease Activity	Action	Physical Activity	Environmental Value	Pathway How will the hazard be released	Hazard what is being released or lost	Duration of Impact (without management)	Possible Cumulative Impacts (Yes/No)	Unmitigated risks	Is the risk managed under legislation other than EP Act?	Unmitigated Likelihood	Unmitigated Consequence	Unmitigated Risk Score	Unmitigated Risk Level	What actions should be taken to manage risk?	What EC/SC exist that are relevant to mitigate the risk?	Controlled Likelihood	Controlled Consequence	Controlled Risk Score	Controlled risk level
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Maintainance	Biodiversity	Removal of leaf litter and fallen timber by heavy machinery	Habitat loss and fragmentation	Minor and /or short term effects	Yes	i. Reduction in species, further endangerment or loss		3	2	6	Medium	Scatter fallen timber around other areas of vegetation Avoid, minimise, mitigate impacts to biodiversit	PESCB1, PESCC27.	3	2	6	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Traversing land	Biodiversity	Introducing and spreading weeds when walking or driving	Weeds	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. Nuisance to landholder ii Impact on stock or crops	i. Land Access Code ii. Land Protection (Pest and Stock Route Management) Act 2002 iii. Petroleum industry advisory guideline)				NA	Comply with other legislative requirements					NA
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Protected species	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	i. Avoid, minimise, mitigate impacts to habitat / biodiversity ii. Plan site for minimum disturbance and clearing iii. Use existing access routes where feasible	PESCB1, PESCC27.	2	4	8	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Habitat loss and fragmentation	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	Avoid, minimise, mitigate impacts to habitat / biodiversity	PESCB1, PESCC27.	2	4	8	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	i. Clearing vegetation using heavy machinery (forest mulcher) ii. Construction	Impacts to wetlands (including watercourses, lakes, springs, GAB springs) and watercourses	Long term - duration of lease (activity occurs over duration of lease)	No	i. Decline in water quality and hydrological systems ii. Habitat impacts / loss / fragmentation iii. For GAB springs, loss of pressure		4	3	12	High	i. Use existing infrastructure paths where feasible or avoid the works ii. Plan site for minimum disturbance iii. Plan for works when there is low flow and not carry out works when high flows are expected iv. Stabilise exposed areas as soon as possible v. Restrict the number of works vi. No permanent changes to surface or subsurface hydrological regime	PESCB1, PESCC27.	3	2	6	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Construction	Land	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Runoff and sedimentation	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Sediment runoff ii. Erosion iii. Dust		3	2	6	Medium	i. Use existing infrastructure paths where feasible or avoid the works ii. Plan site for minimum disturbance iii. Plan for works when there is low flow and not carry out works when high flows are expected iv. Stabilise exposed areas as soon as possible v. Restrict the number of works vi. No permanent changes to surface or subsurface hydrological regime vii. Erosion and sediment control measures in place	PESCB1, PESCC27.	2	2	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Construction	Air	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Nuisance	Long term - duration of lease (activity recurring over duration of lease)	No	i. Nuisance to landholder, fauna and flora ii. Erosion		4	2	8	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab.		2	2	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Construction	Water	Runoff from eroded and disturbed soils to waters	Runoff and sedimentation	Long term - duration of lease (activity recurring over duration of lease) if areas remain open with out sediment and erosion control measures	Yes	i. Increase in turbidity in local watercourses		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Maintain separation distances from watercourses	PESCB1, PESCC27	2	2	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Construction	Noise	Vehicle movement and operation of heavy machinery	Nuisance	long term - duration of lease (activity recurring over duration of lease)	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Construction	Social	i. Trucks and equipment ii. Personnel	Gates, fences etc	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to landholder ii Impact on stock or crops	Land access code				NA	Comply with other legislative requirements					NA
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Soil disturbance and release to waters	Sediment and hydrocarbons from equipment	Short to medium term - construction and maintanence impacts only	Yes	i. Stream bank erosion ii. Habitat impacts iii. Turbidity impacts	Published Guideline: Activities in a watercourse, lake or spring associated with a resource activity or mining operations. (Riverine protection permit requirements now repealed)	3	4	12	High	i. No linear infrastructure in HES wetlands, GAB springs, GAB watercourse springs For other wetlands: ii. No negative impact to water quality beyond the duration of the works unless specifically authorised iii. Ambient water quality standards for turbidity and hydrocarbons	PESCB1, PESCC27.	2	3	6	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Clearing vegetation using heavy machinery (forest mulcher)	Protected species	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	i. No linear infrastructure in HES wetlands, GAB springs, GAB watercourse springs For other wetlands: ii. Use existing infrastructure paths where feasible or avoid the works iii.Plan site for minimum disturbance iv. Plan for works when there is low flow and not carry out works when high flows are expected v. No negative impact to water quality beyond the duration of the works unless specifically authorised vi. No filling of the wetland vii. Minimise clearing of riparian vegetation outside of the minimum area necessary to reasonably carry out the works. viii. Ambient water quality standards for turbidity and hydrocarbons	PESCB1, PESCC27.	2	3	6	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Clearing vegetation using heavy machinery (forest mulcher)	Habitat loss and fragmentation	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	i. No linear infrastructure in HES wetlands, GAB springs, GAB watercourse springs For other wetlands: ii. Use existing infrastructure paths where feasible or avoid the works iii.Plan site for minimum disturbance iv. Plan for works when there is low flow and not carry out works when high flows are expected v. No negative impact to water quality beyond the duration of the works unless specifically authorised vi. No filling of the wetland vii. Minimise clearing of riparian vegetation outside of the minimum area necessary to reasonably carry out the works. viii. Ambient water quality standards for turbidity and hydrocarbons	PEEC3, PESCB1, PESCC27, PESCC38, PESCC39, PESCC40, PESCC41.	2	3	6	Medium
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat A ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss ii. Infiltration of invasive species (pests and predators) iii. Habitat impacts / loss / fragmentation	i. P&G Act 2004 ii. NC Act (clearing permits) iii. NC Act (interfering with animal breeding places iv. EPBC Act	5	4	20	Extreme	Not permitted. To mitigate risks in Cat A ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	4	20	Extreme	Not permitted. To mitigate risks in Cat B ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	i.Essential petroleum activities permitted in secondary buffer of Cat A and buffer of Cat B or C as these types of activities still protect the ESA itself (this includes linear infrastructure) ii. Avoid activities in buffers as the first preference iii. Then select pre-disturbed sites iv. Then plan site for minimum disturbance v. Cumulative impacts to be checked as activities progress in Cat C ESAs	PESCB1.	2	3	6	Medium

Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Site Preparation or widening	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	3	15	Very High	i. Essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself (this includes most linear infrastructure) ii. Avoid activities in buffers as the first preference iii. Then select pre-disturbed sites iv. Then plan site for minimum disturbance v. Cumulative impacts to be checked as activities progress in Cat C ESAs	PESCB1.	4	3	12	High
Linear infrastructure: access tracks, roads, above ground powerlines, flow lines (excludes pipelines)	Operation	Water release (low point drain, trench water)	Land	Contamination	Impacts to soil, vegetation, fauna and human health	long term - duration of lease (activity recurring over duration of lease)	Yes	i. Loss of soil productive capacity ii. Impact on future land use iii. Vegetation dieback		3	2	6	Medium	Release from low point drain only within acceptable standards		2	2	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Removal of leaf litter and fallen timber using heavy machinery	Habitat loss and fragmentation	Minor and /or short term effects	No	i. Reduction in species, further endangerment or loss	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	2	3	6	Medium	Avoid, minimise, mitigate impacts to biodiversity; No borrow pits / quarries in ESAs	PESCB1, PESCC27	2	3	6	Medium
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Protected species	Long term - duration of lease (activity occurs over duration of lease)	No	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	i. Avoid, minimise, mitigate impacts to habitat / biodiversity ii. Plan site for minimum disturbance and clearing iii. Use existing access routes where feasible	PESCB1, PESCC27	2	4	8	Medium
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Habitat loss and fragmentation	Long term - duration of lease (activity occurs over duration of lease)	No	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act	3	4	12	High	Avoid, minimise, mitigate impacts to habitat / biodiversity	PESCB1, PESCC27	2	4	8	Medium
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat A ESA values	Long term - duration of lease (activity occurs over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. P&G Act 2004 ii. NC Act (clearing permits) iii. NC Act (interfering with animal breeding places iv. EPBC Act	5	4	20	Extreme	Not permitted. To mitigate risks in Cat A ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Long term - duration of lease (activity occurs over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act	5	4	20	Extreme	Not permitted. To mitigate risks in Cat B ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity occurs over duration of lease)	Yes	i.Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act	5	3	15	Very High	Not permitted. Only essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself		1	3	3	Low
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	i. Clearing vegetation using heavy machinery (forest mulcher) ii. Construction	Impacts to wetlands (including watercourses, lakes, springs, GAB springs) and watercourses	Long term - duration of lease (activity occurs over duration of lease)	Yes	i. Decline in water quality ii. Habitat impacts / loss / fragmentation ii. Impacts to fauna		5	4	20	Extreme	No borrow pits / quarries in wetlands or any watercourse		1	1	1	Very Low
Borrow pits/quarries	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity occurs over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	i. Only essential petroleum activities are permitted in secondary protection zone of Cat A ii. For Cat B, only essential where predisturbed iii. For Cat C only essential in buffers) excluding State Forests and Timber Reserves)		1	3	3	Low
Borrow pits/quarries	Site Preparation	Clearing	SCL or GQAL	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Loss and temporary disturbance of SCL and GQAL	Moderate and/or medium term effects	No	i. Loss of productive capacity ii. Impact on future land use	SCL Act/code (Regional Plan)				NA	Comply with other legislative requirements					NA
Borrow pits/quarries	Site Preparation	Clearing	Air	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Nuisance	Minor and /or short term effects	No	i. Nuisance to landholder, fauna and flora ii. Erosion		3	2	6	Medium	Nuisance control measures and/or alternative arrangements		2	2	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Air	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Fire	Minor and /or short term effects	No	i. Bush fire risk ii. Smoke hazard	i. P&G Act 2004 ii. s62 of the Fire and Rescue Service Act 1990 (Qld)	2	4	8	Medium	Safety requirements of P&G Act; contingency procedures in place and implemented		1	4	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Noise	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		3	2	6	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Land	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Erosion	Moderate and/or medium term effects	No	i. Sediment runoff ii. Erosion iii. Dust		3	3	9	High	Sediment and erosion conditions		2	3	6	Medium
Borrow pits/quarries	Site Preparation	Clearing	Land	Clearing Vegetation Using Heavy Machinery (Forest Mulcher)	Topsoil removal	Moderate and/or medium term effects	No	i. Loss of productive capacity ii. Impact on future land use		3	3	9	High	Sediment and erosion conditions		2	2	4	Low
Borrow pits/quarries	Site Preparation	Clearing	Water	Runoff from eroded and disturbed soils to waters	Runoff	Minor and /or short term effects	No	i. Increase in turbidity in local watercourses		3	3	9	High	Sediment and erosion conditions		2	3	6	Medium
Borrow pits/quarries	Operation	Earthworks	Air	Excavation or fill using heavy machinery	Particulates	Minor and /or short term effects	No	i. Nuisance to landholder, fauna and flora ii. Erosion		3	2	6	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab.		2	2	4	Low
Borrow pits/quarries	Operation	Earthworks	Air	Excavation or fill using heavy machinery	Fire	Minor and /or short term effects	No	i. Bush fire risk ii. Smoke hazard	i. P&G Act 2004 ii. s62 of the Fire and Rescue Service Act 1990 (Qld)	2	4	8	Medium	Safety requirements of P&G Act; contingency procedures in place and implemented		1	4	4	Low
Borrow pits/quarries	Operation	Earthworks	Noise	Excavation or fill using heavy machinery	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		3	2	6	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Borrow pits/quarries	Operation	Earthworks	Land	Excavation or fill using heavy machinery	Erosion	Minor and /or short term effects	No	i. Sediment runoff ii. Erosion iii. Dust		3	3	9	High	Situational measures to prevent erosion and sedimentation		2	2	4	Low
Borrow pits/quarries	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Groundwater	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	No borrow pits in wetlands or their buffers		1	1	1	Very Low

Borrow pits/quarries	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Flow	Short to medium term - construction and maintanence impacts only	Yes	i. Erosion ii. Habitat impacts iii. Turbidity an other contamination impacts iv. Changes to hydrology		5	3	15	Very High	No borrow pits in wetlands or their buffers		1	1	1	Very Low
Borrow pits/quarries	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Clearing Contaminants	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	i. No borrow pits/quarries in wetlands (including watercourses, lakes, springs and GAB springs) and their buffers ii. No impacts to groundwater dependant ecosystems other than that in accordance with UWIR/SIMS		1	1	1	Very Low
Borrow pits/quarries	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contamination	Short to medium term - construction and maintanence impacts only	Yes	i. Erosion ii. Habitat impacts iii. Turbidity an other contamination impacts iv. Changes to hydrology		5	3	15	Very High	No borrow pits in wetlands (including watercourses, lakes, springs and GAB springs) and their buffers		1	1	1	Very Low
Borrow pits/quarries	Operation	Blasting	Noise	Blasting land and boulders	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	Blasting in accordance with relevant AS; alternative arrangements	PESCC 21 to 23.	1	2	2	Low
Borrow pits/quarries	Completion	Rehabilitation	Air	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Particulates	Minor and /or short term effects	No	i. Nuisance to landholder, fauna and flora ii. Erosion		3	2	6	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab; rehab monitoring		2	2	4	Low
Borrow pits/quarries	Completion	Rehabilitation	Water	Runoff from eroded and disturbed soils to waters	Sediment and water contaminants	Medium term	Yes	Increase in turbidity in local watercourses		3	2	6	Medium	i. Erosion and sediment measures ii. Watercourse buffers		2	1	2	Low
Borrow pits/quarries	Completion	Rehabilitation	Noise	Mechanical activity	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		3	2	6	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Construction	Operation	Dust Suppression	Land	Use of produced water for dust supression or contruction activity	Contamination	Potentially long term effects if production water too saline and damages soil structure	Yes	i. Contamination of soil ii. Contamination of waters iii. Contamination of air iv. Soil structure damage and dispersion		3	3	9	High	Standards around application so the amount applied does not exceed the amount required to effectively suppress dust; and the application does not cause on- site ponding or runoff, is directly applied to the area being dust suppressed, does not harm vegetation surrounding the area being dust suppressed and does not cause visible salting. For construction, soil properties to also be protected. Release limits can be used.		3	2	6	Medium
Temporary Construction Camp	Site Preparation	Clearing	Biodiversity	i. Clearing vegetation using heavy machinery (forest mulcher) ii. Construction	Impacts to wetlands (including watercourses, lakes, springs, GAB springs) and watercourses	Long term - duration of lease (activity occurs over duration of lease)	No	i. Decline in water quality and hydrological systems ii. Habitat impacts / loss / fragmentation		5	4	20	Extreme	No camps in wetlands or watercourses		1	1	1	Very Low
Temporary Construction Camp	Sewage	Sewage treatment	Land	Spills	Contamination	Minor and /or short term effects	No	i. Contamination of land ii. Loss productive land		3	2	6	Medium	i. Erosion and sediment control measures in place and maintained ii. Contaminant release limits for microbial quality and nutrients to ensure sustainability iii. Maintenance of irrigation areas, no runoff or ponding or aerosols iv. Buffers to waters		1	2	2	Low
Temporary Construction Camp	Sewage	Sewage treatment	Land	Soil structure damage from treated sewage release	Soil structure	Moderate and/or medium term effects	Yes	Soil degradation		4	2	8	Medium	i. Contaminant release limits for microbial quality and nutrients to ensure sustainability ii. Maintenance of irrigation areas, no runoff or ponding or aerosols ii. Buffers to waters	PESCB1, PESCC27.	2	2	4	Low
Construction Camp	Sewage	Sewage treatment	Land	Erosion from treated sewage release	Erosion	Minor and /or short term effects	No	Loss of topsoil		4	2	8	Medium	i. Erosion and sediment control measures in place and maintained ii. Contaminant release limits for microbial quality and nutrients to ensure sustainability iii. Maintenance of irrigation areas, no runoff or ponding or aerosols iv. Buffers to waters	PESCB1, PESCC27.	2	2	4	Low
Temporary Construction Camp	Sewage	Sewage treatment	Water	Spills	Contamination	Minor and /or short term effects	No	Surface water contamination		4	3	12	High	i. Contaminant release limits for microbial quality and nutrients to ensure sustainability ii. Maintenance of irrigation areas, no runoff or ponding or aerosols ii. Buffers to waters		2	2	4	Low
Temporary Construction Camp	Sewage	Sewage treatment	Water	Spills	Contamination	Minor and /or short term effects	No	i. Contamination of waters ii. Contamination of shallow aquifers.		4	3	12	High	i. Emergency response and contigency procedures ii. Pumps station alarms and back up power iii. No spills authorised		2	2	4	Low
Temporary Construction Camp	Waste generation	General waste	Waste	Release of contaminants and odour	Nuisance	Minor and /or short term effects	No	i. Land contamination ii. Surface water contamination iii. Shallow aquifer contamination iv. odour nuisance		4	2	8	Medium	i. Landfill standards - suitably designed and located, excludes stormwater runoff, day cover and properly capped ii. Waste acceptance standards - limited organic, no liquids or regulated iii. Pest and litter management		2	2	4	Low
Temporary Construction Camp	Waste generation	Regulated waste	Waste	Release of contaminants	Contamination	Minor and /or short term effects	No	i. Land contamination ii. Surface water contamination iii. Shallow aquifer contamination iv. Odour nuisance	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	4	2	8	Medium	No regulated waste disposal on site		2	2	4	Low
Drilling	Preliminary	Traversing land	Social	i. Trucks and equipment ii. Personnel	Gates, fences etc	Minor and /or short term effects	No	i. Nuisance to landholder ii Impact on stock or crops	Land Access Code				NA	Comply with other legislative requirements					NA
Drilling	Preliminary	Traversing land	Biodiversity	Introducing and spreading weeds when walking or driving	Weeds	Moderate and/or medium term effects	Yes	i. Nuisance to landholder ii Impact on stock or crops	i. Land Access Code ii. Land Protection (Pest and Stock Route Management) Act 2002 iii. Petroleum industry advisory guideline)				NA	Comply with other legislative requirements					NA
Drilling	Site Preparation	Clearing	Biodiversity	Removal of leaf litter and fallen timber by heavy machinery	Habitat loss and fragmentation	Moderate and/or medium term effects	Yes	i. Reduction in species, further endangerment or loss		3	2	6	Medium	Scatter fallen timber around other areas of vegetation; Avoid, minimise, mitigate impacts to biodiversity	PESCB1, PESCC27	2	2	4	Low
Drilling	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Protected species	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	3	4	12	High	i. Avoid, minimise, mitigate impacts to habitat / biodiversity ii. Plan site for minimum disturbance and clearing iii. Use existing access routes where feasible		2	4	8	Medium
Drilling	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Habitat loss and fragmentation	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss ii. Infiltration of invasive species (pests and predators)	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	4	16	Very High	ESA, buffer and other clearing restrictions		2	4	8	Medium
Drilling	Site Preparation	Clearing	Biodiversity	i. Clearing vegetation using heavy machinery (forest mulcher) ii. Construction	Impacts to wetlands (including watercourses, lakes, springs, GAB springs) and watercourses	Long term - duration of lease (activity occurs over duration of lease)	No	i. Decline in water quality and hydrological systems ii. Habitat impacts / loss / fragmentation		5	4	20	Extreme	No camps in wetlands or watercourses		1	1	1	Very Low
Drilling	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity occurring over duration of lease)	Yes	i.Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	3	15	Very High	i. Essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself (this includes drilling) ii. Avoid activities in Cat C ESAs as the first preference iii. Then select pre-disturbed sites iv. Then plan site for minimum disturbance v. Cumulative impacts to be checked as activities progress in Cat C ESAs	PESCB1.	4	3	12	High

Drilling	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	i.Essential petroleum activities permitted in secondary buffer of Cat A and buffer of Cat B or C as these types of activities still protect the ESA itself (this includes drilling) ii. Avoid activities in buffers as the first preference iii. Then select pre-disturbed sites iv. Then plan site for minimum disturbance v. Cumulative impacts to be checked as activities progress in Cat C ESAs	PESCB1.	2	3	6	Medium
Drilling	Site Preparation	Clearing	SCL or GQAL	clearing vegetation using heavy machinery (forest mulcher)	Temporary disturbance	Short term	Yes	i. Loss of productive capacity ii. Impact on future land use	SCL Act/code (Regional plan)				NA	Comply with other legislative requirements					NA
Drilling	Site Preparation	Clearing	Air	clearing vegetation using heavy machinery (forest mulcher)	Particulates	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to landholder, fauna and flora ii. Erosion		4	2	8	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab.		2	2	4	Low
Drilling	Site Preparation	Clearing	Air	Clearing vegetation using heavy machinery (forest mulcher)	Fire smoke	Minor and /or short term effects	No	i. Bush fire risk ii. Smoke hazard	i. P&G Act 2004 ii. s62 of the Fire and Rescue Service Act 1990 (Qld)	1	4	4	Low	Safety requirements of P&G Act; contingency procedures in place and implemented		1	3	3	Low
Drilling	Site Preparation	Clearing	Noise	Clearing vegetation using heavy machinery (forest mulcher)	Nuisance	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Drilling	Site Preparation	Clearing	Land	Clearing vegetation using heavy machinery (forest mulcher)	Runoff and sedimentation	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. Sediment runoff ii. Erosion iii. Dust		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	2	4	Low
Drilling	Site Preparation	Clearing	Land	Clearing vegetation using heavy machinery (forest mulcher)	Soil quality and structure	Short term	Yes	i. Loss of productive capacity ii. Impact on future land use		4	3	12	High	i. Topsoil management ii. Erosion and sediment control measures in place and maintained.		2	2	4	Low
Drilling	Site Preparation	Clearing	Water	Runoff from eroded and disturbed soils to waters	Runoff and sedimentation	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. Increase in turbidity in local watercourses		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
Drilling	Site Preparation	Earthworks	Air	Excavation or fill using heavy machinery	Particulates	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to landholder, fauna and flora ii. Erosion		4	2	8	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab.		2	2	4	Low
Drilling	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Groundwater	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	No drilling in wetlands or their buffers		1	1	1	Very Low
Drilling	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Flow	Short to medium term - construction and maintanence impacts only	Yes	i. Erosion ii. Habitat impacts iii. Turbidity an other contamination impacts iv. Changes to hydrology		5	3	15	Very High	No drilling in wetlands or their buffers		1	1	1	Very Low
Drilling	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants	Short to medium term - construction and maintanence impacts only	Yes	i. Erosion ii. Habitat impacts iii. Turbidity an other contamination impacts iv. Changes to hydrology		5	3	15	Very High	No drilling in wetlands or their buffers ii. No drilling in wetlands that are cave GDE		1	1	1	Very Low
Drilling	Site Preparation	Earthworks	Land	Excavation or fill using heavy machinery	Soil quality and structure	Short term	Yes	i. Loss of productive capacity ii. Impact on future land use		4	3	12	High	i. Topsoil management ii. Erosion and sediment control measures in place and maintained.		2	2	4	Low
Drilling	Site Preparation	Earthworks	Land	Naturally occuring radioactive substances in waste drill rock	Contaminants	Short to long term	No	i. Possible contamination of soil					NA						NA
Drilling	Site Preparation	Earthworks	Water	Runoff from eroded and disturbed soils to waters	Runoff and sedimentation	Long term - duration of lease (activity occurring over duration of lease)	Yes	i. Increase in turbidity in local watercourses		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
Drilling	Site Preparation	Earthworks	Water	Naturally occuring radioactive substances in waste drill rock	Contaminants	Short to long term	No	i. Possible contamination of soil					NA						NA
Drilling	Operation	Rig activity	Waste	Consumables	Contaminants	Minor and /or short term effects	No	i. Possible contamination of soil ii. Possible contamination of waters iii. Possible contamination of air	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	3	3	9	High	i. No general waste disposal at well sites. ii. Mix bury cover with appropriate quality criteria for residual drilling solids iii. Sumps and pits to be temporary and small for safe containment of drilling fluids.		2	2	4	Low
Drilling	Operation	Rig activity	Noise	Mechanical activity of the rig to drill, insert/remove casing, pump/lift drilling muds and cement and seperate drilling waste at the surface via shaker	Nuisance	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Drilling	Operation	Rig activity	Air	Mechanical activity of the rig to drill, insert/remove casing, pump/lift drilling muds and cement and seperate drilling waste at the surface via shaker	Contaminants	Minor and /or short term effects	No	i. Nuisance at sensitive receptor ii. Emissions from machinery		3	2	6	Medium	Nuisance control measures and/or alternative arrangements; Ensure sensitive receptor mapping completed; ensure that the fuel burning capacity thresholds are lower than the ERA threshold for fuel burning (i.e. <500kg/h)		2	2	4	Low
Drilling	Completions	Stimulation	Water	Aquifer interferance through interconnection	Stimulation fluid/flow back waters	Minor and /or short term effects	No	i. Possible contamination of aquifers ii. Possible connection of aquifers	Mandatory Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Qld P& G Act 2004 - covers construction standards	3	4	12	High	i. No restricted stimulation fluids or PAHs ii. Stimulation procedures iii. Construction standards iv. Integrity testing v. Buffer zones for active groundwater bores and use		2	2	4	Low
Drilling	Completions	Stimulation	Water/Land	Surface contamination	Stimulation fluid/flow back waters	Minor and /or short term effects	No	i. Possible contamination of land ii. Possible connection of surface water		3	2	6	Medium	i. No restricted stimulation fluids or PAHS above the reporting limit ii. Lined storages iii. Temporary storage of flowback iv. Controls on reuse of flowback v. Treatment of flowback wastes iv. Where mixed with drill wastes, mix bury cover methods and standards		1	2	2	Low

Drilling	Operation	Rig Activity	Water	Reuse of frac flow back water in drilling activities contaminating aquifers.	Contaminants	Medium to long term effects	No	i. Possible contamination of aquifers		3	2	6	Medium	1. Assessment of aquifer water quality required including pedogenic material required in order to calculate site specific risks. 2. No reuse of recycled frac flow back waters not be authorised.		1	1	1	Very low
Drilling	Completions	Casing and Cementing	Water	Poor cement job	Cement and entrained contaminants, drilling fluids	Moderate and/or medium term effects	No	i. Contamination of aquifers ii. Connection of aquifers	Mandatory Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Qld P& G Act 2004 - covers construction standards	3	4	12	High	i. No restricted stimulation fluids or PAHs ii. Stimulation procedures iii. Construction standards iv. Integrity testing		1	3	3	Low
Drilling	Completions	Rehabilitation	Air	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Particulates	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to landholder, fauna and flora ii. Erosion		3	2	6	Medium	No dust nuisance to be created; e.g. watering; location away from sensitive places; immediate rehab; rehab monitoring		2	2	4	Low
Drilling	Completions	Rehabilitation	Water	Runoff from eroded and disturbed soils to waters	Sediment and water contaminants	Minor and /or short term effects	Yes	Increase in turbidity in local watercourses		3	2	6	Medium	i. Erosion and sediment measures ii. Watercourse buffers		2	1	2	Low
Drilling	Completions	Rehabilitation	Noise	Mechanical activity	Nuisance	Long term - duration of lease (activity occurring over duration of lease)	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Drilling	Operation	Rig activity	Waste	Drilling fluid loss downhole due to circulation loss	Contaminants	Minor and /or short term effects	No	i. Possible contamination of aquifers ii. Possible connection of aquifers		4	4	16	Very High	Drilling muds products targeted at reducing circulation, drilling muds that have low concentrations of contaminants specifically hydrocarbon based. downhole technologies targeted at preventing circulation loss		3	2	6	Medium
Drilling	Operation	Rig activity	Waste	Managment of cement returns	Contaminants	Minor and /or short term effects	No	i. Possible contamination of soil ii. Possible contamination of waters iii. Possible contamination of air		3	2	6	Medium	Cement returns can be stored in cement bins, allowed to harden and then crushed up for disposal to landfill, or just sent to landfill. Different types of drilling can also reduce the amount of cement return volume.	PESCC 24	2	1	2	Low
Drilling	Operation	Chemical Storage	Land	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Land contamination ii. Surface water contamination if there is run-off	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
Drilling	Operation	Chemical Storage	Water	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Surface water contamination ii. Impacts to aquatic flora and fauna	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
Drilling	Operation	Clean Water Storage	Water/Land	Spills	Contamination	Minor and /or short term effects	No	i.erosion		1	1	1	Very Low	Storage of water in purpose built and lined turkeys nest (pond) on site.		1	1	1	Very Low
Drilling	Operation	Rig activity	Light	Light spillage from night time rig activity	Nuisance	Minor and /or short term effects	No	i. Nuisance to landholder		3	2	6	Medium	i. Apply measures to the lights to direct light away from residences ii. No nuisance permitted		2	2	4	Low
Drilling	Operation	Rig activity	Waste	Storage of drilling muds/cuttings in sumps	Contaminants	Minor and /or short term effects	No	i. Possible contamination of soil ii. Possible contamination of waters iii. Possible contamination of air		3	3	9	High	No general waste disposal at well sites. MBC with appropriate quality criteria for residual drilling solids and burial methods		2	2	4	Low
Drilling	Operation	Rig activity	Waste	Management of waste fluid	Contaminants	Minor and /or short term effects	No	i. Possible contamination of soil ii. Possible contamination of waters iii. Possible contamination of air		3	3	9	High	Drilling fluids can be permitted to evaporate, or if tested and meets general waste conditions disposed of at a suitable facility		2	2	4	Low
Gas storage	Construction	Drilling of gas storage wells	Refer to petroleum lease activities: Drilling (assumption that the impacts and risks are the same)										NA						NA
Gas storage	Operation	Rig activity	Waste	Consumables	Contaminants	Minor and /or short term effects	No	i. Possible contamination of soil ii. Possible contamination of waters iii. Possible contamination of air	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	3	3	9	High	Appropriate contaminant release limits		2	2	4	Low
Gas storage	Operation	Rig activity	Noise	Mechanical activity of the rig to drill, insert/remove casing, pump/lift drilling muds and cement and seperate drilling waste at the surface via shaker	Nuisance	Moderate and/or medium term effects	No	i. Nuisance to sensitive places/receptors		3	2	6	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Gas storage	Operation	Well head compression	Noise	Mechanical activity	Nuisance	Moderate and/or medium term effects	No	i. Nuisance to sensitive places/receptors		3	2	6	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential	Note: SC not lilkely to mitigate noise impacts from long-term operations. Noise limits required.	2	2	4	Low
Gas storage	Operation	Well head compression	Air	Mechanical activity	Nuisance	Minor and /or short term effects	No	i. nuisance at sensitive receptor ii. Emissions from machinery		3	2	6	Medium	nuisance control measures and/or alternative arrangements; Ensure sensitive receptor mapping completed; ensure that the fuel burning capacity thresholds are lower than the ERA threshold for fuel burning (i.e. <500kg/h)		2	2	4	Low
Gas storage	Operation	Gas storage	Air	Fugutive emissions from underground reservoirs through poorly constructed cementing and casing of the well and surrounding wells, monitoring bores or water bores	Nuisance	moderate and /or long term effects	Yes	i. nuisance at sensitive receptor ii. Fugutive emissions from storage	Mandatory Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Qld P& G Act 2004 - covers construction standards. Minimum Construction Standards for Water Bores in Australia in Water Act 2000	3	4	12	High	Ensure sensitive receptor mapping completed; No gas storage authorised where gas may migrate to surrounding infrastructure. leak detection and monitoring at the well site and surrounding wells, water bores or monitoring bores. Proper construction and maintenance of the well and surrounding wells, water bores and monitoring bores.		2	2	4	Low
Gas storage	Operation	Rig activity	Air	Mechanical activity of the rig to drill, insert/remove casing, pump/lift drilling muds and cement and seperate drilling waste at the surface via shaker	Nuisance	Minor and /or short term effects	No	i. nuisance at sensitive receptor ii. Emissions from machinery		3	2	6	Medium	Nuisance control measures and/or alternative arrangements; Ensure sensitive receptor mapping completed; ensure that the fuel burning capacity thresholds are lower than the ERA threshold for fuel burning (i.e. <500kg/h)		2	2	4	Low
Gas storage	Completions	Stimulation	Water	Aquifer interferance through interconnection	Stimulation fluids	Minor and /or short term effects	No	i. Contamination of aquifers ii. Connection of aquifers		3	4	12	High	i. Injection well standards ii. Integrity testing		2	3	6	Medium
Gas storage	Completions	Stimulation	Water/Land	Land contamination Water contamination from contaminated land runoff	Stimulation fluid/flow back of new wells cause contamination	Moderate and/or medium term effects	No	i. Contamination of aquifers ii. Connection of aquifers		3	4	12	High	i. Chemical storage requirements, ii. No authorised contaminant releases		2	2	4	Low
Gas storage	Completions	Casing and Cementing	Water	Poor cement job	Cement and entrained contaminants, drilling fluids	Moderate and/or medium term effects	No	i. Contamination of aquifers ii. Connection of aquifers	Mandatory Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Qld P& G Act 2004 - covers construction standards	3	4	12	High	i. No restricted stimulation fluids or PAHs ii. Stimulation procedures iii. Construction standards iv. Integrity testing	Nil	1	3	3	Low

Gas storage	Completions	Rehabilitation	Air	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Particulates	Minor and /or short term effects	No	i. Nuisance to landholder, fauna and flora ii. Erosion		3	2	6	Medium	Erosion and sediment controls in place and maintained	PESCC27.	2	2	4	Low
Gas storage	Completions	Rehabilitation	Water	Runoff from eroded and disturbed soils to waters	Sediment and water contaminants	Long term (for duration of activity)	No	Increase in turbidity in local watercourses		3	2	6	Medium	i. Erosion and sediment measures ii. Watercourse buffers		2	1	2	Low
General Waste Landfill (<5% organic)	Operation	Chemical Storage	Land	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Land contamination ii. Surface water contamination if there is run-off	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (<5% organic)	Operation	Chemical Storage	Water	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Surface water contamination ii. Impacts to aquatic flora and fauna	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (<5% organic)	Operation	Disposal operations	Community	Waste become food / harbourage for pests.	Vermin	Short term	No	Spread of disease to the community	Health Act	5	2	10	High	i. Exclude pest animals ii. Cover waste to reduce access to food source iii. Remove breeding opportunities (i.e. limiting water ponding reduces mosquito breeding)		2	2	4	Low
General Waste Landfill (<5% organic)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat A ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss ii. Infiltration of invasive species (pests and predators) iii. Habitat impacts / loss / fragmentation	i. P&G Act 2004 ii. NC Act (clearing permits) iii. NC Act (interfering with animal breeding places iv. EPBC Act	5	4	20	Extreme	Not permitted. To mitigate risks in Cat A ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
General Waste Landfill (<5% organic)	Widening, or repair or construction	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	4	20	Extreme	Not permitted. To mitigate risks in Cat B ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
General Waste Landfill (<5% organic)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	3	15	Very High	Not permitted. Only essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself		1	3	3	Low
General Waste Landfill (<5% organic)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	No landfill activities in ESA buffers (note: state forests and timber reserves do not have buffers)	PESCB1.	1	3	3	Low
General Waste Landfill (<5% organic)	Site Preparation	Clearing	Land	Construction activities / earthworks exposes soil.	Erosion from site smothering surrounding vegetation.	Short term	No	Localised impact to vegetation surrounding the site.		4	2	8	Medium	i. Erosion and sediment controls in place and maintained ii. Dust suppression	PESCB1, PESCC27.	2	2	4	Low
General Waste Landfill (<5% organic)	Site Preparation	Clearing	Air	Construction activities / earthworks exposes soil.	Wind erosion (dust) creates an environmental nuisance.	Short term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	2	4	Low
General Waste Landfill (<5% organic)	Site Preparation	Traversing	Biodiversity	Movement of vehicles / machinery introduces invasive species onto the site.	Weeds	Long term	Yes	Reduction in species diversity. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
Drilling	Operation	Earthworks	Subterreanean wetlands (including caves and aquifers)	Activities in subsurface wetlands	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	Yes	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	P&G Act 2004	5	3	15	Very High	i. No drilling in subterreanean wetlands that are caves. ii. Activities unavoidable in aquifers		1	1	1	Very Low
Borrow pits/quarries	Operation	Earthworks	Subterreanean wetlands (including caves and aquifers)	Activities in subsurface wetlands	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	Yes	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	P&G Act 2004	5	3	15	Very High	i. No borrow pits in subsurface wetlands that are caves ii. Activities unavoidable in aquifer wetlands		1	1	1	Very Low
General Waste Landfill (<5% organic)	Operation	Acceptance	Waste	Insufficent construction standards for waste characteristics	Contamination	Long term	Yes	Harm caused by the inappropriate storage, transport or disposal of waste. Note: (1) Waste tracking requirements under the EP Act (2) Offence of giving regulated waste to an unlicensed transporter.	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	3	3	9	High	Conditions to restrict the types of waste that can be disposed of on site.		2	3	6	Medium
General Waste Landfill (<5% organic)	Operation	Management of landfill surface	Land	Erosion of cover material or batters	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	2	4	Low
General Waste Landfill (<5% organic)	Operation	Management of landfill surface	Air	Wind erosion of cover material or batters	Nuisance	Short to medium term	Yes	Dust generated from site negatively impacts on surrounding sensitive places		4	3	12	High	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	3	6	Medium
General Waste Landfill (<5% organic)	Operation	Stockpilling of cover material	Water	Erosion of stockpiled cover material	Runoff and sedimentation	Long term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	4	16	Very High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	4	8	Medium
General Waste Landfill (<5% organic)	Operation	Stockpilling of cover material	Land	Erosion of stockpiled cover material	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Dust suppression	PESCB1, PESCC27.	2	2	4	Low
General Waste Landfill (<5% organic)	Operation	Stockpilling of cover material	Air	Wind erosion of stockpiled cover material	Nuisance	Long term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	3	12	High	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	2	4	Low
General Waste Landfill (<5% organic)	Operation	Mechanical activity	Noise	Movement of vehicles / machinery	Nuisance	Long term (for duration of activity)	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Traversing	Biodiversity	Movement of vehicles / machinery introduces invasive species onto the site.	Weeds	Long term	Yes	Reduction in species diversity. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste with <5% organics)	Operation	Waste Burial	Air	Disposal of waste generates odours	Nuisance	Long term	No	Odours emitted from site negatively impacts on surrounding sensitive places.		3	2	6	Medium	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		1	2	2	Low

General Waste Landfill (<5% organic)	Post Closure Care	Management of settlement	Water	Cover material failure, water seepage and leachate to groundwater	Contamination	Long term	No	i. Contamination of groundwater ii. Contamination of surface waters Ii. Negative effects to groundwater dependant ecosystems		4	4	16	Very High	i. Waste restricted to non-organic general waste only ii. Liner and cover standards required iii. No contaminant releases to waters as a result of landfill activities iv. Rehabilitation conditions		2	2	4	Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Mechanical activity	Noise	Construction activities generate noise	Nuisance	Short term	Yes	i. Nuisance to sensitive places/receptors if in close proximity		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Mechanical activity	Light	Construction activities generate excess light	Nuisance	Short term	Yes	Light emitted from site negatively impacts on surrounding sensitive place if in close proximity.		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	2	4	Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Waste Burial	Social	Spontaneous combustion of waste.	Fire	Short term	No	(1) Release of toxic fumes due to combustion. (2) Damage to infrastructure. (3) Spread of fire to surrounds	P&G Act 2004				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste with <5% organics)	Operation	Waste Burial	Social	Waste provides a food source or harbourage for disease vectors and other pest species	Pests	Long term	No	i. Spread of disease to humans ii.Impacts on biodiversity by inflating numbers for pest species.	Related requirements under the Public Health Act				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste with <5% organics)	Operation	Waste Burial	Biodiversity	Native animal enters the landfill site.	Injury to fauna (struck by machinery, falling into landfill cell)	Short term	No	Injury or mortality of animal due to being stuck by machinery or falling into landfill void		3	3	9	High	Measures to prevent fauna entrapment.		2	3	6	Medium
General Waste Landfill (Solid waste with <5% organics)	Operation	Leachate management and disposal	Land	Leachate is released from site due to poor leachate containment systems	Contaminants	Long term	No	Contamination of land		4	4	16	Very High	Prescriptive conditions to: i. Reduce water entry into landfill ii.Restrict waste type to general waste iii. Landfill constructed to engineering standards iv. Leachate collection system v. Leachate monitoring requirements vi. No liquid wastes		2	3	6	Medium
General Waste Landfill (Solid waste with <5% organics)	Operation	Leachate management and disposal	Water	Leachate is released from site due to poor leachate containment systems	Contaminants	Long term	Yes	i. Contamination of groundwater ii. Contamination of surface waters Ii. Negative effects to groundwater dependant ecosystems		5	5	25	Extreme	i. Waste restricted to non-organic general waste only ii. Liner and cover standards required iii. No contaminant releases to waters as a result of landfill activities iv. Rehabilitation conditions		2	3	6	Medium
General Waste Landfill (<5% organic)	Operation	Chemical Storage	Water	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Surface water contamination ii. Impacts to aquatic flora and fauna	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (Solid waste)	Operation	Chemical Storage	Land	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Land contamination ii. Surface water contamination if there is run-off	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (Solid waste)	Operation	Chemical Storage	Water	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Surface water contamination ii. Impacts to aquatic flora and fauna	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (Solid waste)	Operation	Chemical Storage	Water	i. Leakage ii. Spillage	Contaminants	Minor and /or short term effects	No	i. Surface water contamination ii. Impacts to aquatic flora and fauna	AS1940 - Fuel Storage	3	2	6	Medium	i. Fuel - AS1940 storage requirements ii. Chemical Storage - bunding or still containment pallets iii. No contaminant releases to waters from chemical storage activities iv. No contaminant releases to land from chemical storage activities		2	1	2	Low
General Waste Landfill (Solid waste with <5% organics)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	4	20	Extreme	Not permitted. To mitigate risks in Cat B ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
General Waste Landfill (Solid waste with <5% organics)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	3	15	Very High	Not permitted. Only essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself		1	3	3	Low
General Waste Landfill (Solid waste with <5% organics)	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	No landfill activities in ESA buffers (note: state forests and timber reserves do not have buffers)		1	3	3	Low
General Waste Landfill (Solid waste)	Construction	Clearing	Water	Construction activities / earthworks exposes soil.	Runoff and sedimentation	Short term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
General Waste Landfill (Solid waste)	Construction	Clearing	Air	Construction activities / earthworks exposes soil.	Nuisance	Short term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	2	8	Medium	Nuisance control measures and/or alternative arrangements		2	2	4	Low
General Waste Landfill (Solid waste)	Construction	Traversing	Biodiversity	Movement of vehicles / machinery introduces invasive species onto the site.	Weeds	Long term	Yes	Reduction in species diversity. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste)	Operation	Acceptance	Waste	Insufficent construction standards for waste characteristics	Contamination	Long term	Yes	Harm caused by the inappropriate storage, transport or disposal of waste. <u>Note:</u> (1) Waste tracking requirements under the EP Act (2) Offence of giving regulated waste to an unlicensed transporter.	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	3	3	9	High	Conditions to restrict the types of waste that can be disposed of on site.		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Leachate management and disposal	Land	Leachate is released from site due to poor leachate containment systems	Contaminants	Long term	No	Contamination of land		4	4	16	Very High	Limited organic material reduces this risk and the need for leachate systems.		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Leachate management and disposal	Water	Leachate is released from site due to poor leachate containment systems	Contaminants	Long term	Yes	i. Contamination of groundwater ii. Contamination of surface waters Ii. Negative effects to groundwater dependant ecosystems		4	4	16	Very High	i. Waste restricted to non-organic general waste only ii. Liner and cover standards required iii. No contaminant releases to waters as a result of landfill activities iv. Rehabilitation conditions		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Management of landfill surface	Land	Erosion of cover material or batters	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	2	8	Medium	Sediment and erosion conditions		2	2	4	Low
General Waste Landfill (Solid waste)	Operation	Management of landfill surface	Air	Wind erosion of cover material or batters	Nuisance	Short to medium term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	3	12	High	i. Site planning activities to locate away from sensitive receptors ii. Nuisance conditions and alternative arrangements		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Stockpilling of cover material	Water	Erosion of stockpiled cover material	Erosion from stockpiled material leading to the sedimentation of waterways.	Long term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	4	16	Very High	Sediment and erosion conditions		2	4	8	Medium
General Waste Landfill (Solid waste)	Operation	Stockpilling of cover material	Land	Erosion of stockpiled cover material	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	3	12	High	Sediment and erosion conditions		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Stockpilling of cover material	Air	Wind erosion of stockpiled cover material	Nuisance	Long term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	3	12	High	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	3	6	Medium

General Waste Landfill (Solid waste)	Operation	Mechanical activity	Noise	Movement of vehicles / machinery	Nuisance	Long term	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
General Waste Landfill (Solid waste)	Operation	Traversing	Biodiversity	Movement of vehicles / machinery introduces invasive species onto the site.	Weeds	Long term	Yes	Reduction in species diversity. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste)	Operation	Waste Burial	Air	Disposal of waste generates odours	Nuisance	Long term	No	Odours emitted from site negatively impacts on surrounding sensitive places.		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Nuisance conditions and alternative arrangements		1	2	2	Low
General Waste Landfill (Solid waste)	Post Closure Care	Management of capping	Water	The inappropriate post closure management of the site leads to failure of the integrity of the landfill capping.	Water entering the landfill through the capping which generates leachate which exceeds the capacity or expected working life of the leachate management system.	Long term	No	Reduction in quality of groundwater which limits its use.		4	4	16	Very High	i. Conditions for the post closure care of the landfill until it is proven to be geotechnically stable and there are no ongoing risks to the environment ii. Landfill constructed on freehold land owned by the holder of the EA iii. Location of landfill and waste contained is recorded iv. Landfill added to EMR (contaminated lands) with associated management requirements.		2	4	8	Medium
General Waste Landfill (Solid waste)	Post Closure Care	Natural disaster type event – Future storm event uproots tree growing on landfill capping	Water	Overtime trees establish on surface of closed landfill. Then in the future a storm event uproots a tree.	The removal of root-ball exposes buried waste.	Short term	No	(1) Generation of leachate which contaminants waters (2) Generation of landfill gas causes fire or explosion risk		2	4	8	Medium	Ongoing and longterm removal of deep rooted vegetation from surface of completed landfill.		1	4	4	Low
General Waste Landfill (Solid waste)	Rehabilitation	Maintainance	Biodiversity	The inappropriate post closure management of the site leads to the spread of invasive species	Weeds	Long term	Yes	Reduction in species diversity. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste)	Post Closure Care	Management of settlement	Water	Settlement of the landfill leads to failure of the landfill capping.	Water entering the landfill through the capping which generates leachate which exceeds the capacity or expected working life of the leachate management system.	Long term	No	i. Reduction in quality of groundwater which limits its use. Ii.Potential negative impact on springs and their associated ecosystems.		4	4	16	Very High	i. Conditions for the post closure care of the landfill until it is proven to be geotechnically stable and there are no ongoing risks to the environment ii. Landfill constructed on freehold land owned by the holder of the EA iii. Location of landfill and waste contained is recorded iv. Landfill added to EMR (contaminated lands) with associated management requirements.		2	4	8	Medium
General Waste Landfill (Solid waste)	Operation	Mechanical activity	Noise	Movement of vehicles / machinery	Nuisance	Short term	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
General Waste Landfill (Solid waste)	Operation	Mechanical activity	Light	Light nuisance	Nuisance	Short term	Yes	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Nuisance conditions and alternative arrangements		2	2	4	Low
General Waste Landfill (Solid waste)	Operation	Waste gas management (decomposion of waste generates landfill gas 50% CO2 50% CH4 + trace elements)	Air	The burial of general waste and the generation of landfill gas creates odours	Nuisance	Long term	No	Odours emitted from site negatively impacts on surrounding sensitive places.		5	2	10	High	i. Waste covered (daily if near sensitive place, otherwise weekly) ii. Nuisance conditions		3	2	6	Medium
General Waste Landfill (Solid waste)	Operation	Waste gas management (decomposion of waste generates landfill gas 50% CO2 50% CH4 + trace elements)	Air	Uncontrolled release of landfill gas to the atmosphere	Greenhouse gas emissions	Long term	Yes	Release of greenhouse gases to the atmosphere negatively impacting on the environmental value of air.		5	2	10	High	Destruction of gases through flaring at completion of cell for as long as significant levels of landfill gases are being generated.	PESCC34 flaring SC only relates to P&G authorised	2	2	4	Low
General Waste Landfill (Solid waste)	Operation	Waste gas management (decomposion of waste generates landfill gas 50% CO2 50% CH4 + trace elements)	Social	Landfill gas is explosive under certain conditions	Explosion of landfill gas.	Short term	No	Explosion of landfill gas causes injuries to people, animals or damages flora.		3	5	15	Very High	i.Waste covered (daily if near sensitive place, otherwise weekly) ii. Completed cells capped. Iii.Flaring of landfill gas. (4) Control of ignition sources on site - e.g. no naked flames. (5) Post closure conditions for ongoing management of site		1	5	5	Medium
General Waste Landfill (Solid waste)	Operation	Waste Burial	Social	Spontaneous combustion of waste.	Fire	Short term	No	i. Release of toxic fumes due to combustion. Ii. Damage to infrastructure. Iii.Spread of fire to surrounds		3	3	9	High	i. Provision of fire fighting equipment. ii. Fire break to surround landfill. iii. Control of ignition sources on site to reduce risk of igniting landfill gas (e.g. no naked flames).		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Waste Burial	Social	Waste provides a food source or harbourage for disease vectors and other pest species	Vermin	Long term	No	Spread of disease to humans.	Related requirements under the Public Health Act				NA	Comply with other legislative requirements					NA
General Waste Landfill (Solid waste)	Operation	Fauna enters landfill	Biodiversity	Native fauna enters the landfill site	Injury to fauna (struck by machinery, falling into landfill cell)	Short term	No	Injury or mortality of animal due to being stuck by machinery or falling into landfill void		3	3	9	High	Measures to prevent fauna entrapment condition required.		2	3	6	Medium
General Waste Landfill (Solid waste)	Operation	Stock enters landfill	Social	Stock enters the landfill site - ie foraging on disposed food waste.	Injury to fauna (struck by machinery, falling into landfill cell)	Short term	No	Injury or mortality of animal due consuming contaminated food waste.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
General Waste Landfill (<5% organic)	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Flow	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology		5	3	15	Very High	No landfill activities in wetlands or their buffer		1	1	1	Very Low
General Waste Landfill (<5% organic)	Operation	Earthworks	Subterreanean wetlands (including caves and aquifers)	Activities in subsurface wetlands	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	Yes	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	P&G Act 2004	5	3	15	Very High	i. No landfill activities in subsurface wetlands that are caves ii. Activities unavoidable in aquifer wetlands		1	1	1	Very Low
General Waste Landfill (Solid waste)	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Groundwater	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	No landfill activities in wetlands or their buffer		1	1	1	Very Low

General Waste Landfill (Solid waste)	Operation	Earthworks	Subterreanean wetlands (including caves and aquifers)	Activities in subsurface wetlands	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	Yes	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	P&G Act 2004	5	3	15	Very High	i. No landfill activities in subsurface wetlands that are caves ii. Activities unavoidable in aquifer wetlands		1	1	1	Very Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs vi. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	No landfill activities in wetlands or their buffer		1	1	1	Very Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Earthworks	Subterreanean wetlands (including caves and aquifers)	Activities in subsurface wetlands	Contaminants Groundwater Flow	Potentially long term depending on the nature of the event	Yes	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	P&G Act 2004	5	3	15	Very High	i. No landfill activities in subsurface wetlands that are caves ii. Activities unavoidable in aquifer wetlands		1	1	1	Very Low
General Waste Landfill (Solid waste with <5% organics)	Operation	Earthworks	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Activities in surface water systems	Contaminants Flow	Potentially long term depending on the nature of the event	No	i. Contamination ii. Loss of water supply to dependant systems iii. Impacts to related groundwater dependant ecosystems iv. Changes to pressure of GAB springs v. Impacts to fauna vi. Change in surface and subsurface hydrology	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	5	3	15	Very High	No landfill activities in wetlands or their buffer		1	1	1	Very Low
General Waste Landfill (Solid waste)	Operation	Waste Burial	Social	Waste provides a food source or harbourage for disease vectors and other pest species	Artificially increasing pest numbers (e.g. feral cats)	Long term	No	Impacts on biodiversity by inflating numbers for pest species.	Related requirements under the Public Health Act				NA	Comply with other legislative requirements					NA
Pipelines for production	Clear and grade	Watercourse crossing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Protected species	Moderate and/or medium term effects	protected species - permanent loss	i. Reduction in species, further endangerment or loss		5	3	15	Very High	i. Route selection to limit or avoid watercourse crossings where practicable ii. HDD or similar for high value watercourses where practicable iii. Reduce ROW width as far as practical iv. Site to avoid EVR species iv. Time crossing in periods of low or no flow v. Divert flow if necessary vi. Reinstate as soon as possible	PESCB1	3	2	6	Medium
Pipelines for production	Clear and grade	Watercourse crossing	Water	Clearing vegetation using heavy machinery (forest mulcher)	Erosion	Minor and/or short term effects	yes	i. Increase in erosion ii. Increase in sedimentation and turbidity		5	3	15	Very High	i. Limit or avoid grading topsoil from pipeline construction area on watercourse approaches ii. Delay clearing of clearing of slopes leading to watercourses until construction is iminent iii. Maximise ground cover retention where practicable iv. Reinstate as soon as practical	PESCB1	3	2	6	Medium
Pipelines for production	Clear and grade	Watercourse crossing	Water	runoff from eroded and disturbed soils to waters	Contaminants		yes	destabilisation of bank or beds, increases turbidity of water		5	3	15	Very High	i. Route selection to limit or avoid watercourse crossings where practicable ii. HDD or similar for high value watercourses where practicable iii. Reduce ROW width as far as practical iv. Time crossing in periods of low or no flow v. Divert flow if necessary vi. Reinstate as soon as possible		3	2	6	Medium
Pipelines for production	Trenching	Watercourse crossing	Water	Flow disruption/ diversion	Flow disruption/ diversion	Moderate and/or medium term effects	Yes	Impacts on aquatic ecosystem		5	3	15	Very High	i. Trenchless method; e.g. directional drilling or aerial crossing ii. Works conducted in times of no flow iii. Works conducted in times of flow - water impoundment, flow diversion - duration minimised iv. Rehabilitation immediately upon cessation activity		3	2	6	Medium
Pipelines for production	Trenching	Watercourse crossing	Water	Soil disturbance (cut, fill, grading, compaction) using heavy machinery	Contamination	Moderate and/or medium term effects	Yes	i. Increased turbidity ii. Impact on aquatic ecosystems		5	3	15	Very High	i. Trenchless methods (e.g. directional drilling or aerial crossing) ii. Minimise duration iii. No impeding flow iv. No draining, filling, ingress,change to water table and pressure iv. Bank stabilisation v. Rehabilitation immediately upon cessation activity vi. Guideline as reference tool		3	2	6	Medium
Pipelines for production	Trenching	Watercourse crossing	Biodiversity	Soil disturbance (cut, fill, grading and compaction) using heavy machinery	Loss of aquatic species	Moderate and/or medium term effects	Yes	i. Impacts to fauna		5	3	15	Very High	i. Trenchless methods (e.g. directional drilling or aerial crossing) ii. Minimise duration iii. No impeding flow iv. No draining, filling, ingress,change to water table and pressure iv. Bank stabilisation v. Rehabilitation immediately upon cessation activity vi. Guideline as reference tool		3	2	6	Medium
Pipelines for production	Hydrotest	Hydrotest	Groundwater dependant ecosystems (includes caves but excludes subterreanean aquifer systems by virtue of the unfetted right to take)	Mechanically pumping out underground water to reduce the water level/pressure downhole	Lack of supply	Moderate and/or medium term effects	No	Lack of supply	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	1	3	3	Low	i. Minimise extraction of water to only that volume necessary ii. No activities in or above cave GDEs.		1	3	3	Low
Pipelines for production	Hydrotest	Hydrotest	Water	Water storage	Temporary pond construction	Short term effects	No	Contamination of land Contamination of water		3	2	6	Medium	i. Above ground storage ii. Short term, temporary storage ii. Containment of the wetting front		2	2	4	Low
Pipelines for production	Hydrotest	Hydrotest	Biodiversity	Releases to water	Impact to aquatic ecosystems	Moderate and/or medium term effects	No	Toxicity		3	3	6	Medium	i. Not authorised unless site specific assessment ii. No toxicity so biocides and additives to be controlled.		1	1	1	Very Low
Pipelines for production	Hydrotest	Hydrotest	Land	Release to land	Soil contamination	Moderate and/or medium term effects	Yes	Contamination of land		3	3	6	Medium	i. Controls on release methods to the environment ii. Controls of quality of releases including no biocides to be released to the environment without site specific assessment		3	2	6	Medium
Pipelines for production	Hydrotest	Hydrotest	Biodiversity	Spills	Impact to aquatic ecosystems	Moderate and/or medium term effects	No	Toxicity		3	2	6	Medium	i. Emergency response or contingency procedures ii. Controls on release methods to the environment ii. Controls of quality of releases including no biocides to be released to the environment without site specific assessment iii. Discharges to waters not authorised unless site specific assessment		2	2	4	Low
Pipelines for production	Hydrotest	Hydrotest	Land	Spills	Soil contamination	Short to medium term effects	No	Contamination of land		3	2	6	Medium	i. Emergency response or contingency procedures ii. Controls on release methods to the environment ii. Controls of quality of releases including no biocides to be released to the environment without site specific assessment iii. Discharges to waters not authorised unless site specific assessment		2	1	2	Low

Production testing	Flow Testing	Flaring or venting	Noise	Flaring or venting combustion or fuel burning equipment	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Production testing	Flow Testing	Flaring or venting	Air	Flaring or venting combustion or fuel burning equipment	Greenhouse gas emissions	Minor and /or short term effects	No	i. Increase in air emissions	i. P&G Act 2004 ii. Carbon legislative framework	3	3	9	High	Minimise flaring and venting per P&G Act; increase combustion efficiency.		2	3	6	Medium
Production testing	Water Production	Depressurise coal	Groundwater dependant ecosystems (includes caves but excludes subterreanean aquifer systems by virtue of the unfetted right to take)	Mechanically pumping out produced water and lowering downhole pressures	Lack of supply	Minor and /or short term effects	Yes	i. Landholder water supply impacted	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	3	4	12	High	i. Comply with the Underground Water Impact Report ii. Comply with the Spring Impact Management Strategy iii.No activities in or above subterranean cave GDE iv. Terrestrial GDEs that are riverine RE GDE vegetation to be protected under disturbance to land/ESA conditions		3	4	12	High
Production testing	Water Production	Dam constuction	Land	Poor construction standard	Erosion and Compaction	Moderate and/or medium term effects	No	i. Loss of productive capacity ii. Impact on future land use		3	4	12	High	Appropriate dam design construction and operation standards		2	3	6	Medium
Production testing	Water Production	Dam constuction	Land	Poor construction standard	Contaminants	Moderate and/or medium term effects	No	i. Land contamination ii. Shallow aquifer contamination		3	4	12	High	Appropriate dam design construction and operation standards		2	3	6	Medium
Production testing	Water Production	Dam constuction	Land	Poor construction standard	Erosion	Moderate and/or medium term effects	No	i. Erosion impacts from water release ii. Potential stock or crop losses iii. Impact on existing infrastructure		3	3	9	High	Appropriate dam design construction and operation standards		2	3	6	Medium
Salt Landfill	Site Preparation	Clearing	Surface wetlands (including watercourse, lakes, springs, GAB springs, GAB watercourse springs)	Impacts to wetlands (including watercourses, lakes, springs, GAB springs) and watercourses	Activities in surface water systems	Long term - duration of lease (activity occurs over duration of lease)	No	i. Decline in water quality and hydrological systems ii. Habitat impacts / loss / fragmentation		5	4	20	Extreme	No camps in surface wetlands		1	1	1	Very Low
Salt Landfill	Operation	Storage of chemicals (including fuel)	Land	Leakage or spillage of chemicals.	Contamination	Short term	No	Damage to fauna, flora and soil structure.		4	4	16	Very High	Design requirements for chemical storage containers / facilities		2	4	8	Medium
Salt Landfill	Operation	Chemical Storage	Water	Leakage or spillage of chemicals.	Release of chemicals to surface waters	Short term	No	Negative impact on aquatic ecosystems (e.g. fish kills)		4	4	16	Very High	Design requirements for chemical storage containers / facilities		2	4	8	Medium
Salt Landfill	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Habitat loss and fragmentation	Long term	Yes	i.Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act	5	3	15	Very High	Landfill prohibited from ESA.		2	3	6	Medium
Salt Landfill	Site Preparation	Clearing	Water	Construction activities / earthworks exposes soil.	Runoff and sedimentation	Short term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
Salt Landfill	Site Preparation	Clearing	Land	Construction activities / earthworks exposes soil.	Erosion from site smothering surrounding vegetation.	Short term	No	Localised impact to vegetation surrounding the site.		4	2	8	Medium	i. Erosion and sediment controls in place and maintained ii. Dust suppression	PESCB1, PESCC27.	2	2	4	Low
Salt Landfill	Site Preparation	Clearing	Air	Construction activities / earthworks exposes soil.	Wind erosion (dust) creates an environmental nuisance.	Short term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	2	8	Medium	Nuisance control measures and/or alternative arrangements		2	2	4	Low
Salt Landfill	Construction	Traversing	Biodiversity	Movement of vehicles / machinery	Weeds	Long term	Yes	i. Reduction in species diversity. Ii. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
Salt Landfill	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat A ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss ii. Infiltration of invasive species (pests and predators) iii. Habitat impacts / loss / fragmentation	i. P&G Act 2004 ii. NC Act (clearing permits) iii. NC Act (interfering with animal breeding places iv. EPBC Act	5	4	20	Extreme	To mitigate risks in Cat A ESAs, activities must not include signficant disturbance - only low impact.		1	4	4	Low
Salt Landfill	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	4	20	Extreme	Not permitted. Only essential petroleum activities are permitted in Cat B ESAs as these types of activities still protect the ESA itself		1	4	4	Low
Salt Landfill	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	5	3	15	Very High	Not permitted. Only essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself		1	3	3	Low
Salt Landfill	Site Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Long term - duration of lease (activity recurring over duration of lease)	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	No landfill activities in ESA buffers (note: state forests and timber reserves do not have buffers)		1	3	3	Low
Salt Landfill	Operation	Acceptance	Waste	Insufficent construction standards for waste characteristics	Contamination	Long term	Yes	Harm caused by the inappropriate storage, transport or disposal of waste. Note: (1) Waste tracking requirements under the EP Act (2) Offence of giving regulated waste to an unlicensed transporter.	Waste management hierarchy under Waste Reduction and Recycling Act 2011 and subordinate legislation	3	3	9	High	Conditions to restrict the types of waste that can be disposed of on site.		2	3	6	Medium
Salt Landfill	Waste generation	Fauna enters landfill	Biodiversity	Injury to animal (struck by machinery, falling into landfill cell)	loss or injury to fauna	Short term	No	Reduction in species, further endangerment or loss		3	3	9	High	i. Measures to prevent fauna entrapment condition required. ii.Animal being stuck by landfill machinery risk would be managed through onsite WHS requirements to protect workings / visitors. Including speed limits, training of operators, fatigue management.		2	3	6	Medium
Salt Landfill	Leachate management	Management and disposal of saline leachate generated form the waste.	Land	Highly saline leachate is released from site due to poor leachate containment systems	Contaminants	Long term	No	Addition of salts to lands impacts plant growth / survival.		4	3	12	High	i. Reduce water entry into landfill ii.Restrict waste type to solid salt iii. Landfill constructed to engineering standards iv. No liquid wastes iv. Leachate collection system v. Leachate monitoring requirements		2	3	6	Medium
Salt Landfill	Operation	Leachate management and disposal	Land	Highly saline leachate is released from site due to poor leachate containment systems	Contaminants	Long term	No	Contamination of land		4	4	16	Very High	i. Reduce water entry into landfill ii.Restrict waste type to solid salt iii. Landfill constructed to engineering standards iv. No liquid wastes iv. Leachate collection system v. Leachate monitoring requirements		2	4	8	Medium
Salt Landfill	Operation	Leachate management and disposal	Water	Highly saline leachate is released from site due to poor leachate containment systems	Contaminants	Long term	Yes	i. Contamination of groundwater ii. Contamination of surface waters Ii. Negative effects to groundwater dependant ecosystems		4	4	16	Very High	i. Reduce water entry into landfill ii.Restrict waste type to solid salt iii. Landfill constructed to engineering standards iv. No liquid wastes iv. Leachate collection system v. Leachate monitoring requirements		2	4	8	Medium

Salt Landfill	Operation	Management of landfill surface	Land	Erosion of cover material or batters	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	2	8	Medium	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	2	4	Low
Salt Landfill	Operation	Management of landfill surface	Air	Wind erosion of cover material or batters	Nuisance	Short to medium term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	3	12	High	i. Site planning activities to locate away from sensitive receptors ii. Environmental nuisance conditions and alternative arrangements		2	3	6	Medium
Salt Landfill	Operation	Stockpilling of cover material	Water	Erosion of stockpiled cover material	Runoff and sedimentation	Long term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	4	16	Very High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	4	8	Medium
Salt Landfill	Operation	Stockpilling of cover material	Land	Erosion of stockpiled cover material	Erosion from stockpiled material smothers surrounding vegetation.	Long term	No	Localised impact to vegetation surrounding the site.		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Dust suppression	PESCB1, PESCC27.	2	3	6	Medium
Salt Landfill	Operation	Stockpilling of cover material	Air	Wind erosion of stockpiled cover material	Wind erosion (dust) creates an environmental nuisance.	Long term	Yes	Dust generated from site negatively impacts on surrounding sensitive places.		4	3	12	High	Nuisance control measures and/or alternative arrangements		2	3	6	Medium
Salt Landfill	Operation	Mechanical activity	Noise	Noise generate from landfill machinery.	Nuisance	Long term	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Salt Landfill	Operation	Traversing land	Biodiversity	Movement of vehicles / machinery	Weeds	Long term	Yes	i. Reduction in species diversity. Ii. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
Salt Landfill	Operation	Waste Burial	Air	Disposal of salt waste generates odours	Nuisance	Long term	No	Odours emitted from site negatively impacts on surrounding sensitive places.		2	2	4	Low	Odours from site should not create a nuisance		1	2	2	Low
Salt Landfill	Operation	Waste Burial	Waste	Reduced life of landfill by not appropriately compacting waste.	Landfill life is not maximised.	Long term	Yes	Inappropriate compaction of waste results in the need to have a larger landfill footprint or shorter landfill life resulting in further land disturbance.		4	3	12	High	Mechanical compaction of waste.		2	3	6	Medium
Salt Landfill	Post Closure Care	Management of capping	Water	The inappropriate post closure management of the site leads to failure of the integrity of the landfill capping.	Water entering the landfill through the capping which generates saline leachate which exceeds the capacity or expected working life of the leachate management system.	Long term	No	Reduction in quality of groundwater which limits its use.		4	5	20	Extreme	i. Conditions for the post closure care of the landfill until it is proven to be geotechnically stable and there are no ongoing risks to the environment ii. Landfill constructed on freehold land owned by the holder of the EA iii.Location of landfill and waste contained is recorded.		2	5	10	High
Salt Landfill	Operation	Management of landfill surface	Water	Erosion of cover material or batters	Runoff and sedimentation	Long term	Yes	Degradation of waterways by changing the water quality / increasing the sediment load.		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
Salt Landfill	Rehabilitation	Maintainance	Biodiversity	Inappropriate post closure management of the site leads to the spread of invasive species	Weeds	Long term	Yes	i. Reduction in species diversity. Ii. Replacement of native species with invasive species.	Land Protection (Pest and Stock Route Management) Act 2002.				NA	Comply with other legislative requirements					NA
Salt Landfill	Post Closure Care	Management of settlement	Water	Settlement of the landfill leads to failure of the landfill capping.	Water entering the landfill through the capping which generates saline leachate which exceeds the capacity or expected working life of the leachate management system.	Long term	No	Reduction in quality of groundwater which limits its use.		4	4	16	Very High	i.Conditions for the post closure care of the landfill until it is proven to be geotechnically stable and there are no ongoing risks to the environment ii. Landfill constructed on freehold land owned by the holder of the EA iii. Location of landfill and waste contained is recorded.		2	5	10	High
Salt Landfill	Vehicles and Plant	Use of vehicles, plant and equipment.	Noise	Construction activities generate noise	Nuisance	Short term	Yes	i. Nuisance to sensitive places/receptors		5	2	10	High	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Salt Landfill	Vehicles and Plant	Use of vehicles, plant and equipment.	Light	Construction activities generate excess light	Nuisance	Short term	Yes	Light emitted from site negatively impacts on surrounding sensitive places.		5	2	10	High	Outcome foused general environmental nuisance conditions.		2	2	4	Low
Salt Landfill	Post Closure Care	Longterm management of saline leachate	Water	Post closure failure leads to release of contaminants	Release of saline leachate to groundwater	Long term	Yes	Reduction in quality of groundwater which limits its use.		4	5	20	Extreme	i.Landfill liner and capping system ii.Leachate collection systems iii.Exclusion of rainfall and runoff from the waste to reduce leachate generation iv.Site on freehold land owned by EA holder v.Records of amount of waste disposed vi.Groundwater monitoring vii.Post closure care of the site until the site becomes geotechnically stable					NA
Salt Landfill	Vehicles and Plant	Use of vehicles, plant and equipment.	Air	Construction activities generate odours	Nuisance	Short term	No	Odours emitted from site negatively impacts on surrounding sensitive places.		3	2	6	Medium	Odours from site should not create a nuisance		3	2	6	Medium
Seismic	Line Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat A ESA values	Moderate and/or medium term effects	Yes	i. Reduction in species, further endangerment or loss ii. Infiltration of invasive species (pests and predators) iii. Habitat impacts / loss / fragmentation	i. P&G Act 2004 ii. NC Act (clearing permits) iii. NC Act (interfering with animal breeding places iv. EPBC Act	4	3	12	High	Not permitted. To mitigate risks in Cat A ESAs, activities must not include signficant disturbance - only low impact.		1	3	3	Low
Seismic	Line Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat B ESA values	Moderate and/or medium term effects	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	Not permitted. To mitigate risks in Cat B ESAs, activities must not include signficant disturbance - only low impact.		1	3	3	Low
Seismic	Line Preparation	Clearing	Biodiversity	clearing vegetation using heavy machinery (forest mulcher)	Loss of Cat C ESA values	Moderate and/or medium term effects	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	i. Essential petroleum activities are permitted in Cat C ESAs as these types of activities still protect the ESA itself (this includes seismic) ii. Avoid activities in Cat C ESAs as the first preference iii. Then select pre-disturbed sites iv. Then plan site for minimum disturbance v. Cumulative impacts to be checked as activities progress in Cat C ESAs	PESCB1.	4	3	12	High
Seismic	Line Preparation	Clearing	Biodiversity	Clearing vegetation using heavy machinery (forest mulcher)	Loss of ESA buffer values	Moderate and/or medium term effects	Yes	i. Reduction in species, further endangerment or loss; ii. Infiltration of invasive species (pests and predators); iii. Habitat impacts / loss / fragmentation	i. NC Act (clearing permits) ii. NC Act (interfering with animal breeding places) iii. EPBC Act 1999 (Cth)	4	3	12	High	i. Only essential petroleum activities in secondary buffer of Cat A and buffer of Cat B or C as these types of activities still protect the ESA itself (seismic is permitted) ii. Plan site for minimum disturbance iii. Select pre-disturbed sites as the preference	PESCB1.	3	2	6	Medium
Gas production	Flow Line construction	Construction	Water	Runoff from eroded and disturbed soils to waters	Runoff and sedimentation	long term - duration of lease (activity recurring over duration of lease)	Yes	i. Increase in turbidity in local watercourses		4	3	12	High	i. Erosion and sediment controls in place and maintained ii. Buffers to watercourses	PESCB1, PESCC27.	2	3	6	Medium
Gas production	Pumping gas to the surface	Flaring or venting	Noise	Flaring or venting combustion or fuel burning equipment	Nuisance	Minor and /or short term effects	No	i. Nuisance to sensitive places/receptors		4	2	8	Medium	i. Noise management hierarchy to minimise accoustic emissions ii. Accoustic modelling for assessing impacts to sensitive receptors iii. Limits and measures to manage the risk or alternative arrangements iv. Noise management plan recommended but not essential		2	2	4	Low
Gas production	Pumping gas to the surface	Flaring or venting	Air	Flaring or venting combustion or fuel burning equipment	Greenhouse gas emissions	Moderate and/or medium term effects	No	i. Increase in air emissions	i. P&G Act 2004 ii. Carbon legislative framework	4	3	12	High	Minimise flaring and venting per P&G Act 2004; increase combustion efficiency.		2	3	6	Medium
Gas production	Seperation	Flaring or venting	Air	Flaring waste gas produced in seperation or venting waste gas in tanks and facilities that store oil, water or oily water from seperation	Greenhouse gas emissions	Moderate and/or medium term effects	No	i. Increase in air emissions	i. P&G Act 2004 ii. Carbon legislative framework	4	3	12	High	Minimise flaring and venting per P&G Act 2004; capture and reuse of waste gas;		2	3	6	Medium

Gas production	Water Production	Depressurise coal	Groundwater dependant ecosystems (includes caves but excludes subterreanean aquifer systems by virtue of the unfetted right to take)	Mechanically pumping out produced water and lowering downhole pressures	Lack of supply	Long term	Yes	i. Aquifer and spring drawdown ii. Recharge impacts	Water Act 2000 - Underground water impact reports Water Act 2000 - Make Good deals with supply of water aspects Water Act 2000 - Spring Impact Management Strategy deals with supply of water aspects	3	4	12	High	i. Comply with the Underground Water Impact Report ii. Comply with the Spring Impact Management Strategy iii. No activities in or above subterranean cave GDE iv. Terrestrial GDEs that are riverine RE GDE vegetation to be protected under disturbance to land/ESA conditions		3	4	12	High
Gas production	Pumping gas to the surface	Gas extraction	Land	Mechanically pumping out produced water and lowering downhole pressures	Subsidence	Long term	Yes	Subsidence	i. Managed on tenure by rehabilitation stability standards	2	1	2	Low	i. Rehabilitation standards for tenure areato be stable.		2	1	2	Low
Gas production	Water Production	Water extraction	Land	Mechanically pumping out produced water and lowering downhole pressures	Subsidence	Long term	Yes	Subsidence	i. Managed on tenure by rehabilitation stability standards	2	1	2	Low	i. Rehabilitation standards for tenure areato be stable.		2	1	2	Low
Gas production	Water Production	Transport to central facility via pipeline or flowline	Land	Spills	Soil contamination	Moderate and/or medium term effects	No	i. Loss of productive capacity ii. Impact on future land use		3	3	9	High	i. Flowline construction standards ii. Monitoring iii. Reporting		2	3	6	Medium

Appendix E – 2021 Groundwater Model Report

Australasian
Groundwater
& Environmental
Consultants

Report on

PL 253 FID 1 Environmental Approval Amendment Support

Prepared for
Arrow Energy Pty Ltd

Project No. ARR5000.001
October 2021

ageconsultants.com.au

ABN 64 080 238 642

Document details and history

Document details

Project number	ARR5000.0001
Document title	PL 253 FID1 Environmental Approval Amendment Support
File name	ARR5000 FID Arrow EA Amendment Support v01.01.docx

Document status and review

Edition	Comments	Author	Authorised by	Date
v01.01	Initial draft for client review	NM/MA		01/10/2021

Australasian Groundwater and Environmental Consultants Pty Ltd

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PL 253 FID 1 Environmental Approval Amendment Support

1 Introduction

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were commissioned in September 2021 to provide further production licensing modelling support to Arrow Energy Pty Ltd (Arrow Energy). AGE were previously commissioned to develop a groundwater model to assess the potential impact of CSG development around the former Linc Energy Site (Lot 40 DY 85 within PL253) in the Hopeland area south west of Chinchilla, Queensland (Figure 1.1). This report provides a summary of work undertaken to further develop this model to assess the transport of contaminants.

1.1 Scope of work

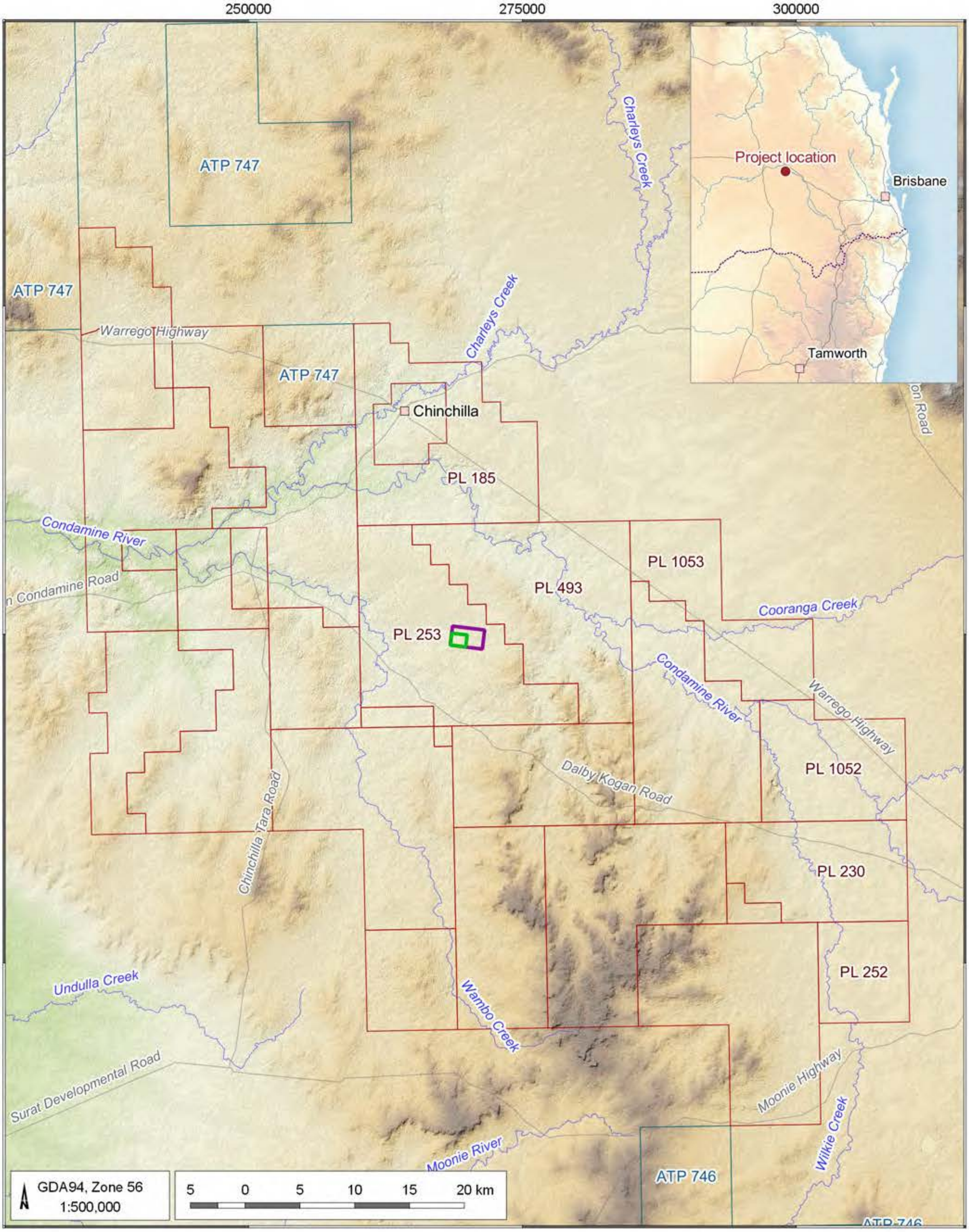
The work program primarily involved updating the existing numerical groundwater flow model (AGE, 2020) and using the updated model to assess particle and transport movement due to updated Arrow CSG operations. This involved extending the model duration, adjusting Arrow Energy and Origin Energy field development plans, and making changes to the porosity parameters applied in contaminant transport simulations.

Model verification (or validation) to additional groundwater level/chemistry data, for the period June 2019 to May 2021, which was not available at the time of the initial model development and calibration (AGE, 2020) has also been undertaken.

1.2 In this report

Consistent with the recommendations included in the current Australian Groundwater Modelling Guidelines (Barnett et al, 2012) this report is structured as follows:

- Section 2 outlines the objectives of the modelling work undertaken and presents a summary of the hydrogeological conceptualisation of the area.
- Key components of the updated groundwater flow and contaminant transport models are presented in Section 3.
- Model validation results are presented in Section 4.
- Groundwater flow and particle tracking predictions are presented in Section 5.
- Overall summary and conclusions are presented in Section 6.



LEGEND

□ Populated place
— Road
— Rivers and other watercourses
▭ MDL309 boundary
▭ Lot 40 DY 85
▭ Petroleum Lease (PL) area
▭ Authority to Prospect (ATP) area

Elevation (mAHD)

■ 250
■ 275
■ 300
■ 350
■ 400

Arrow EA Amendment Support (G2002d)

Project Location

AGE

DATE
03/08/2021

FIGURE No:
1.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002d.LINC_containment\3_GIS\Workspaces\001_Deliverable1\01.01_G2002d_Project Location.qgs

2 Model objectives and conceptualisation

2.1 Model objectives

As mentioned previously in Section 1.1 the objectives of the study and the associated revised Hopeland groundwater flow model included:

- updating the existing groundwater flow model previously developed by AGE (2020);
- using the resulting model to assess the impacts of existing and proposed Arrow Energy and other CSG wells on contaminant movement in and around the former Linc Energy Site; and

2.2 Previous modelling and other studies

The numerical model reported herein represents the latest stage in the development of models to assess potential impacts on existing contamination at the former Linc Energy site from proposed CSG field development in the surrounding Arrow Energy Petroleum Lease (PL) areas PL253 and PL493. Previous modelling activities have included:

- in 2018 Arrow Energy used the regional scale groundwater flow model developed by the Office of Groundwater Impact Assessment (OGIA, 2016a) for the purposes of assessing the cumulative impacts of approved CSG activities in the Surat Cumulative Management Area (CMA);
- in 2019 a local scale model of the PL253 and PL185/493 areas was developed by GHD with a refined grid mesh and geological structure (GHD, 2019); and
- this model was further refined by AGE and used to assess the impact of proposed activities in PL253, PL493 and PL185 (AGE, 2020)

2.3 Conceptualisation

Detailed conceptualisation reports relating to the Surat Basin as a whole and PL253 have previously been prepared by OGIA (2016b) and Arrow Energy (2018) respectively and are not repeated here. Further information on the hydrogeological setting is also provided in Section 2 of the GHD modelling report which was included as an Appendix to the previous AGE report (AGE, 2020; included as Appendix D). This report therefore assumes familiarity with these documents and of the strata present within this part of the Surat Basin.

A simple conceptual model using the existing groundwater model and heads prior to 2021 is presented as Figure 2.1. The figure shows inward groundwater flow directions to the LINC gasifiers and effects of regional CSG depressurisation.

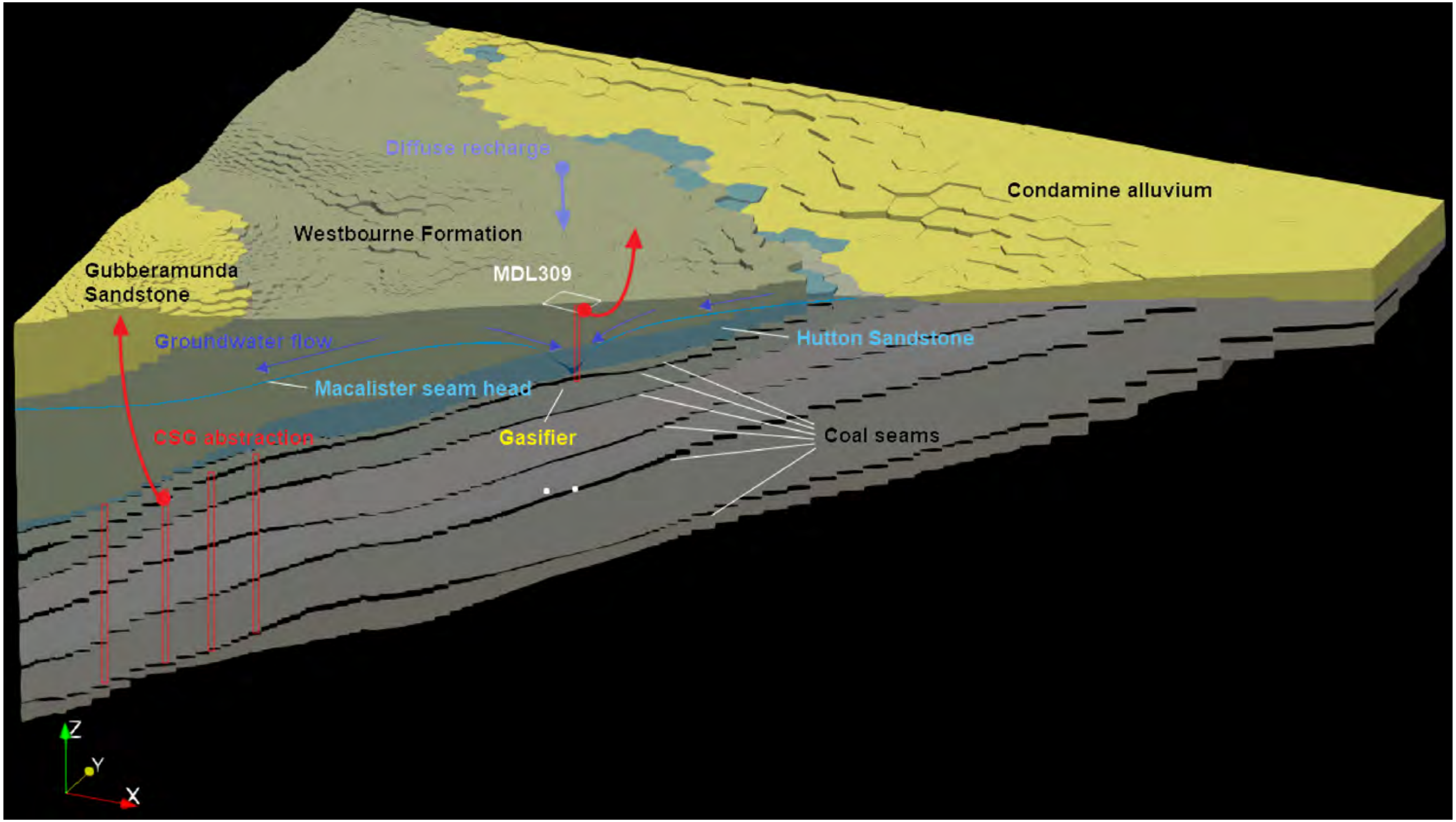


Figure 2.1 Conceptual model through MDL309

3 Groundwater flow and contaminant transport model updates

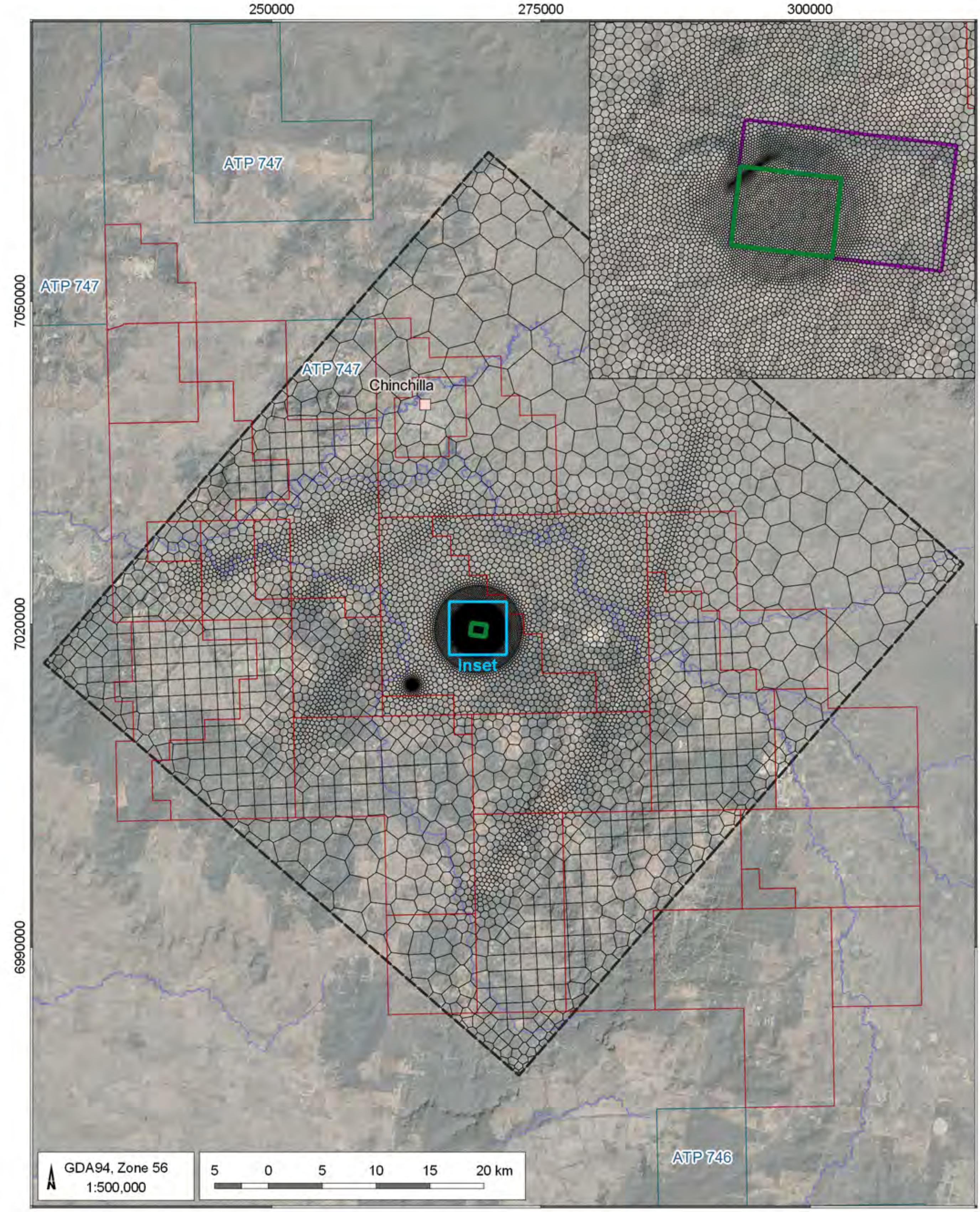
As mentioned previously the groundwater flow model of PL253 and PL185/493 reported herein represents a further development of an existing model of the area (AGE, 2020). Changes made to the groundwater flow and contaminant transport simulations are outlined in Sections 3.1 to 3.6 below and predominantly comprise relatively minor refinements, including:

- extending the model simulation stress periods to represent post-field development conditions from 2045 to 2060;
- updating field development plans relating to Arrow Energy and Origin Energy CSG fields in the surrounding areas for the period 2022 to 2060; and
- refining the extent of Gasifier 5, based on additional information (Perkins, 2018; AECOM, 2018; LINC, 2016).

Consideration was also given to whether or not any refinements to the numerical model itself were required, to address issues raised by an external peer review of the model (RDM Hydro, 2021) commissioned by the Department of Environment and Science (DES). However, as described in Section 3.5 the only changes that resulted from this assessment were some increases to the range of parameters considering during the uncertainty analysis. Responses to the peer review comments are provided in section 3.5.

3.1 Model domain and mesh

Groundwater simulations were undertaken using the same model domain and mesh as the work undertaken by AGE in 2020 (AGE, 2020). Figure 3.1 presents the domain of the model used for this assessment.



LEGEND

- ■ Populated place
- — Rivers and other watercourses
- — Groundwater elevation contour (mAHD)
- ▭ MDL309 boundary
- ▭ Lot 40 DY 85
- ▭ Petroleum Lease (PL) area
- ▭ Authority to Prospect (ATP) area
- ▭ Model extent
- ▭ Model mesh

Arrow EA Amendment Support (G2002d)

Model domain and mesh

AGE

DATE 06/08/2021

FIGURE No: **3.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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3.2 Stress periods

The previous model (AGE, 2020) was extended to simulate post mining conditions from Jan 2042 to December 2060. A total of 117 model stress periods (SPs) were simulated, distributed as follows:

- Steady state stress period (SP 1).
- Annual – January 2000 to December 2013 (SP 2 to 15).
- Monthly – January 2014 to December 2018 (SP 16 to 75).
- Annual – January 2019 to December 2060 (SP 76 to 117).

3.3 Gasifier voids

Additional information pertaining to the extent and location of the extent of the LINC gasifiers sourced from published mapping of the LINC site, provided by Arrow Energy, are shown as blue polylines on Figure 3.2 (Perkins, 2018; AECOM, 2018; LINC, 2016). The exact location and extent of the gasifier voids varied significantly from the numerous information sources. As there were conflicting information in the dataset, the extent of Gasifiers 2 to 4 and their representation in the model were unchanged to the previous groundwater modelling exercise. However, the datasets indicated Gasifier 1 extended to the north, and Gasifier 5 extended to cover the 'Predicted G5 Expansion'. Figure 3.2 presents the updated gasifier cells represented in the revised groundwater model as coloured polygons.

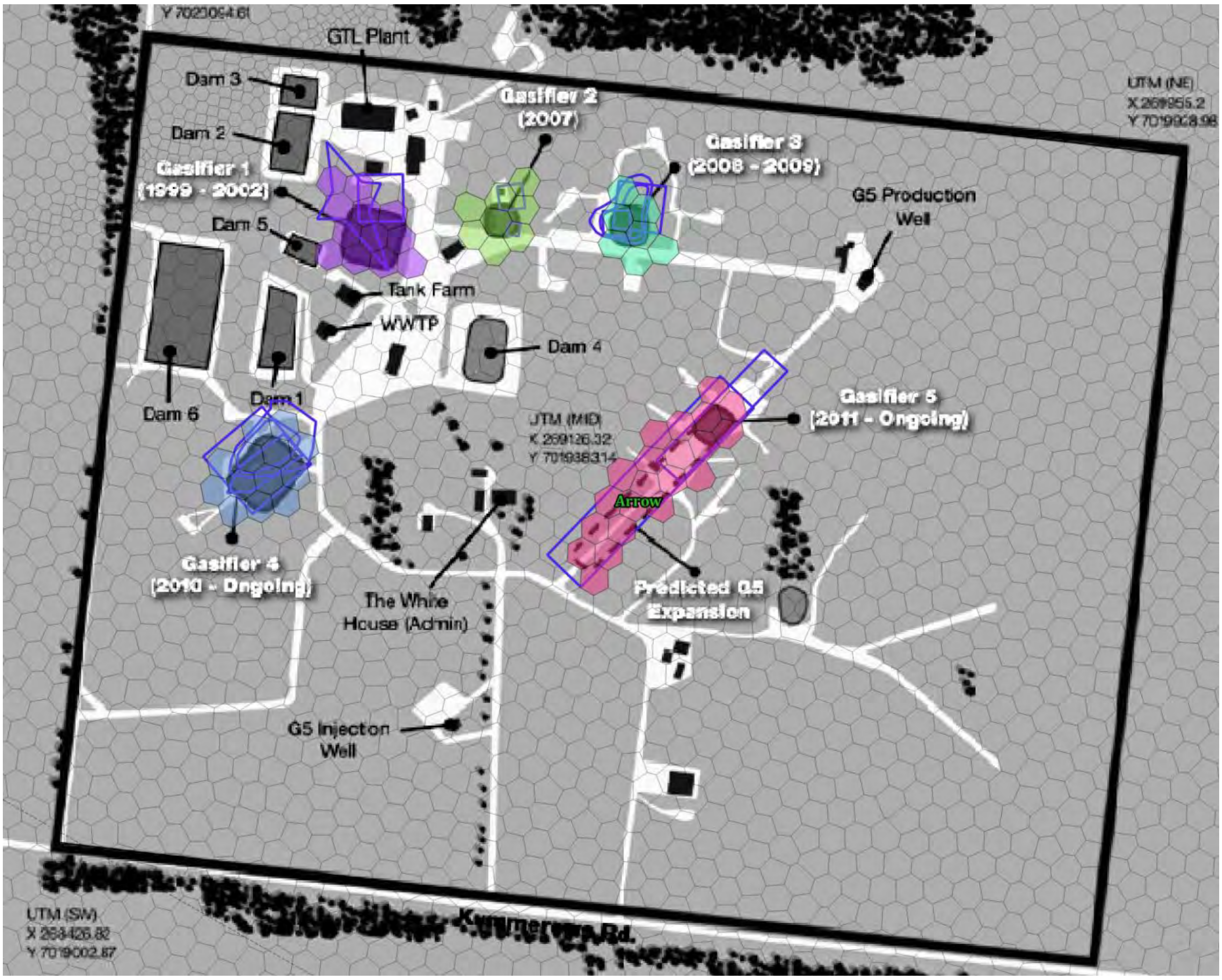

Figure 3.2 Modelled Gasifier void extents (Perkins 2018 map in background)

3.4 Field Development Plan update

Two predictive scenarios were run using the revised model as described below.

The distribution of existing and proposed CSG wells included in the ‘**baseline scenario**’ is shown in Figure 5.1. This scenario includes only currently authorised CSG wells within PLs 253 and 493.

Figure 5.2 shows the ‘**Arrow FID1 scenario**’, the proposed full field development plan (FID1) for PL253 and PL493.

3.5 Peer review findings

A number of perceived shortcomings of the previous modelling work (AGE, 2020) are raised in Section 3.1 of the peer review report (RDM Hydro, 2021). Many of the issues raised fail to recognise that the purpose of the modelling work, which was to assess whether or not development of PL253 surrounding the former Linc Energy Site by Arrow Energy would increase the risk of existing contamination moving off site. The model was never intended to be able to simulate historical contamination of the site due to operation of the gasifiers. Indeed, as recognised by the peer reviewer, the availability (or lack thereof) of information on Linc Energy operations at the site “precludes the modelling of historic operations”. Furthermore, based on a series of validation calculations and other assessments, the review goes on to conclude that:

- Arrow’s conclusions regarding contaminant transport from the gasifiers are likely to be mostly accurate;
- it is considered unlikely that Arrow’s activities would mobilise contaminants from the gasifiers that would reach a site boundary; and
- hydraulic gradients are currently generally into the site and therefore the potential for off-site contamination is currently low, with DES monitoring data also indicating that contaminant concentrations are decreasing.

For the most part the reviewer therefore appears to agree with many of the conclusions of the previous modelling work (AGE, 2020). The only areas of disagreement identified in the conclusions are that:

- the model was unable to match observed hydraulic heads at the site scale and generally under-predicted historic contaminant concentrations relative to their measured concentrations; and
- since residual contaminants are likely to remain outside of the gasifiers then it cannot be conclusively stated that contaminants will not migrate beyond the site boundaries.

With regard to the first comment the failure of the model to match observed hydraulic heads is due to an assumption that the Macalister Coal Seam at the site is highly permeable, homogenous and present throughout the model domain. In terms of contaminant transport within the coal seams at the site this is considered to be an extremely conservative assumption, since it increases the likelihood that extraction from CSG wells within PL253 will affect hydraulic gradients at the site. In reality the Macalister Coal seams targeted by the gasifiers are not homogenous or continuous across the model domain. For instance, local drilling information suggests the thickness of the Macalister coal seam varies from 2 to 10 m within distances of less than 1,000 m. As a result of this heterogeneity CSG wells in local fields are typically installed at 750 m centres since their zone of influence is limited.

We understand that the comment regarding under-prediction of measured concentrations relates to Figure 6.1 in the report (AGE, 2020) which shows observed versus modelled benzene concentrations. Whilst it is true that this plot shows more locations where observed concentrations exceed modelled, observed concentrations at a number of locations are over-estimated. It should also be noted that, consistent with good modelling practice and recommendations in the AGMG (Barnett et al., 2012), calibration has been undertaken to both observed heads and concentrations. Simultaneous calibration to more than one observation type is recommended since it reduces the potential for non-uniqueness in the calibration (i.e. the possibility that the observations can be fitted equally well using a different combination of parameters). However, it often also results in a reduced level of fit to one or both observation types since conflicts between the targets can occur. For instance, in this case the parameterisation required to match observed heads may result in a relatively poor match to observed concentrations, and vice versa. In any case the sensitivity of the model predictions to the calibration was then also reduced by undertaking an uncertainty analysis, in which over 200 alternative parameter sets were tested without applying any calibration constraints. As reported in Section 8.2 of the previous report (AGE, 2020) the results of this analysis suggests the predictions are relatively insensitive to parameter uncertainty and hence the model calibration.

Finally, with regard to the potential for off-site migration, in the event that contamination is currently present close to the site boundaries then it is possible that off site transport could occur. However, this would likely occur anyway, irrespective of whether PL253 is developed further, once groundwater levels have recovered on the site. Furthermore, the previous modelling work suggests that the additional distance travelled by any contaminants in the event that PL253 was developed would be less than 16 m over a 20 year period, despite the highly conservative assumptions about the permeability and continuity of the Macalister Coal Seam discussed above. Consequently, the closest monitoring point to the MDL309 boundary is 15 m away, therefore the potential for observed impact to move off site is remote.

Accordingly, no changes to the model design or approach were made in response to the peer review findings. However, as discussed further in Section 3.6.3, a wider range of porosity values was considered for uncertainty analysis purposes, to address the peer reviewers comment that porosity may have been over-estimated.

3.6 Contaminant transport model

3.6.1 Scenario overview

The existing contaminant transport model presented in AGE 2020 was also updated according to the modifications described above in relation to the groundwater flow model (i.e., stress periods extended, gasifier extents expanded, FID1 updated development plan). Recent data collected at the site also indicates Benzene concentrations of up to 1,000 µg/l adjacent to Gasifier 1, suggesting a possible ongoing source at this gasifier which was not represented in the previous model (AGE, 2020). While this is well below aqueous solubility, it was recognised by DES to consider the potential for a NAPL source term. Accordingly, some changes were made to the representation of initial and ongoing concentrations at the site gasifiers, as described in Section 3.6.2.

3.6.2 Source timing

As mentioned above based predominantly on recent data for Gasifier 1 all water entering each gasifier post closure was assumed to attain 1,000 µg/l benzene and 1,000 µg/l naphthalene. This was achieved by injecting a small quantity of water (0.0001 m^3/d) into each gasifier using the MODFLOW well package at a much higher concentration, such that the water entering the modelled gasifiers attains these ‘target’ concentrations within the gasifier cell. Since the volume of water predicted to enter each gasifier varies from gasifier to gasifier and also with time the concentrations required to achieve the target also varies and were determined by an initial trial and error calibration. Final concentrations simulate in each gasifier are summarised in Table 3.1 and Table 3.2.

Table 3.1 Benzene source summary

Gasifier	Injection start date	Injection concentration range (µg/l)	Long term groundwater concentration range achieved in gasifier cells (µg/l)
G1 (10 model cells)	2001	7.85×10^9 – 10.78×10^9	1,000
G2 (7 model cells)	2007	9.39×10^9 – 10.78×10^9	1,000
G3 (6 model cells)	2009	10.78×10^9 – 11.46×10^9	1,000
G4 (13 model cells)	March 2012	9.44×10^9 – 12.65×10^9	1,000
G5 (6 model cells)	October 2013	9.09×10^9 – 9.68×10^9	1,000
Gasifier	Injection start date	7.85×10^9 – 10.78×10^9	Long term groundwater concentration range achieved in gasifier cells (µg/l)
G1 (10 model cells)	2001	9.39×10^9 – 10.78×10^9	1,000

Table 3.2 Naphthalene source summary

Gasifier	Injection start date	Injection concentration range (µg/l)	Long term groundwater concentration range achieved in gasifier cells (µg/l)
G1 (10 model cells)	2001	19×10^6 – 26×10^6	1190 – 1201
G2 (7 model cells)	2007	23×10^6 – 26×10^6	1195 – 1202
G3 (6 model cells)	2009	26×10^6 – 28×10^6	1197 – 1202
G4 (13 model cells)	March 2012	23×10^6 – 30×10^6	1196 – 1204
G5 (6 model cells)	October 2013	22×10^6 – 23×10^6	1196 – 1201
G1 (10 model cells)	2001	19×10^6 – 26×10^6	1190 – 1201
G2 (7 model cells)	2007	23×10^6 – 26×10^6	1195 – 1202

All gasifier sources were assumed to continue at the same concentrations from the dates shown in in Table 3.1 and Table 3.2 until the end of the model simulation in 2060.

Time series charts showing benzene and naphthalene concentrations attained in each of the 6 to 13 cells comprising each gasifier are shown in Appendix B and Appendix C.

3.6.3 Storage parameters

As mentioned previously (Section 3.5) one perceived issue identified in the previous modelling work (AGE, 2020) was that the model calibrated porosity value of 7% for the Macalister coal seam was too high. As evidence for this the reviewer alludes to history matching and prediction of water production rates carried out by CSG operators. However, as the peer reviewer identifies flow to CSG wells will be governed by the **effective porosity** (or specific yield) of the coal seams rather than their porosity. As documented in the previous report (Table 4.2; AGE, 2020) model calibrated specific yield (or effective porosity) in modelled coal seams was 2%. During calibration this parameter was also allowed to vary widely between 0.1% and 10%, a range which encompasses the peer reviewer's preferred value of 1% (RDM Hydro, 2021). Furthermore, as shown in Table 3.3, the mean calibrated for the Macalister coal seam in the vicinity was 1.1%. The same range of effective porosity values used for calibration was also used for uncertainty analysis purposes.

For contaminant transport purposes an additional **porosity** parameter is required. Since porosity always exceeds the effective or drainable porosity or specific yield then the MODFLOW BCT package will not accept a porosity value of less than the specific yield. Hence, the lower bound allowed during solute transport calculations must be linked to calibrated specific yield value used in the flow calculations. This was achieved somewhat crudely previously by adopting a porosity lower bound of 7%, close to the upper bound of range adopted for specific yield. This has been revised for the current modelling work such that the porosity value used for contaminant transport simulations is calculated from the previously calibrated effective porosity or specific yield (S_y) values plus specific retention (S_R) as shown in Table 3.3. As shown a specific retention value of 1% was adopted based on values for similar grade coal in the International Standard Organisation (ISO, 1975). Since the previous groundwater model calibration (AGE, 2020) involved changing specific yield at pilot points close to and informed by groundwater level observations the resulting porosity values after adding specific retention also vary spatially. Table 3.3 therefore presents a range of modelled values for MDL309 (i.e. former Linc Energy site area).

Table 3.3 Modelled storage values in the vicinity of MDL309

Unit	Effective porosity or specific yield S_y- (%)	Specific retention S_R - (%)	Porosity – n (%) $S_y + S_R$
Springbok Sandstone (layer 3)	2.9 – 7.4 (5.0 mean)	1	3.9 – 8.4 (6.0 mean)
Springbok Sandstone (layer 5)	0.5 – 0.5 (0.5 mean)	1	1.5 – 1.5 (1.5 mean)
MCM coal (layer 6)	0.9 – 1.3 (1.1 mean)	1	1.9 – 2.3 (2.1 mean)

4 Model validation

4.1 Validation approach

The observation groundwater level and concentration datasets previously used to calibrate the AGE 2020 model were updated to incorporate new observations sampled from June 2019 to May 2021.

4.1.1 Head validation

Comparisons of modelled and observed groundwater levels are shown in Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4. As shown in Figure 4.1 overall a scaled root mean square error of 8.9% has been achieved, within the 10% target typically adopted for transient calibrations (Barnett et al, 2012). However, a significant proportion of the misfit relates to data for the Hopelands pilot CSG wells to the west of the former Linc Energy site. Groundwater levels observations in these wells may be unreliable since they have been processed using the Theim equation to account for differences between the model cell and well diameters and also since they are likely to have been influenced by dual phase flow effects. Accordingly, it is unlikely that they could be matched accurately using a single phase MODFLOW model. Removing these observations results in a reduced in a reduced overall SRMS of 6.9% and confirms that the model is able to achieve a relatively good fit to the remainder of the calibration data set which is likely to be less prone to measurement error. As shown in Figure 4.3 observed groundwater levels at each of the horizons monitored in the nearby Hopelands 17 nested monitoring facility are also well matched.

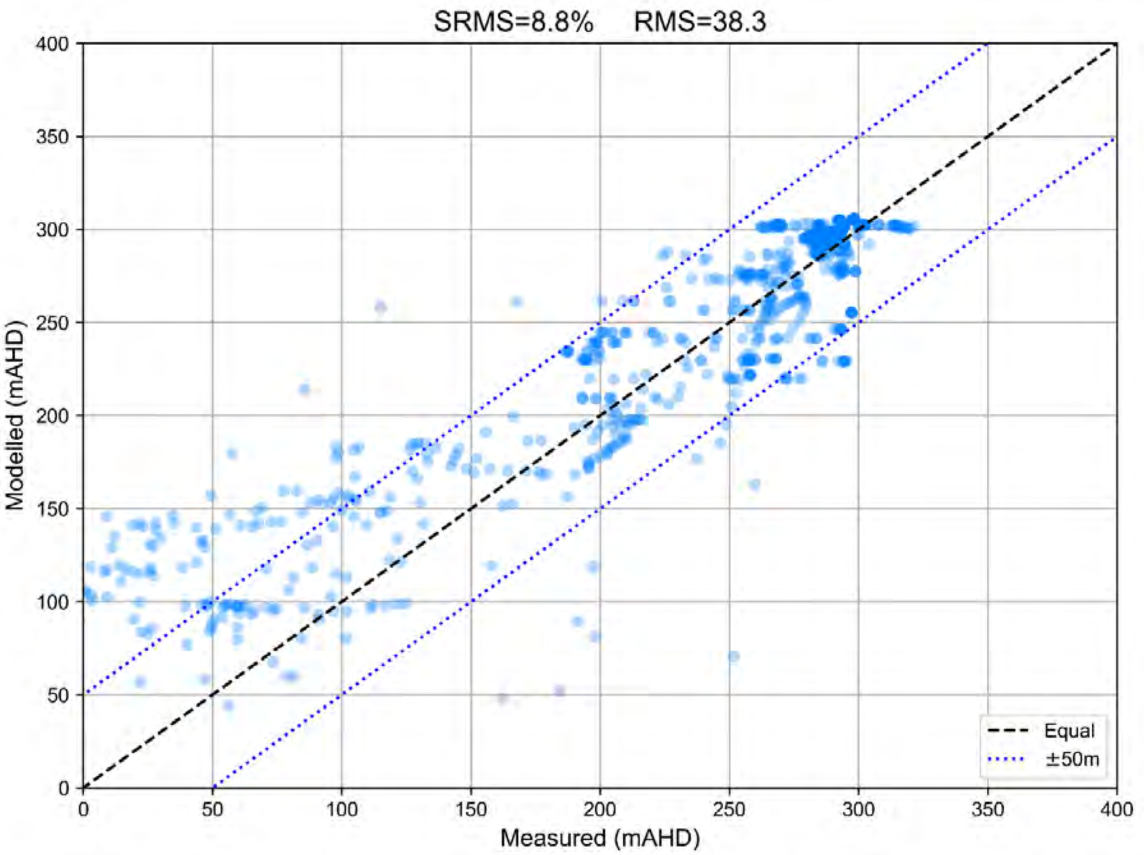

Figure 4.1 Modelled versus observed head calibration scatter plot

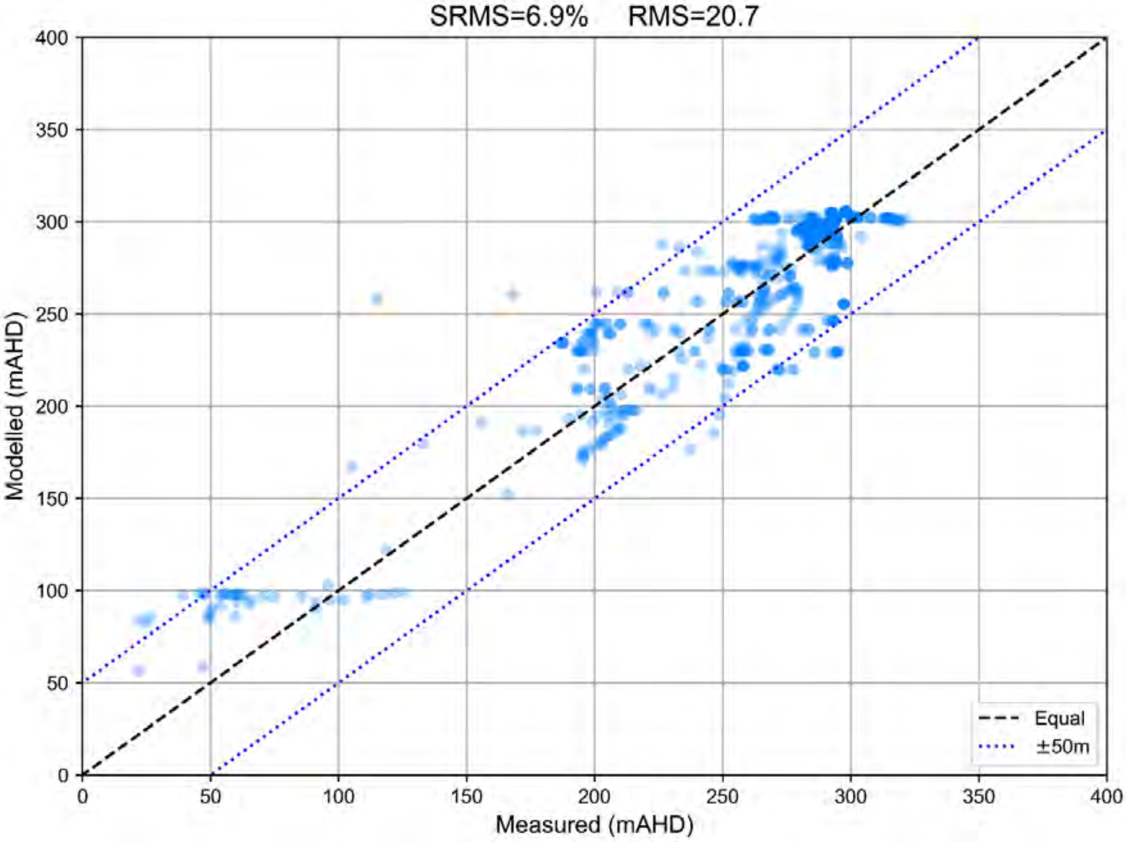

Figure 4.2 Modelled versus observed head calibration scatter plot, excluding estimated head data for pilot CSG production bores

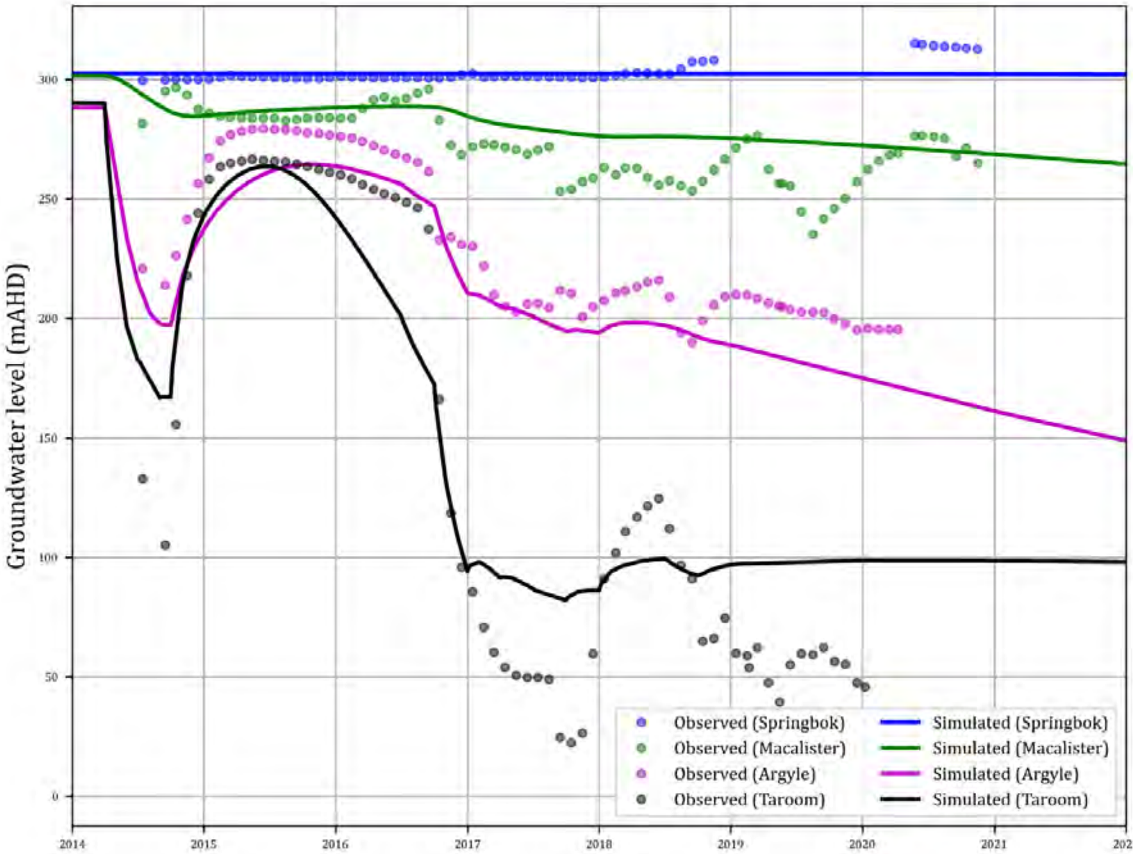

Figure 4.3 Modelled versus observed groundwater level time series, Hopelands 17

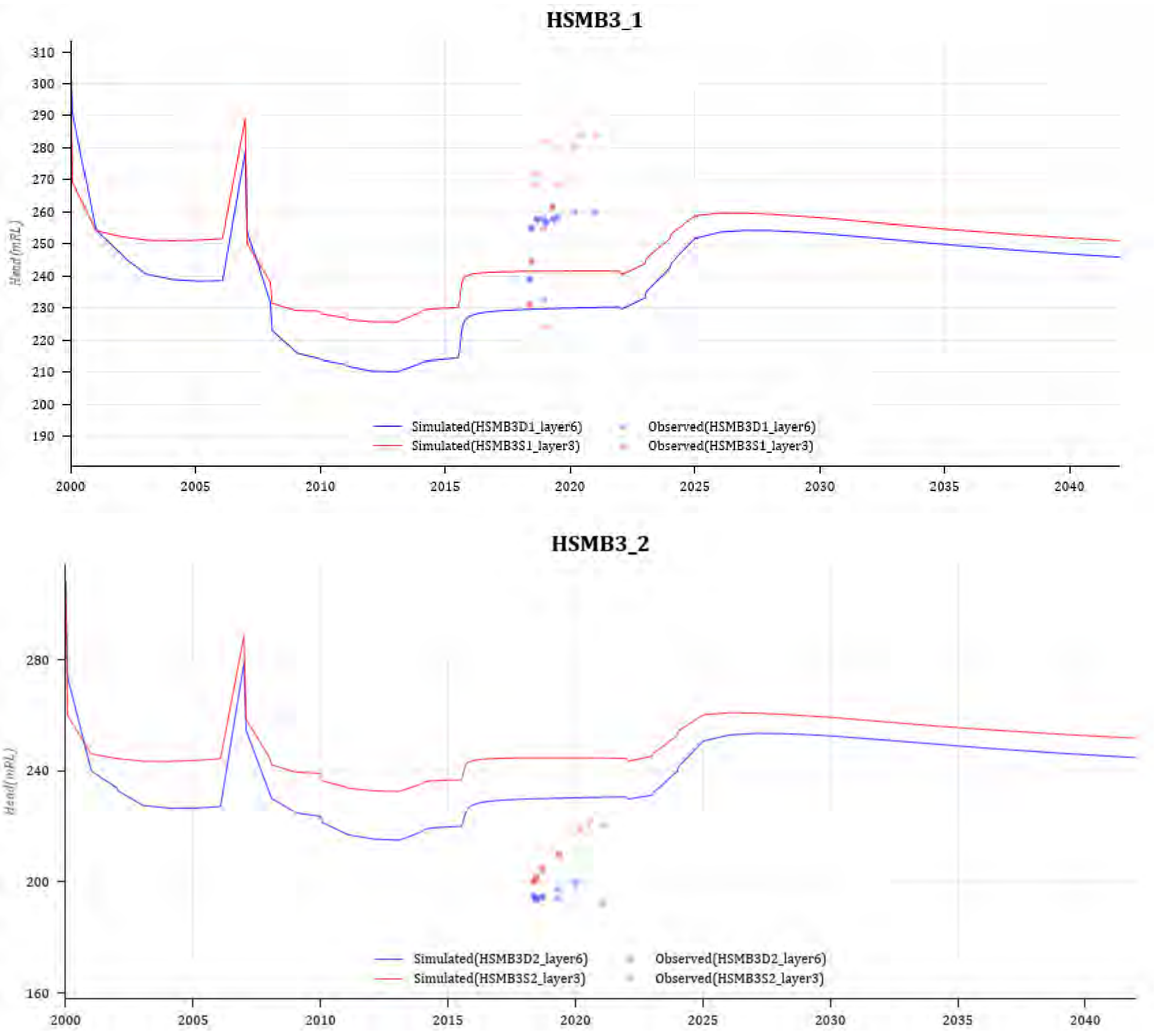

Figure 4.4 Modelled versus observed groundwater level time series, HSMB3*

Analysis of inferred groundwater level recovery within the gasifiers suggests the recovery of groundwater levels across MDL309 is complicated and compartmentalised. Figure 4.4 shows a comparison of modelled and observed groundwater levels at HSMB3D and HSM3S, located approximately 175 m north of gasifiers 1-3 (observation locations are shown on Figure 5.3). The hydrographs show groundwater level recovery is inconsistent along the northern MDL309 boundary. The model replicates the average groundwater level between these closely spaced wells. It should be noted that the extended gasifier extents (discussed in Section 3.3) have slowed down the recovery of groundwater levels within MDL309 compared to the AGE 2020 model, with the notable steps in the modelled hydrographs relating to the switch between unconfined and confined conditions delayed by up to 4 years.

Appendix A presents transient calibration hydrographs showing the performance of the model from 2000 to 2042. The model appropriately matches updated groundwater level observations taken from 2019 to 2021 and displays similar matched trends and misfits to the AGE 2020 modelled residuals.

Modelled heads in the Springbok Sandstone and Macalister coal seam at the end of the model validation period in December 2021 are shown in Figure 4.5 and Figure 4.6 respectively. The inset maps on these diagrams show modelled heads in and around the former Linc Energy site confirming heads of below 250 mAHD in the Macalister coal seam (model layer 6) within the site.

A summary of calibrated model parameters is presented in Table 4.1 and Table 4.2.

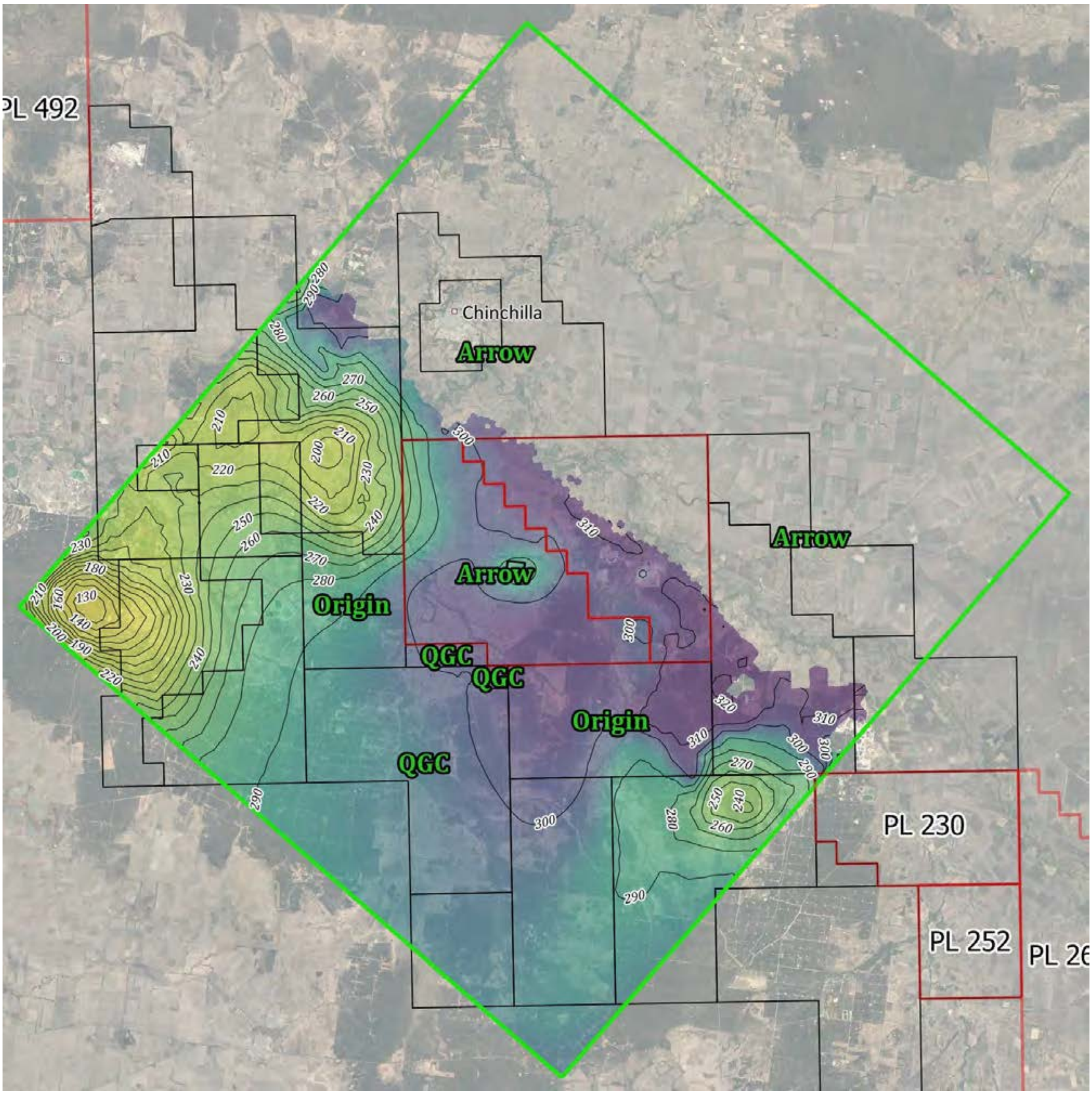

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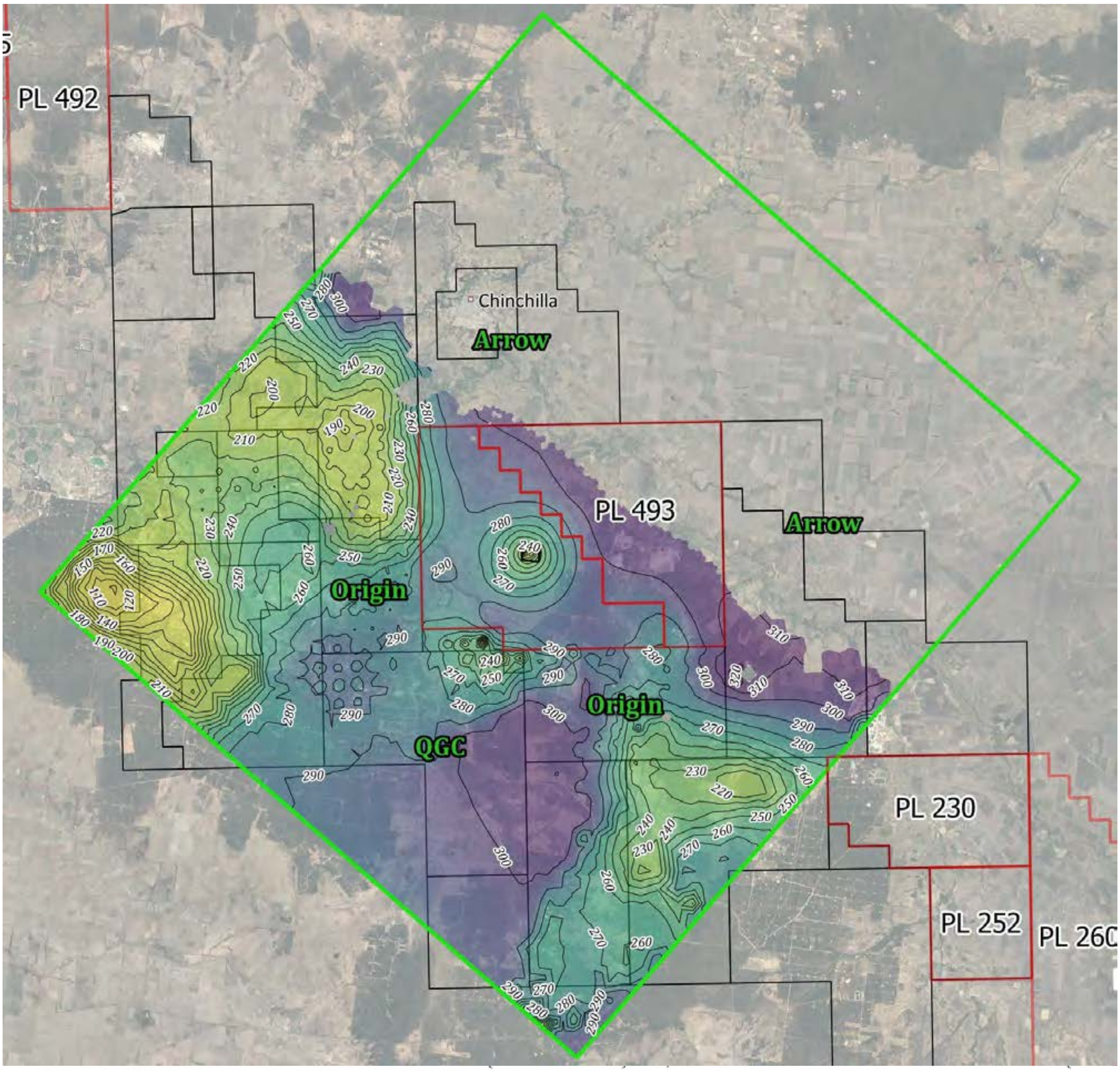
Figure 4.5 Modelled groundwater levels, June 2021, Springbok Sandstone (model layer 3)



G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\04.10_G2002_Modelled groundwater levels, December 2019, Macalister coal seam (model layer 6).qgs

Figure 4.6 Modelled groundwater levels, June 2021, Macalister coal seam (model layer 6)

Table 4.1 Calibrated hydraulic conductivity parameter summary

Hydrostratigraphic Unit	Model Layer	Median Kh, Calibrated (m/d)	Kh, Range (m/d)	Median Kv, Calibrated (m/d)	Kv Range (m/d)	Median Anisotropy (Kh:Kv)	Anisotropy Range (Kh:Kv)
Condamine Alluvium/Gubberamunda Sandstone	1	2.7	$2x10^{-4}$ – 50	1	$7x10^{-8}$ – 23	10	2-20,000
Westbourne Formation	2	$1x10^{-4}$	$4x10^{-5}$ – $4x10^{-3}$	$2x10^{-7}$	$6x10^{-9}$ – $1x10^{-5}$	1000	50-550,000
Springbok Sandstone	3	0.2	$2x10^{-4}$ – 1.4	$1x10^{-5}$	$2x10^{-8}$ – $6x10^{-4}$	20,000	20-150,000
Walloon Coal Measures (Kogan Coal)	4	0.27	$6x10^{-5}$ – 0.3	0.1	$1x10^{-7}$ – 0.1	5	1-18,000
Walloon Coal Measures (Kogan Interburden)	5	0.11	$1x10^{-4}$ – 0.1	$2x10^{-8}$	$1x10^{-9}$ – $2x10^{-5}$	450,000	1,000-2,000,000
Walloon Coal Measures (Macalister Coal)	6	0.02	$1x10^{-5}$ – 0.09	0.02	$1x10^{-5}$ – 0.09	3	1-20
Walloon Coal Measures (Macalister Interburden)	7	0.001	$1x10^{-5}$ – 0.1	$1x10^{-8}$	$4x10^{-9}$ – $2x10^{-5}$	100,000	100–7,000,000
Walloon Coal Measures (Wambo Coal)	8	0.3	0.001 – 0.3	0.1	0.001 – 0.1	3	1-4
Walloon Coal Measures (Wambo Interburden)	9	0.002	$1x10^{-4}$ – 0.05	$5x10^{-9}$	$3x10^{-9}$ – $7x10^{-6}$	450,000	1,000-750,000
Walloon Coal Measures (Argyle Coal)	10	0.3	$1x10^{-4}$ – 0.3	0.1	$1x10^{-4}$ – 0.1	3	1-3
Walloon Coal Measures (Argyle Interburden)	11	$7x10^{-4}$	$1x10^{-4}$ – 0.08	$8x10^{-9}$	$3x10^{-9}$ – $1x10^{-5}$	70,000	1,000–7,000,000
Walloon Coal Measures (Tangalooma Sandstone)	12	0.002	$1x10^{-4}$ – 0.1	$5x10^{-9}$	$1x10^{-9}$ – $1x10^{-5}$	250,000	1,000-5,000,000
Walloon Coal Measures (Upper Taroom Coal)	13	0.3	$2x10^{-4}$ – 0.3	0.1	$1x10^{-7}$ – 0.1	3	1-31,000
Walloon Coal Measures (Upper Taroom Interburden)	14	0.007	$2x10^{-5}$ – 0.1	$6x10^{-9}$	$1x10^{-9}$ – $2x10^{-4}$	1,000,000	100-23,000,000
Walloon Coal Measures (Condamine Coal)	15	0.3	$1x10^{-4}$ – 0.3	0.1	$1x10^{-7}$ – 0.1	3	1-26,000
Walloon Coal Measures (Condamine Interburden)	16	0.007	$3x10^{-4}$ – 0.1	$4x10^{-7}$	$3x10^{-8}$ – $7x10^{-6}$	15,000	500-350,000
Eurombah Formation	17	$2x10^{-4}$	$3x10^{-5}$ – $5x10^{-4}$	$8x10^{-8}$	$1x10^{-8}$ – $2x10^{-6}$	2,500	50-7,500
Hutton Sandstone	18	0.03	$2x10^{-3}$ – 0.08	$1x10^{-5}$	$6x10^{-7}$ – $6x10^{-5}$	3,000	1,200-11,000

Table 4.2 Calibrated Storage parameter summary

Hydrostratigraphic Unit	Model Layer	Sy, Calibrated	Sy, Range	Ss, Calibrated (m^{-1})	Ss Range (m^{-1})
Condamine Alluvium/Gubberamunda Sandstone	1	0.015 -0.018	0.002 – 0.15	5.5 $x10^{-5}$ 8.0 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Westbourne Formation	2	0.004	0.001 – 0.1	2.7 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Springbok Sandstone	3	0.009	0.001 – 0.1	2.3 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Kogan Coal)	4	0.02	0.001 – 0.1	2.0 $x10^{-5}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Kogan Interburden)	5	0.008	0.001 – 0.1	2.0 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Macalister Coal)	6	0.02	0.001 – 0.1	2.3 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Macalister Interburden)	7	0.013	0.001 – 0.1	5.1 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Wambo Coal)	8	0.02	0.001 – 0.1	2.0 $x10^{-5}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Wambo Interburden)	9	0.010	0.001 – 0.1	8.7 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Argyle Coal)	10	0.02	0.001 – 0.1	1.5 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Argyle Interburden)	11	0.006	0.001 – 0.1	4.8 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Tangalooma Sandstone)	12	0.018	0.001 – 0.1	2.3 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Upper Taroom Coal)	13	0.02	0.001 – 0.1	5.4 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Upper Taroom Interburden)	14	0.008	0.001 – 0.1	2.3 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Condamine Coal)	15	0.02	0.001 – 0.1	1.1 $x10^{-5}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Condamine Interburden)	16	0.008	0.001 – 0.1	3.3 $x10^{-7}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Eurombah Formation	17	0.01	0.001 – 0.1	5.0 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Hutton Sandstone	18	0.01	0.001 – 0.1	1.0 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$

4.1.2 Concentration validation

Plots of observed versus modelled Benzene and Naphthalene concentrations resulting from the model calibration are presented in Figure 4.7 and Figure 4.8 respectively and show similar SRMS values and level of fit to the observed concentration data to that achieved for the head calibration (Section 4.1.1). In the authors experience the degree of fit which can be achieved to contaminant concentration data is typically lower than that achieved to heads since simulation of contaminant concentrations as well as flows adds another level of complexity to the calculations required. The relatively good fit achieved despite the adoption of a simple calibration approach, using layer wide rather than spatially variable transport parameters, therefore suggests that contaminants at the site are behaving in a relatively predictable manner.

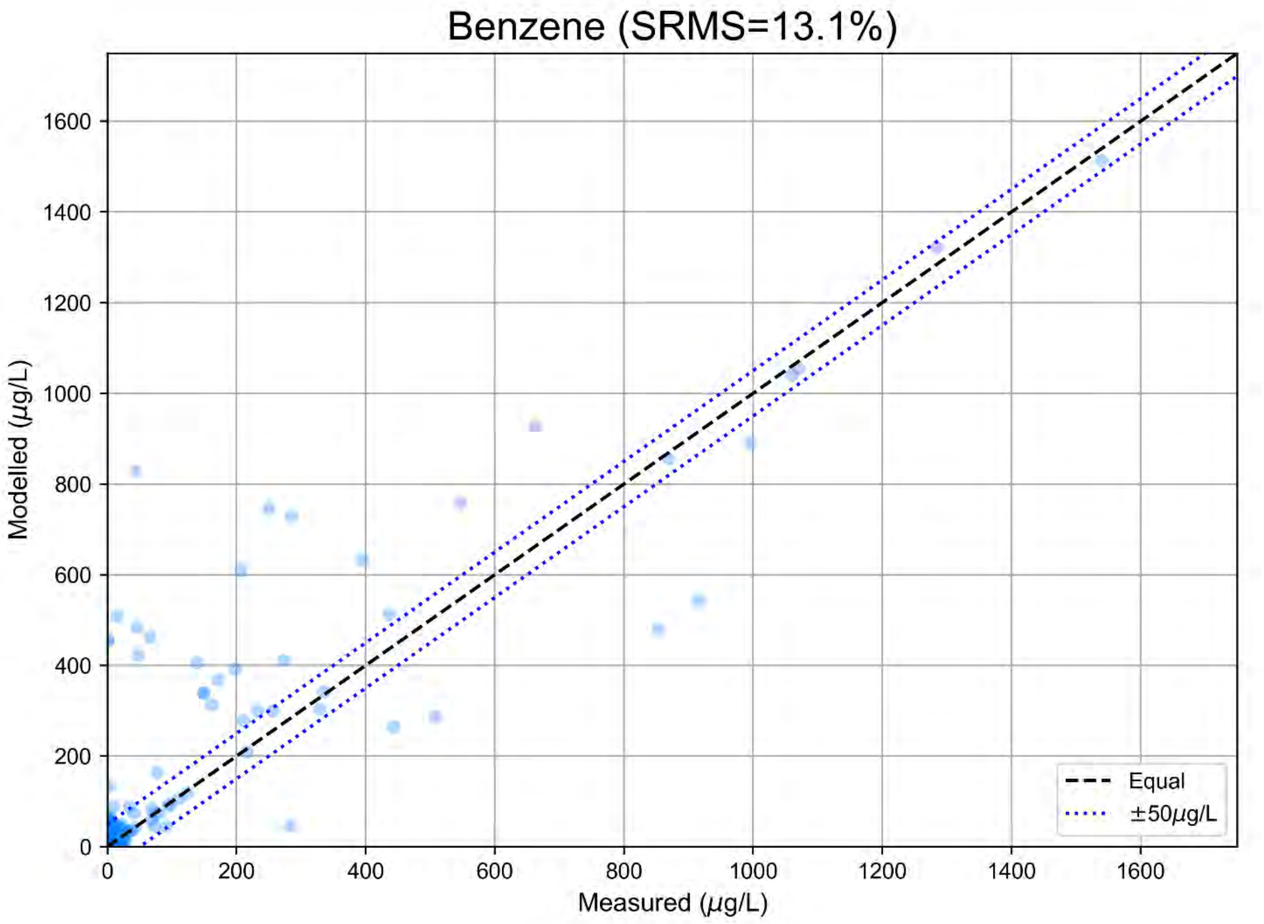


Figure 4.7 Modelled versus observed contamination calibration scatter plot – Benzene

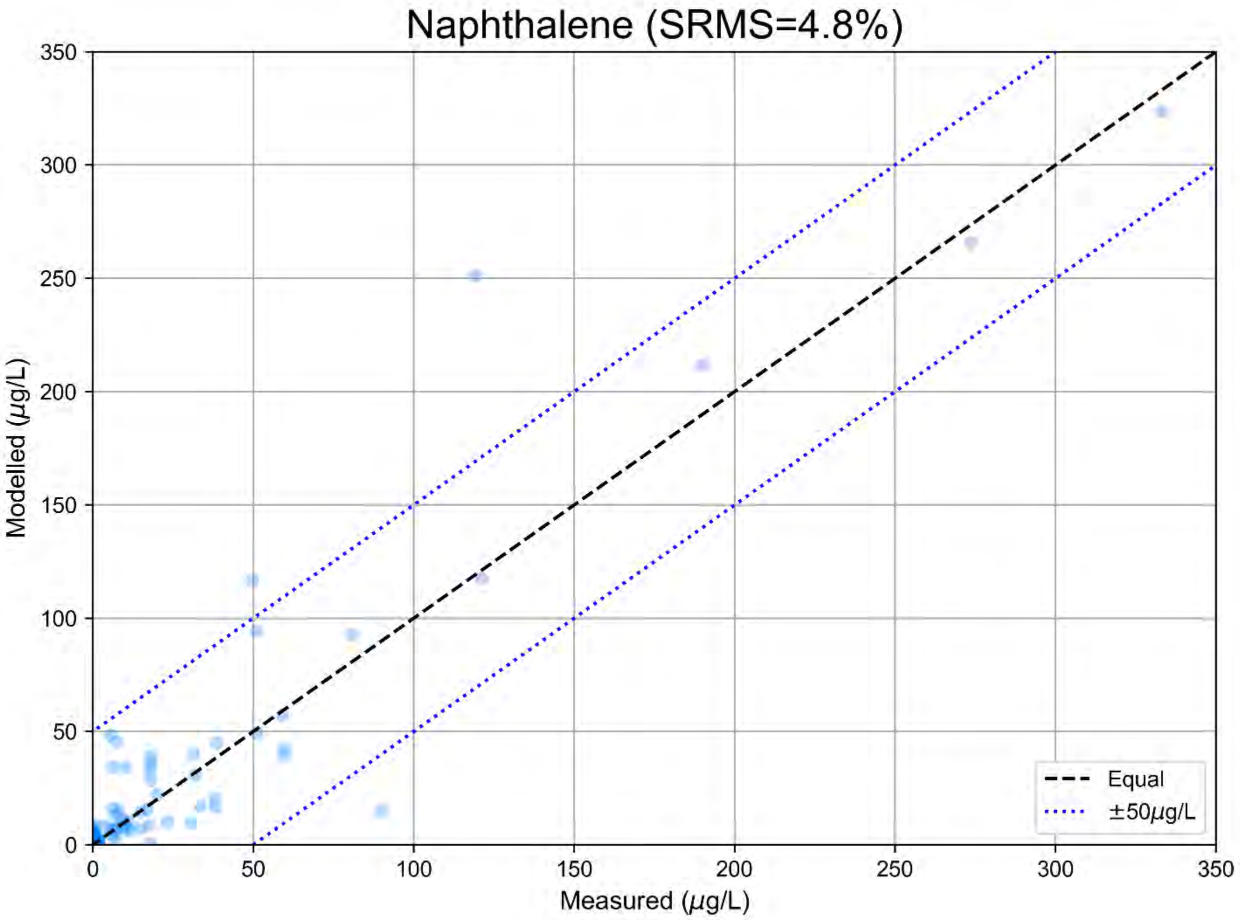


Figure 4.8 Modelled versus observed contamination calibration scatter plot – Naphthalene

Appendix A presents the transient observed vs. simulated hydrographs from the contaminant transport model. The results show the model replicates measured concentrations between 2019 and 2021 adequately. At most locations modelled concentrations decline less rapidly than observed which implies that predictive simulation results for the period 2022 to 2060 are likely to be conservative.

5 Model predictions

5.1 Predictive scenarios

As mentioned previously (Section 3.4) two predictive scenarios were run using the model as described below.

The distribution of existing and proposed CSG wells included in the '**baseline scenario**' is shown Figure 5.1. This scenario only includes currently authorised CSG wells to be operated by Arrow Energy on PLs 253 and 493 and those operated by other companies within the model domain.

Figure 5.2 shows the '**Arrow FID1 scenario**', the proposed field development plan (FID1) for PL253.

A summary of the number of Arrow Energy CSG wells included in the Arrow FID1 scenario is provided below in Table 5.1. These comprise of 55 proposed wells in PL253, 5 proposed wells in PL493 and 211 authorised wells (PL493, PL1052 and PL1053).

Table 5.1 Arrow FID1 scenario modelled CSG well counts

CSG well type	Number of CSG wells
Currently authorised	193
Proposed - completed into the Macalister coal seam	25
Proposed - not completed into the Macalister coal seam	51
Total	**269**

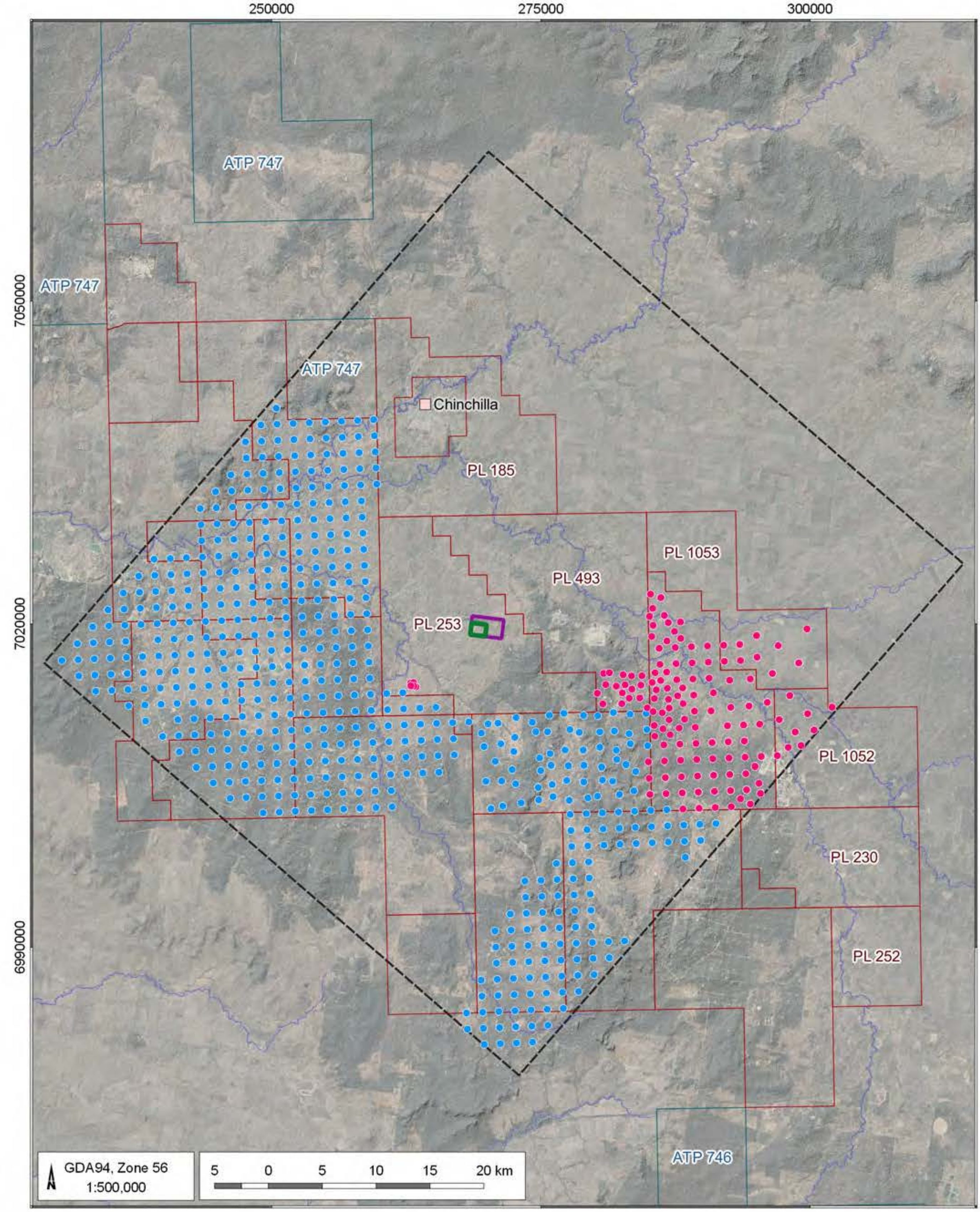
5.1.1 Particle tracking

Particle tracking was simulated using mp3du (SS Papadopoulos, 2020) using modelled heads related to the baseline and Arrow FID1 scenarios to determine the relative change in groundwater movement due to CSG abstraction. As shown in Table 5.2 results indicate that the average total distance travelled under the baseline scenario from the point of application within each of the gasifiers ranges from 32 m in the Springbok Sandstone to 25 m in the Macalister sub-unit over the 20-year forecast period (January 2020 to December 2040). Under the Arrow FID1 scenario average distances travelled during the forecast period remain approximately the same due to significant reduction in the number of wells in PL 253 with the closets well located over 5 km away.

Table 5.2 Predicted particle tracking impacts, 1 January 2020 to 31 December 2040

Scenario	Total distance travelled (m)			Predicted impact (m)		
	Min	Average	Max	Min	Average	Max
Springbok Sandstone						
Baseline	4	32	224	NA	NA	NA
Arrow FID1 scenario	4	32	225	<1	<1	1
Macalister sub-unit						
Baseline	4	25	207	NA	NA	NA
Arrow FID1 scenario	4	25	207	<1	<1	<1

Particle migration distance in the FID1 scenario has increased compared to results presented in the AGE 2020 report from an average movement of 24 to 25 m in the Macalister sub-unit due to the decreases in porosity represented in the model.



LEGEND

- 🟥 Populated place
- Rivers and other watercourses
- 🟩 MDL309 boundary
- 🟪 Lot 40 DY 85
- 🟥 Petroleum Lease (PL) area
- 🟦 Authority to Prospect (ATP) area
- Model extent

CSG Well

- ● Arrow authorised
- ● Non - Arrow

Arrow EA Amendment Support (G2002d)

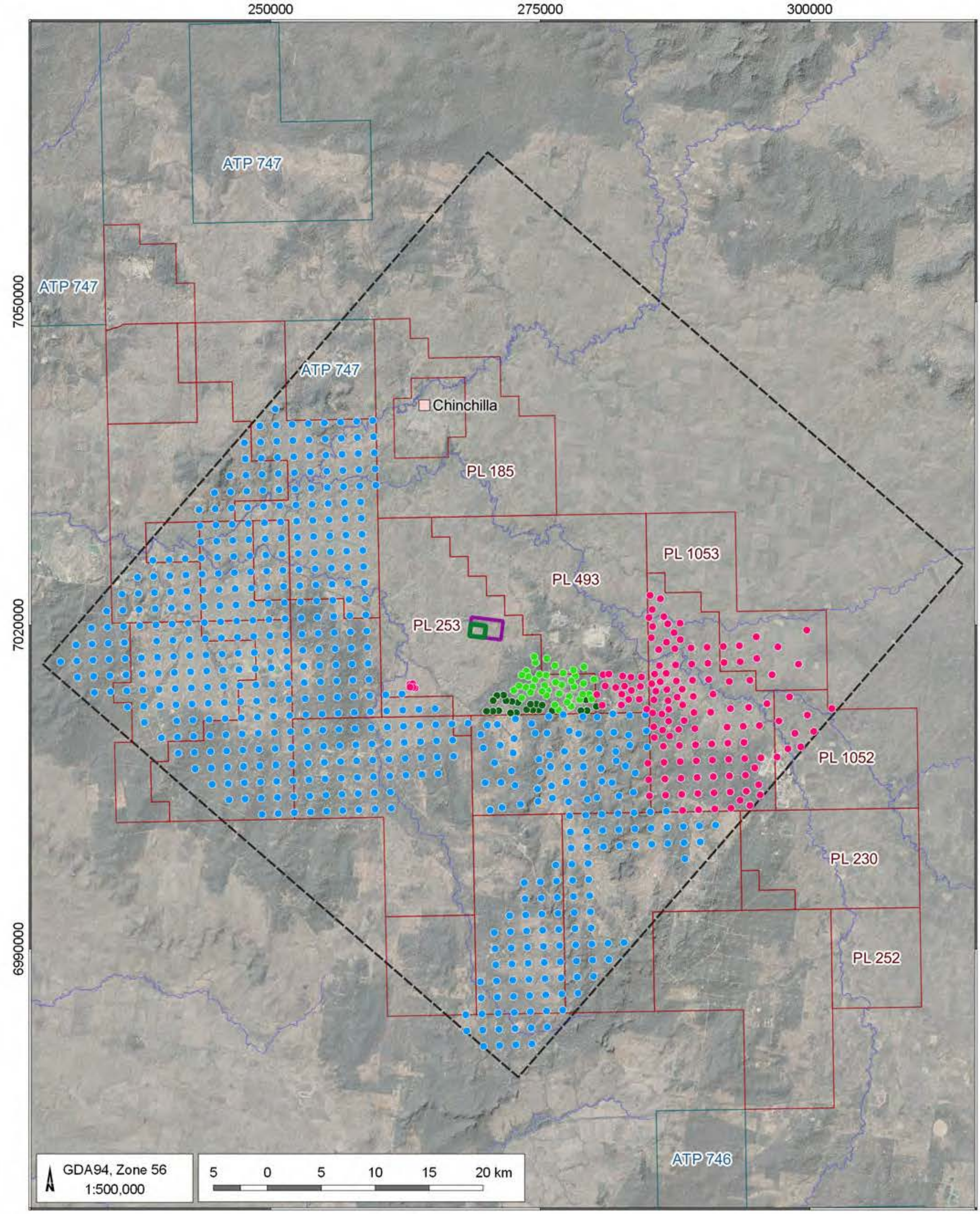
Baseline scenario

AGE

DATE
01/10/2021

FIGURE No:
5.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.; G:\Projects\G2002d.LINC_containment\3_GIS\Workspaces\001_Deliverable1\05.01_G2002d_Baseline scenario.qgs



LEGEND

- 🟥 Populated place
- — Rivers and other watercourses
- 🟩 MDL309 boundary
- 🟪 Lot 40 DY 85
- ▭ Petroleum Lease (PL) area
- ▭ Authority to Prospect (ATP) area
- ⌐¬ Model extent

CSG Well

- ● Arrow authorised
- ● Arrow proposed - not screened into the Macalister
- ● Arrow proposed - screened into the Macalister coal
- ● Non-Arrow

Arrow EA Amendment Support (G2002d)

Arrow FDP scenario

AGE

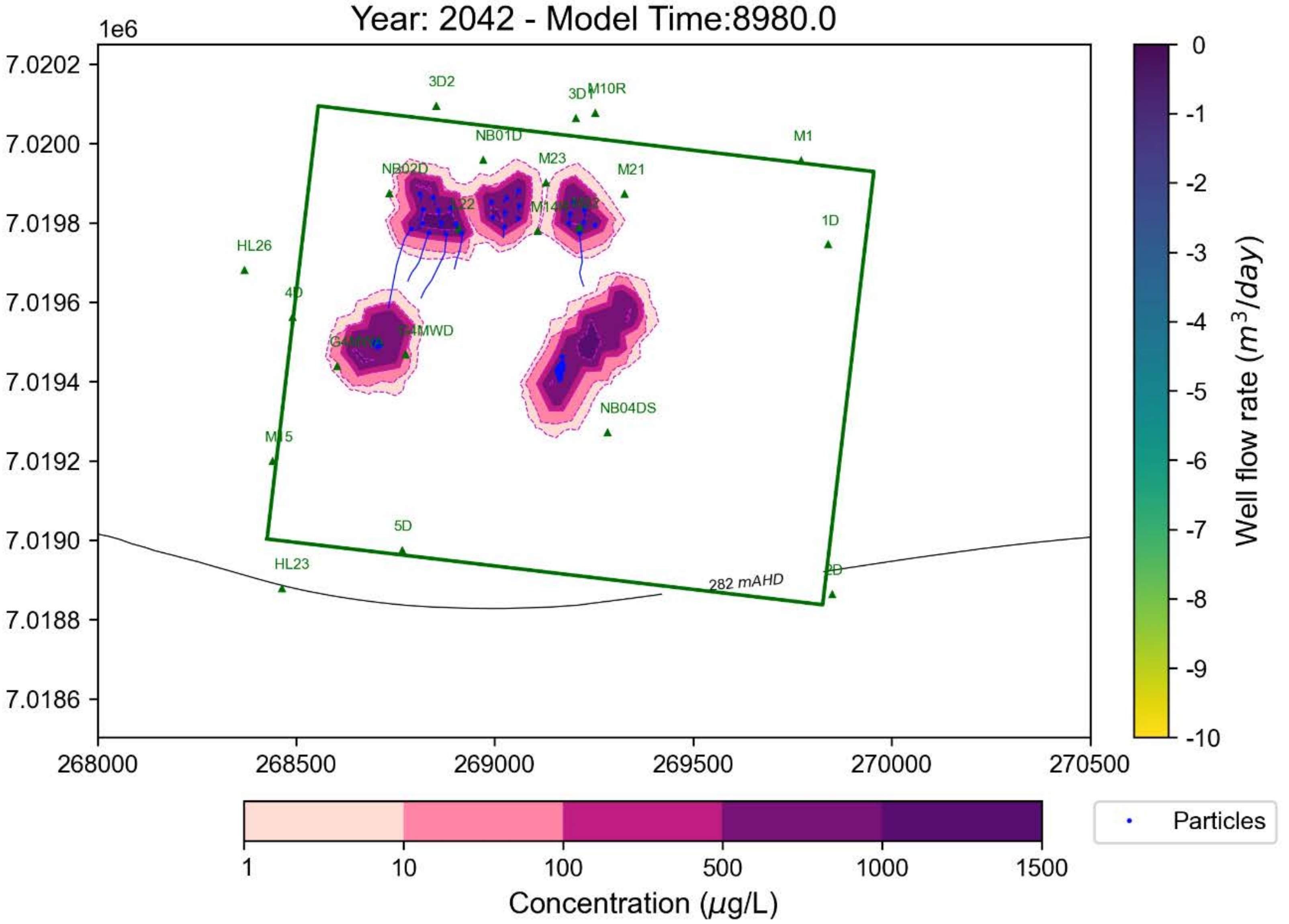
DATE
01/10/2021

FIGURE No:
5.2

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002d.LINC_containment\3_GIS\Workspaces\001_Deliverable1\05.02_G2002d_Arrow FDP scenario.qgs

5.2 Particle tracking and contaminant plume migration

Figure 5.3 to Figure 5.6 show animations of particle tracks and contaminant plume migration for the FID1 Arrow scenario. The animations reinforce the predicted hypothesis that contaminant movement is slow. Results indicate significant contaminant movement is restricted to MDL309, movement is primarily central, and concentrations outside the gasifiers reduce to near non-detectable limits prior to 2042.



Particle tracks and Benzene plume migration – Macalister coal seam (animation) Figure - 5.3

Arrow EA Amendment Support (G2002d)

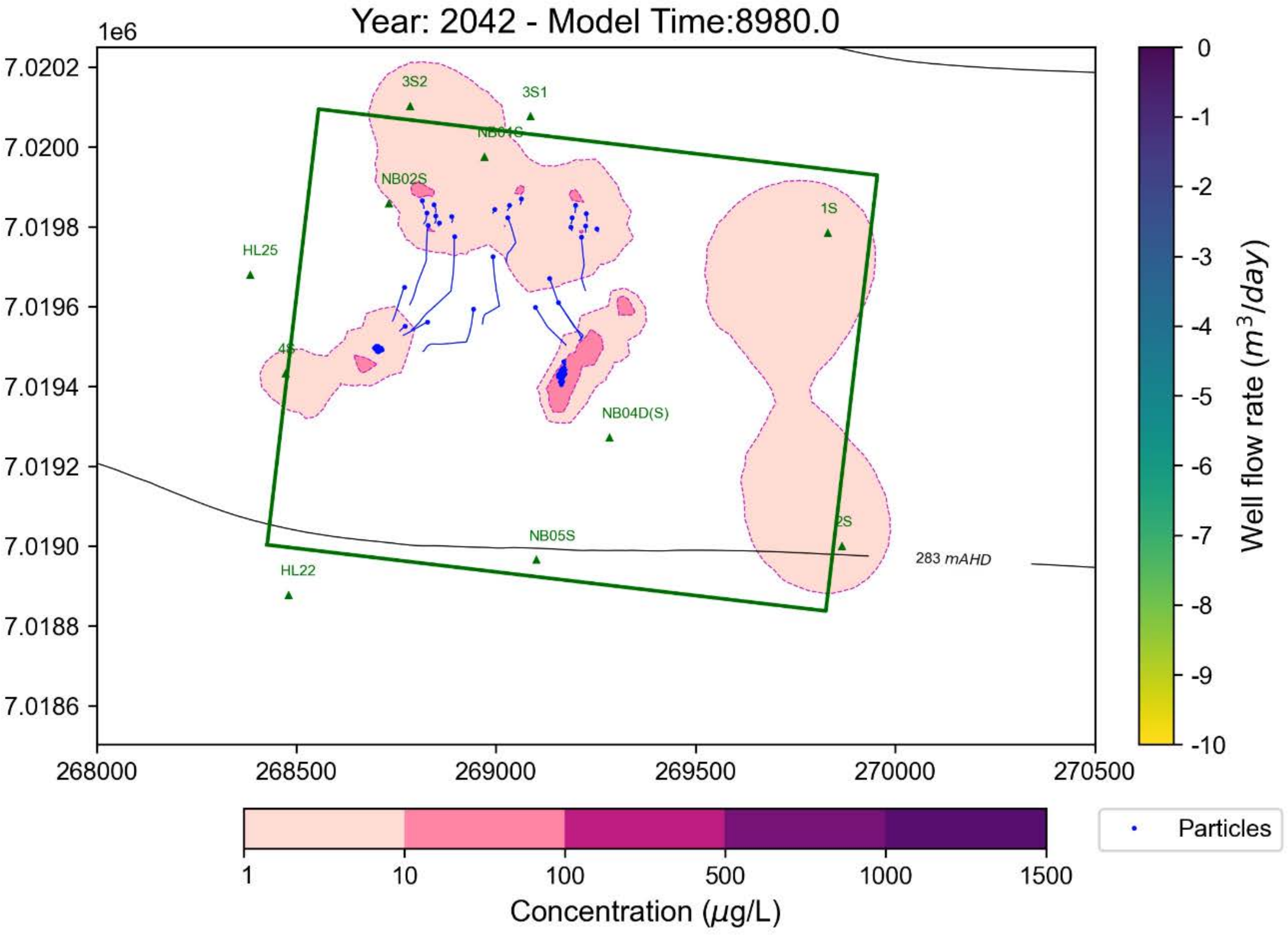
LEGEND

▲ Monitoring site

— Contour line

▭ MDL309 boundary

** To play the video in Adobe, uncheck the following box, restart Adobe, and select "Trust document" when prompted: "Edit>Preferences>Security (Enhanced)>Enable Protected Mode at startup"*



Particle tracks and Benzene plume migration – Springbok sandstone (animation)

Figure - 5.4

Arrow EA Amendment Support (G2002d)

LEGEND

▲ Monitoring site

— Contour line

▭ MDL309 boundary

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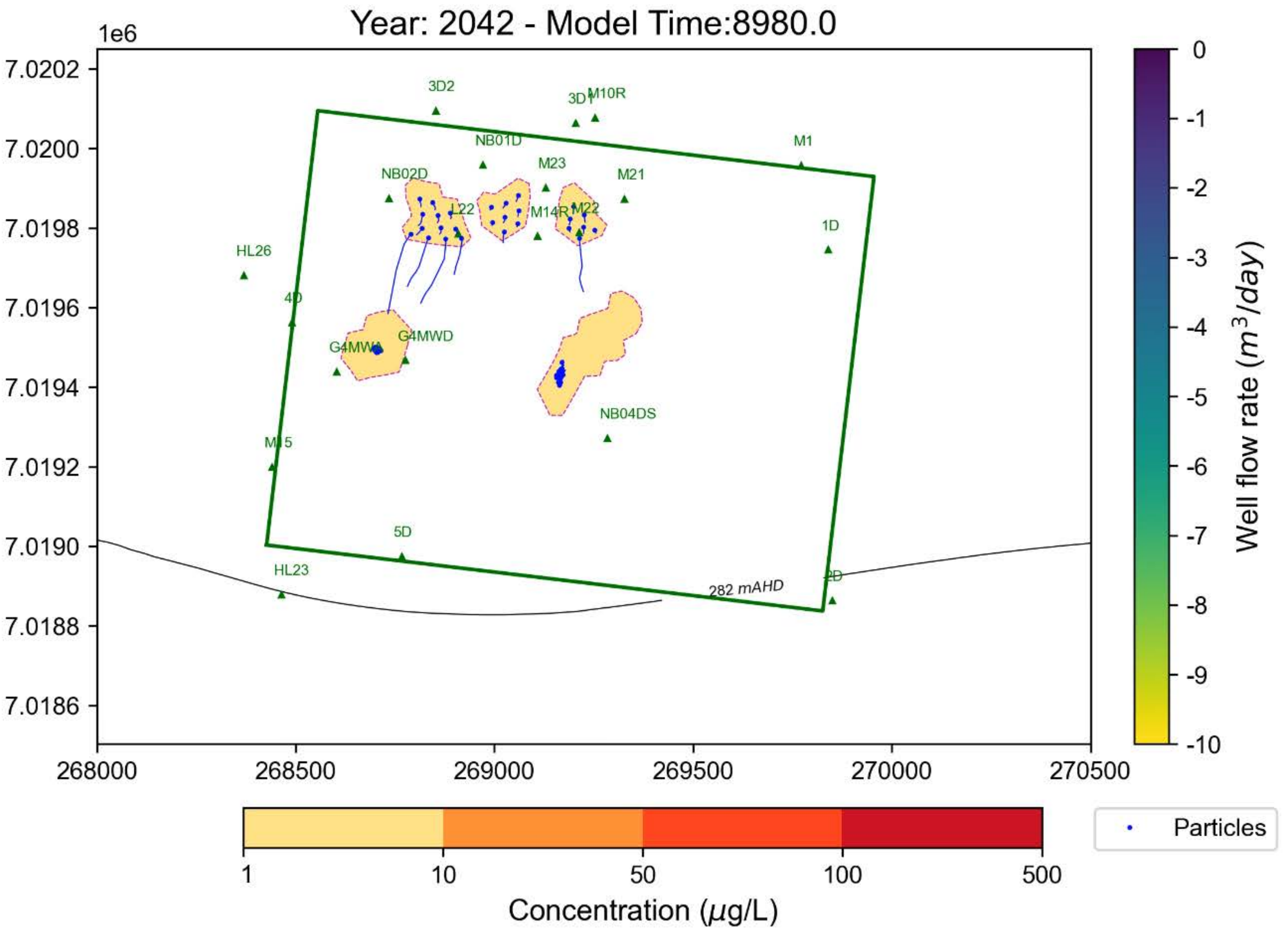

Particle tracks and Naphthalene plume migration – Macalister coal seam (animation)

Figure - 5.5

Arrow EA Amendment Support (G2002d)

LEGEND

▲ Monitoring site

~ Contour line

▭ MDL309 boundary

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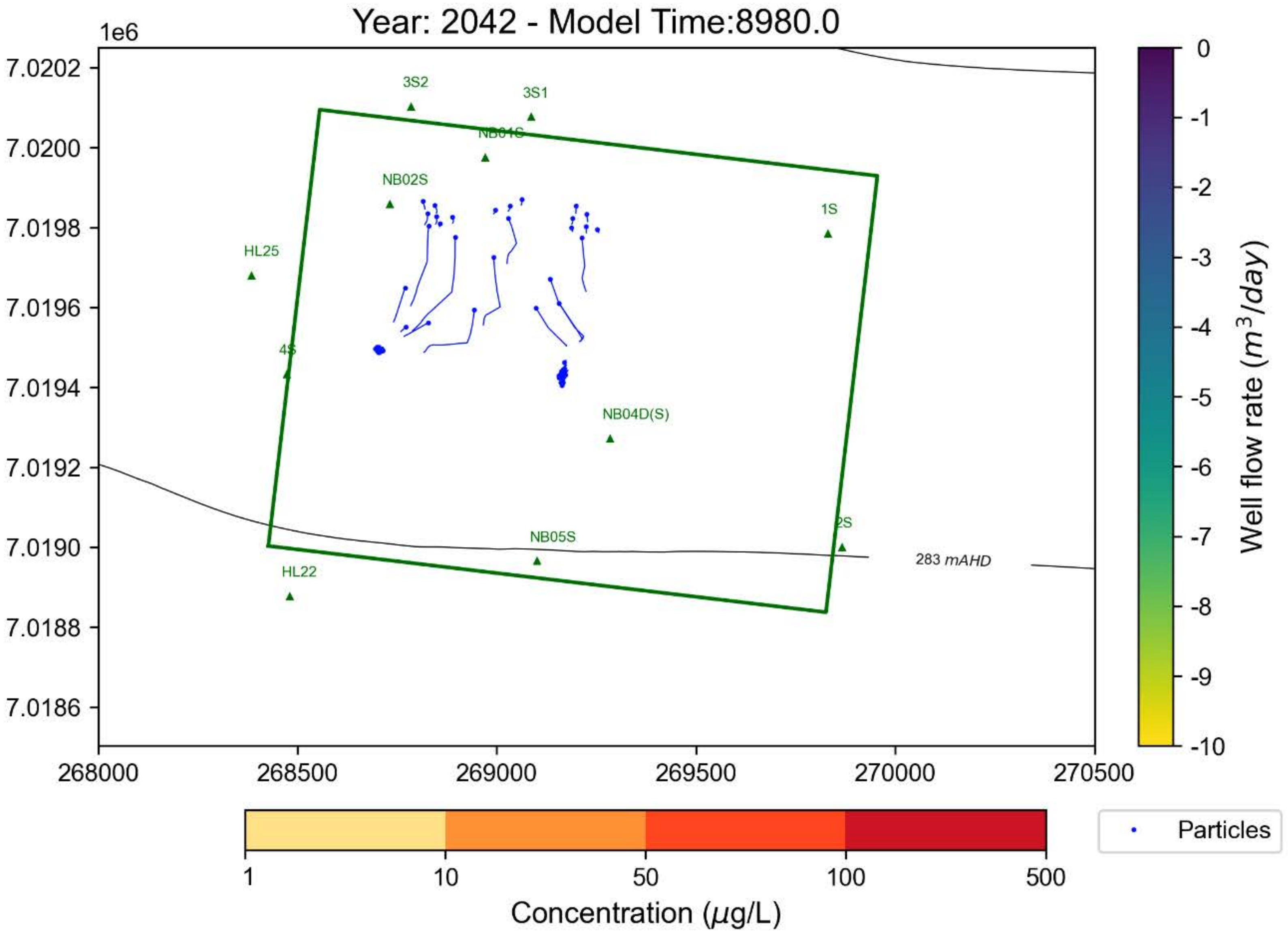

Particle tracks and Naphthalene plume migration – Springbok sandstone (animation)

Figure - 5.6

Arrow EA Amendment Support (G2002d)

LEGEND

▲ Monitoring site

~ Contour line

▭ MDL309 boundary

** To play the video in Adobe, uncheck the following box, restart Adobe, and select "Trust document" when prompted: "Edit>Preferences>Security (Enhanced)>Enable Protected Mode at startup"*

AGE

6 Summary and conclusions

Groundwater flow and contaminant fate and transport models have been updated and validated through further refinement of a model previously developed by AGE (2020). Modelled porosity values have also been revised to address independent peer review comments.

Revised particle tracking results tend to confirm the previous predictions and suggest that development of the surrounding PLs will not affect the movement of existing contamination on the former Linc Energy site (Lot 40 DY85).

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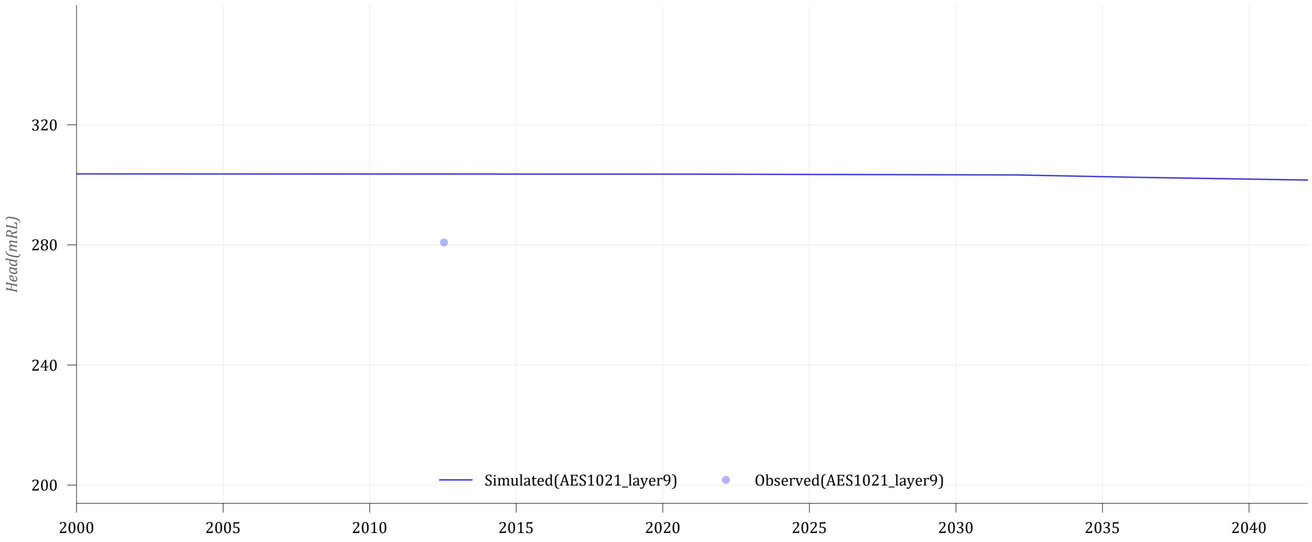
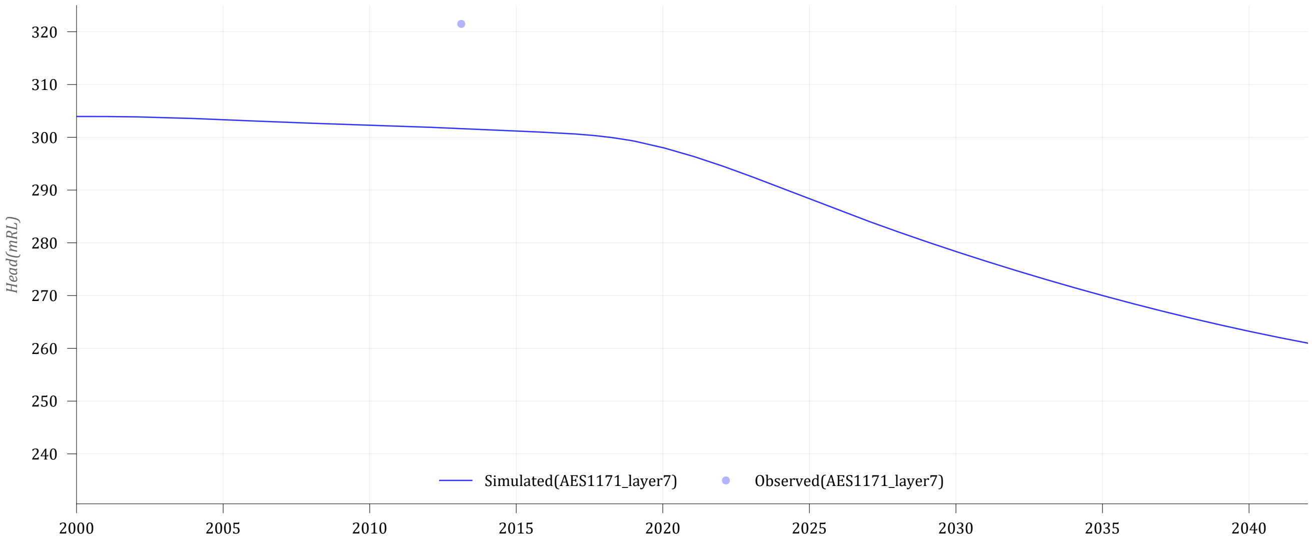
Appendix A

Calibration hydrographs

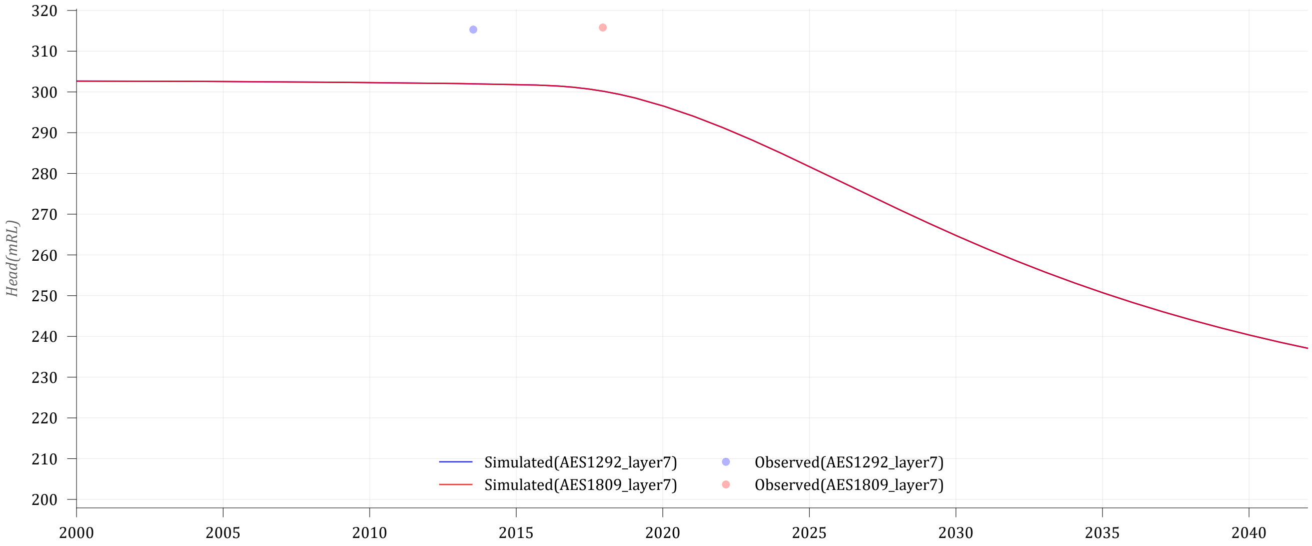
AES1021

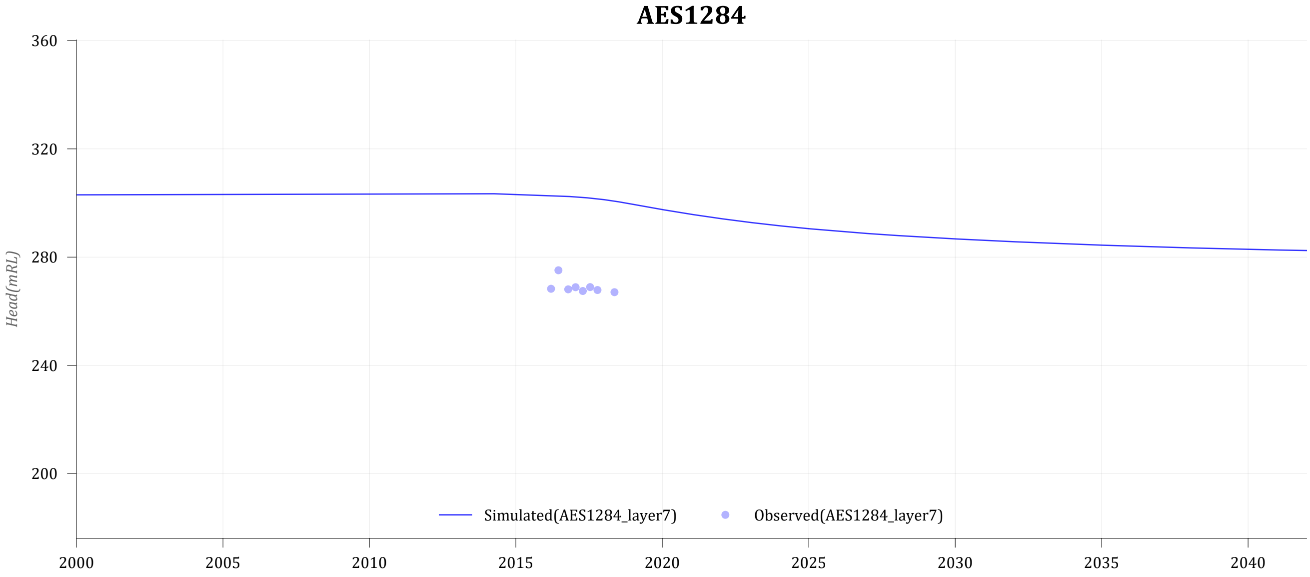


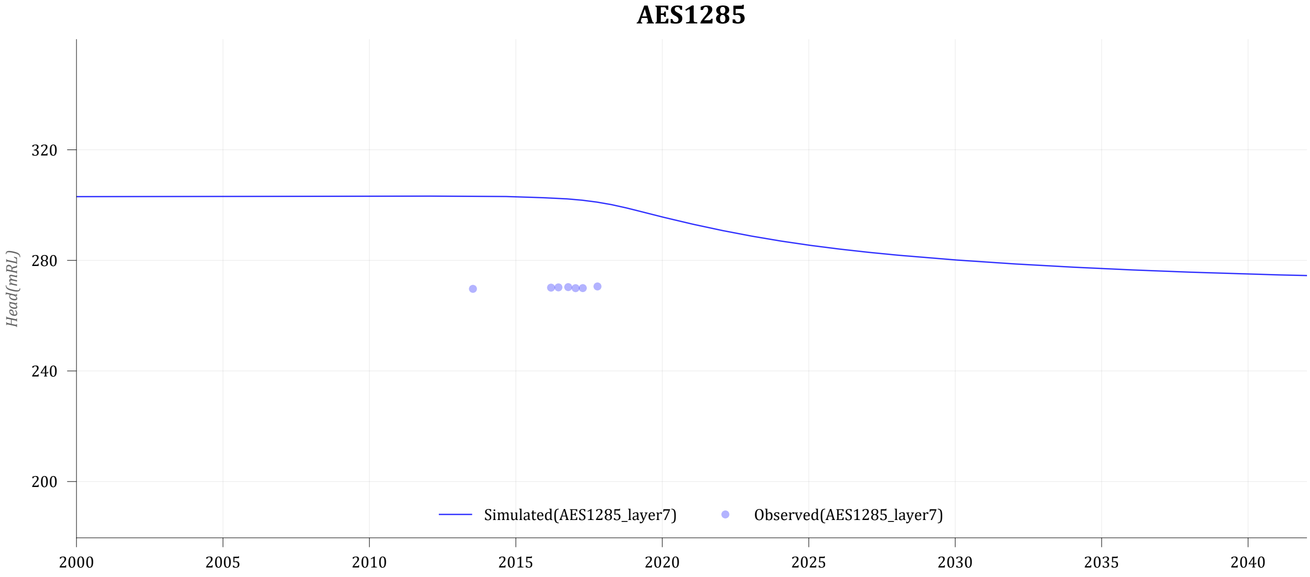
AES1171



AES12




AES1284
360
320
280
240
200
Head(mRL)
Simulated(AES1284_layer7)
Observed(AES1284_layer7)
2000
2005
2010
2015
2020
2025
2030
2035
2040


AES1285
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280
240
200
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Observed(AES1285_layer7)
2000
2005
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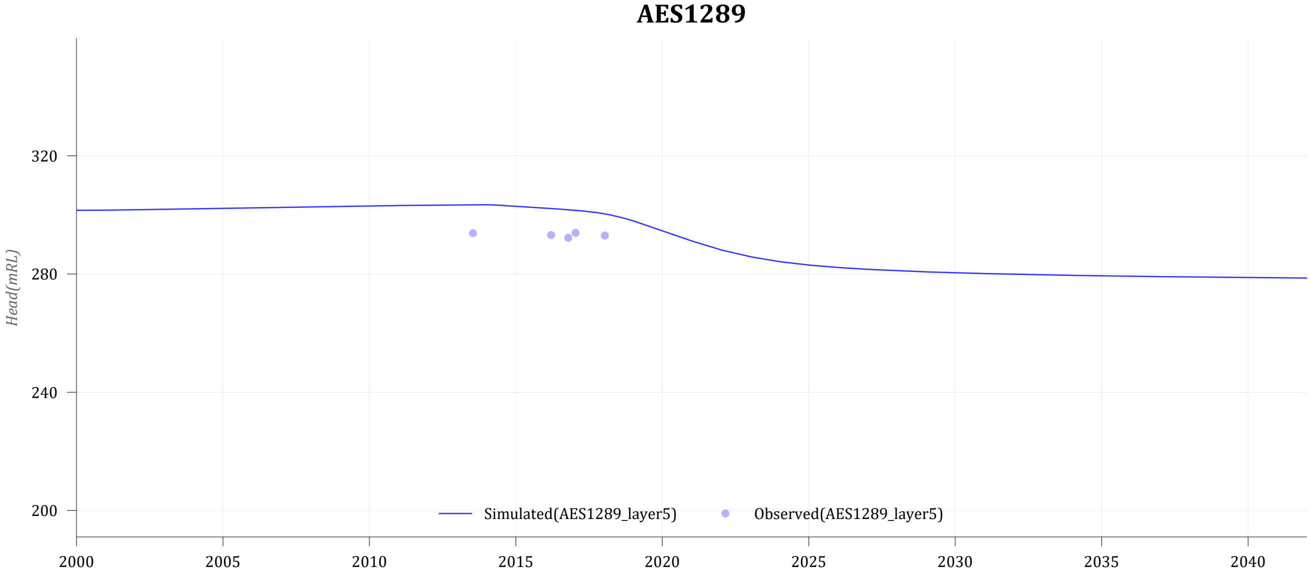
2025
2030
2035
2040


AES1289
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280
240
200
Head(mRL)
Simulated(AES1289_layer5)
Observed(AES1289_layer5)
2000
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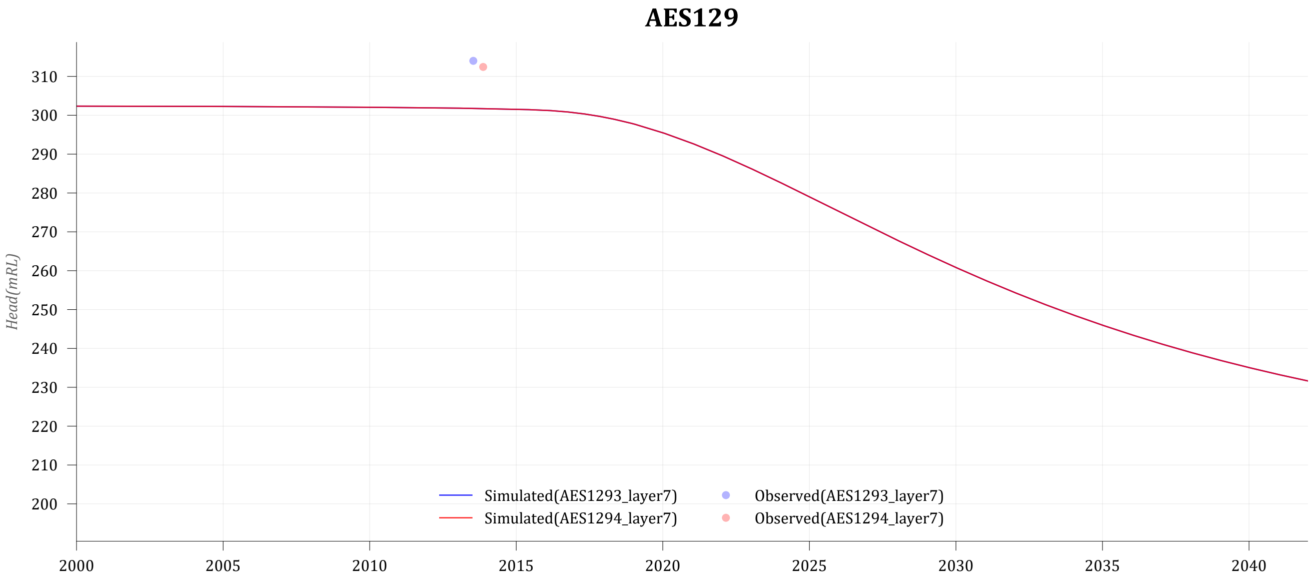
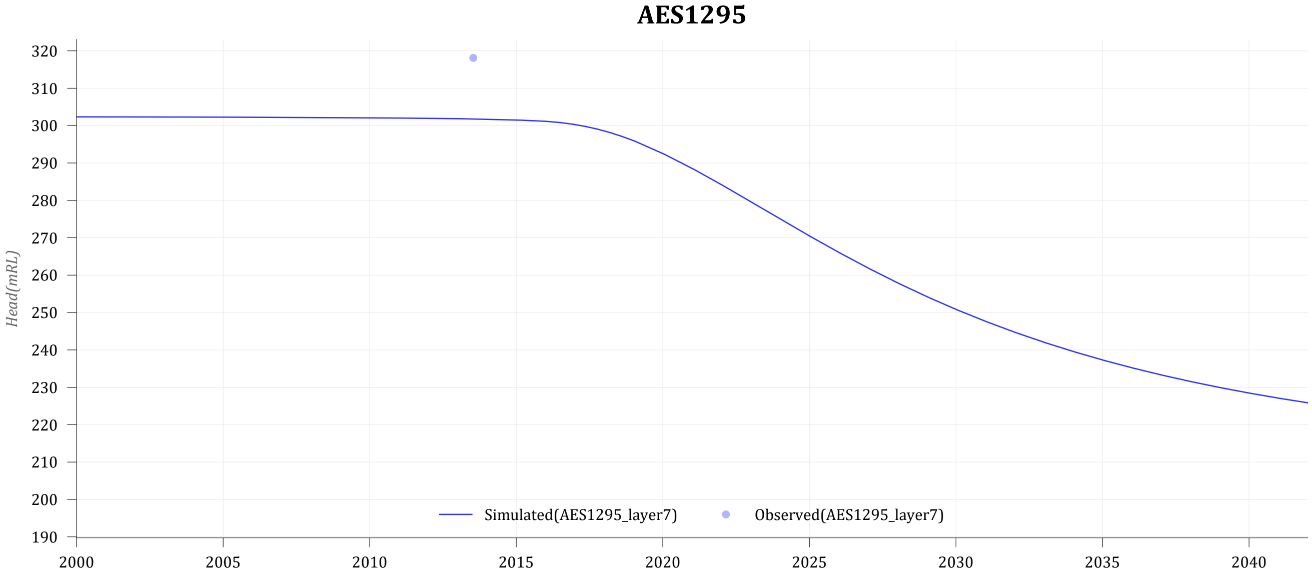
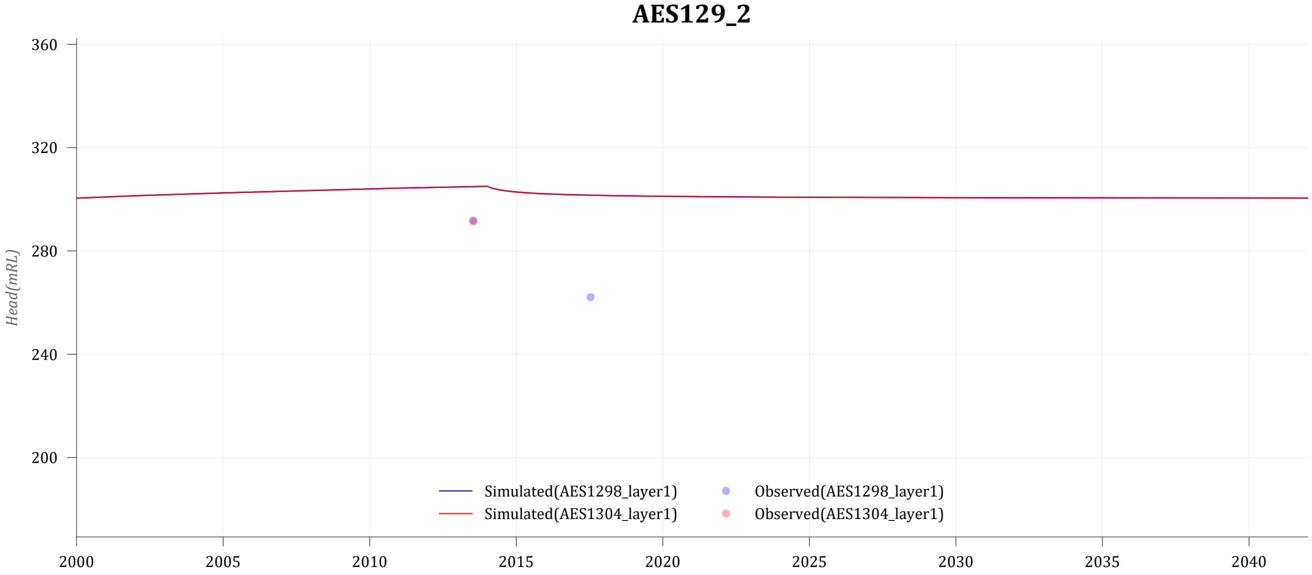
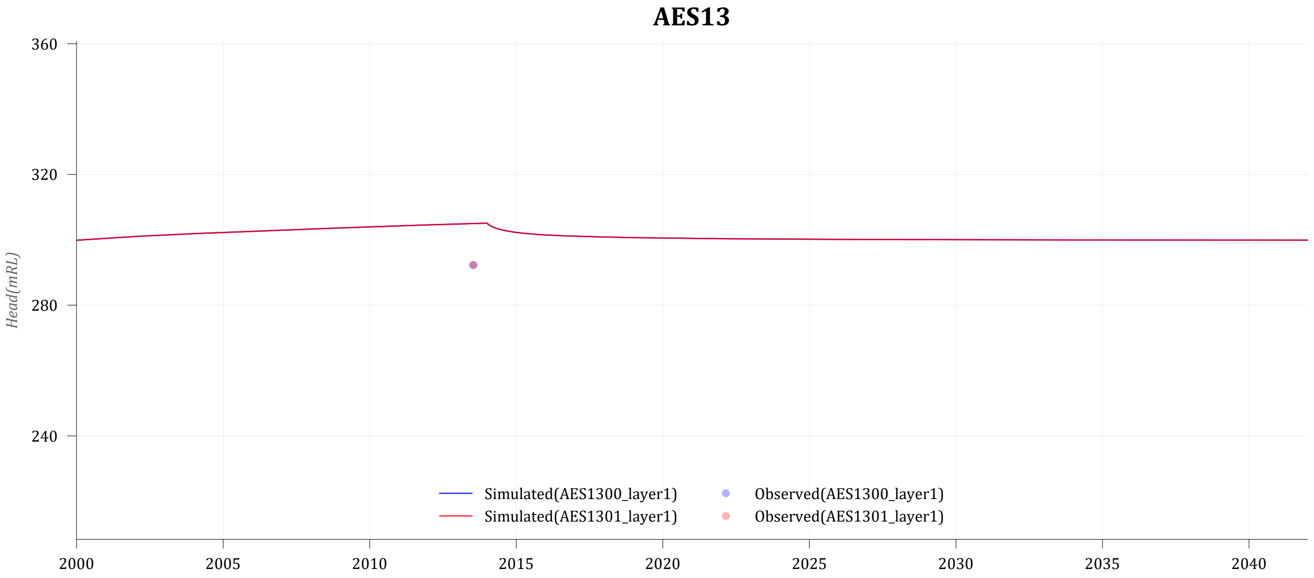
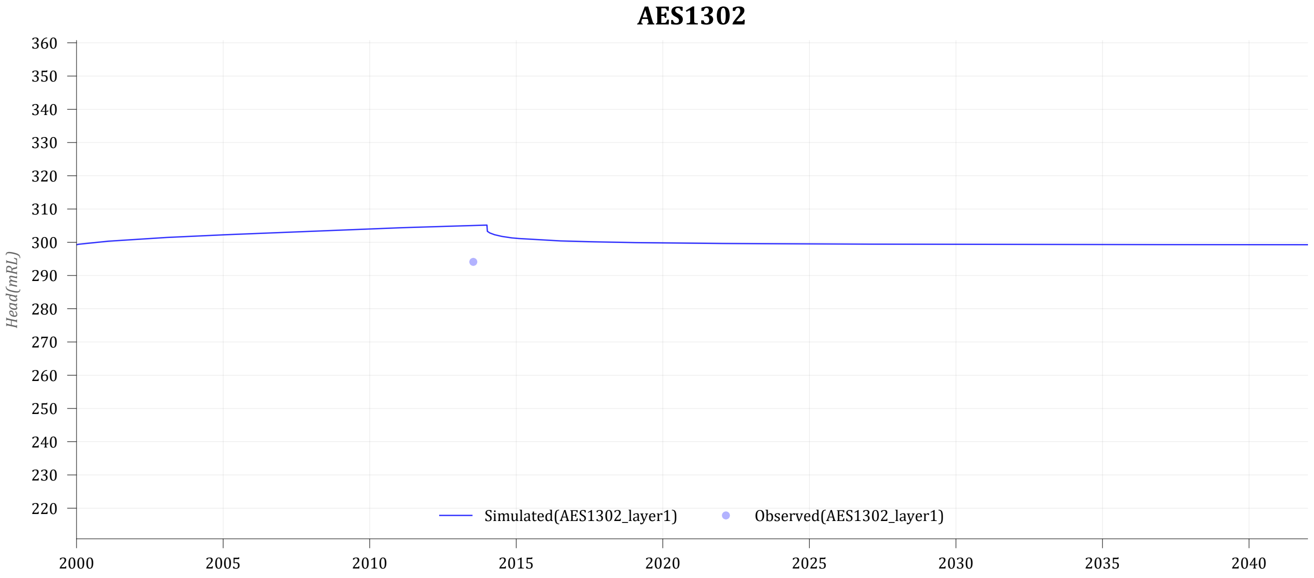
2015
2020
2025
2030
2035
2040

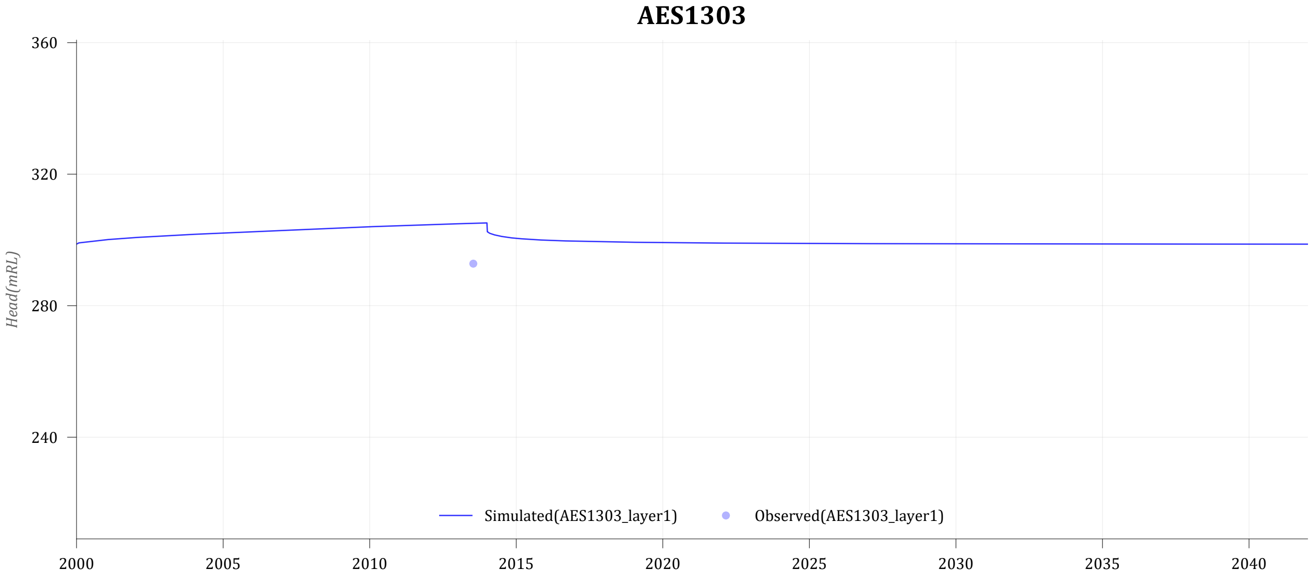

AES129
Head(mRL)
310
300
290
280
270
260
250
240
230
220
210
200
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(AES1293_layer7)
Simulated(AES1294_layer7)
Observed(AES1293_layer7)
Observed(AES1294_layer7)


AES1295
Head(mRL)
320
310
300
290
280
270
260
250
240
230
220
210
200
190
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(AES1295_layer7)
Observed(AES1295_layer7)

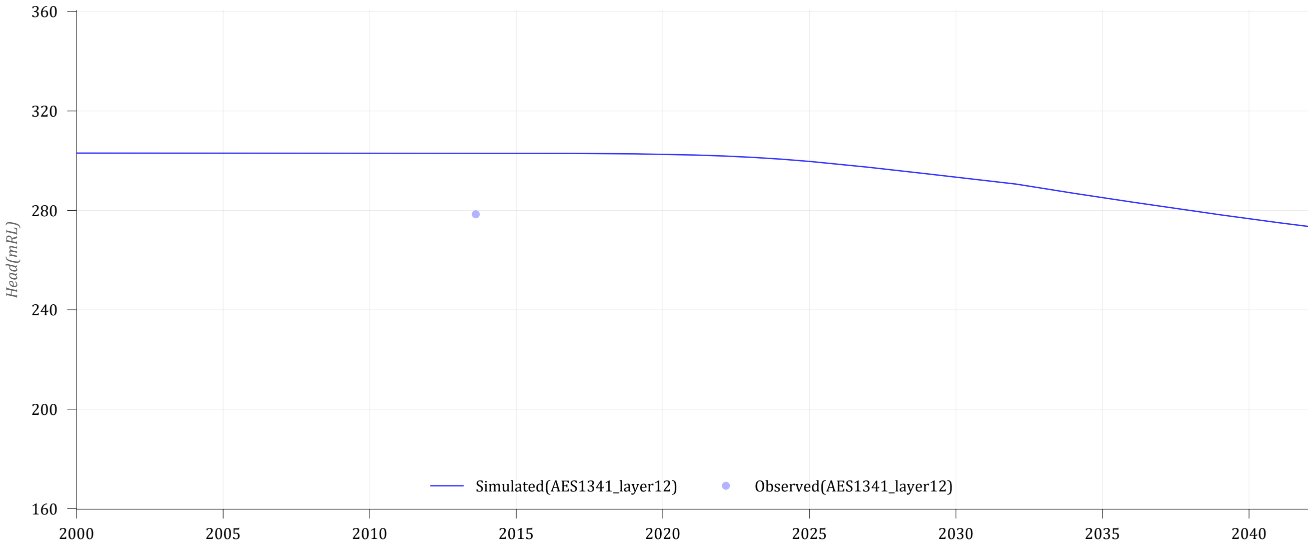

AES129_2
Head(mRL)
360
320
280
240
200
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(AES1298_layer1)
Simulated(AES1304_layer1)
Observed(AES1298_layer1)
Observed(AES1304_layer1)


AES13
360
320
280
240
Head(mRL)
Simulated(AES1300_layer1)
Simulated(AES1301_layer1)
Observed(AES1300_layer1)
Observed(AES1301_layer1)
2000
2005
2010
2015
2020
2025
2030
2035
2040

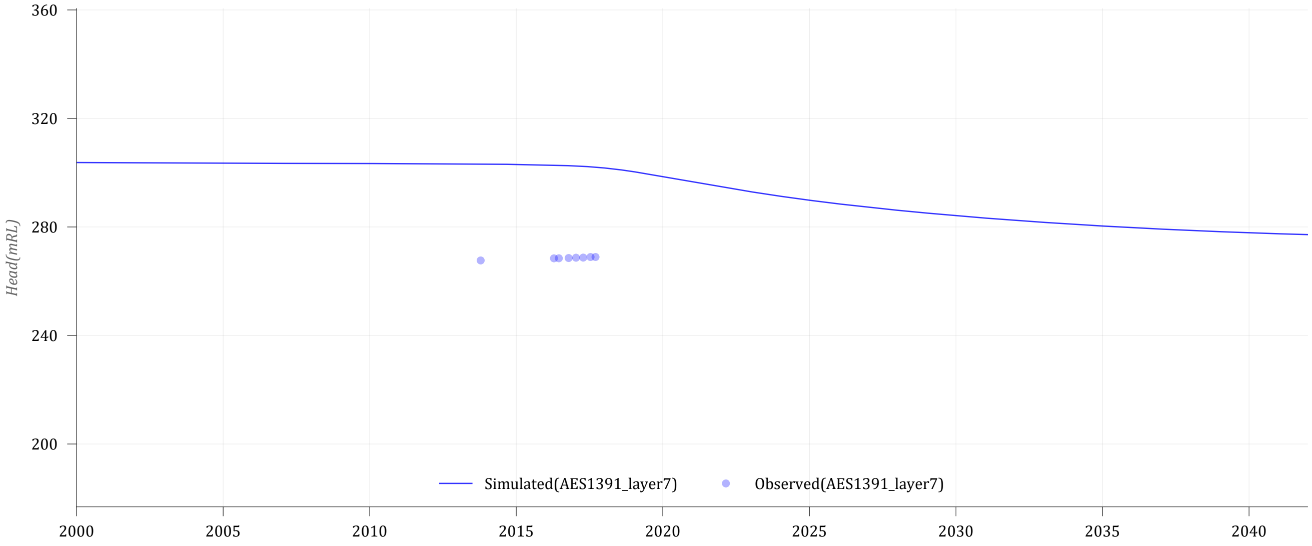

AES1302
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
Head(mRL)
Simulated(AES1302_layer1)
Observed(AES1302_layer1)
2000
2005
2010
2015
2020
2025
2030
2035
2040


AES1303
360
320
280
240
Head(mRL)
Simulated(AES1303_layer1)
Observed(AES1303_layer1)
2000
2005
2010
2015
2020
2025
2030
2035
2040

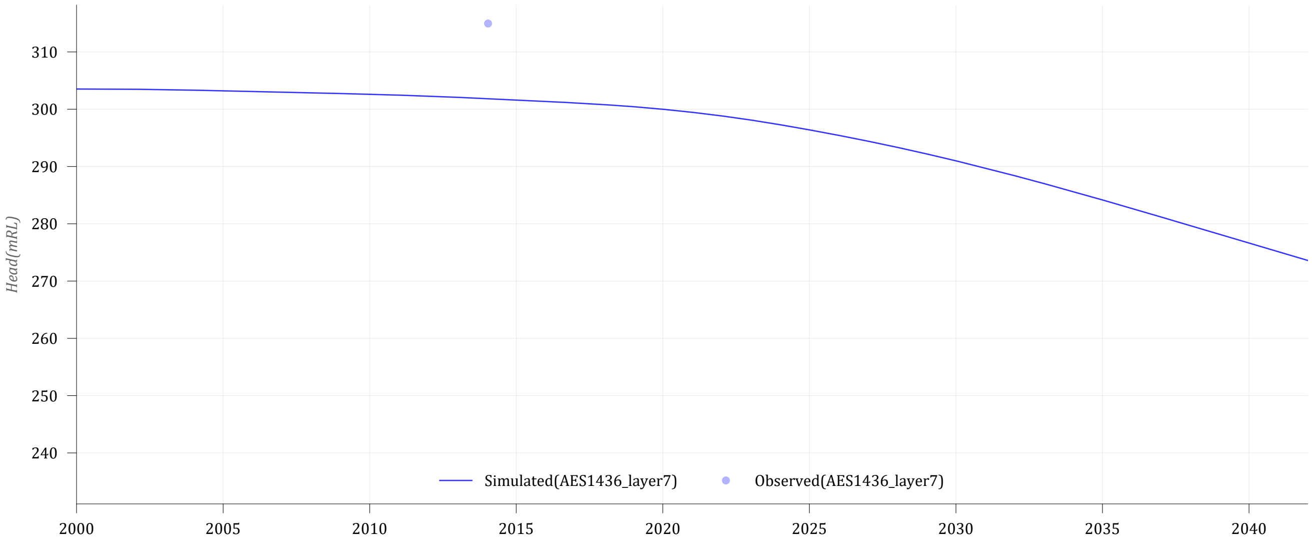
AES1341



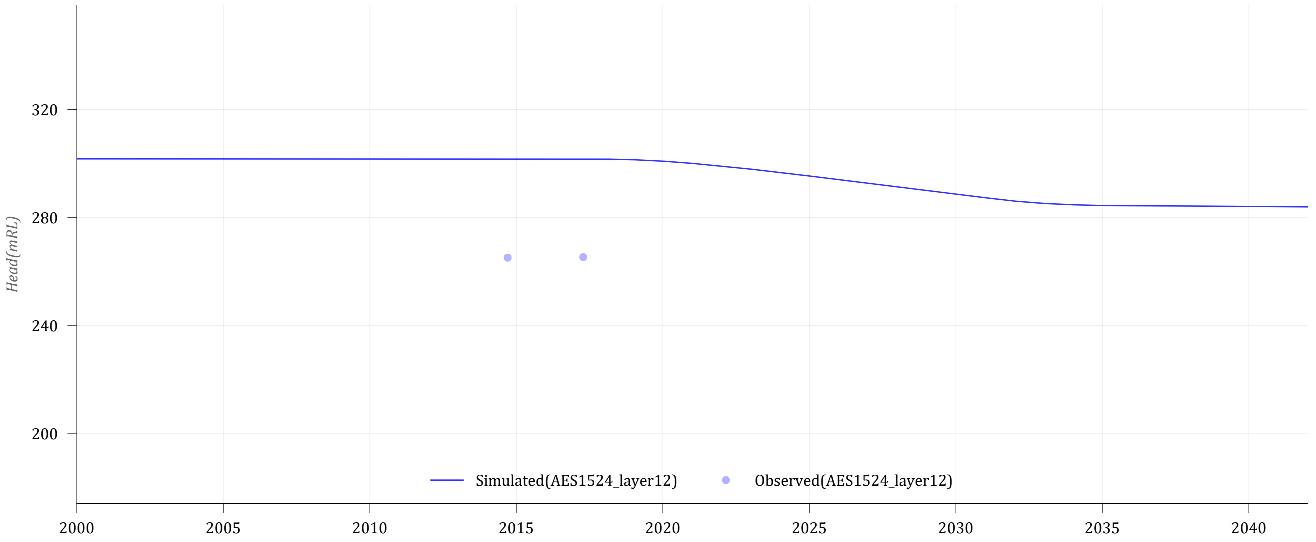
AES1391



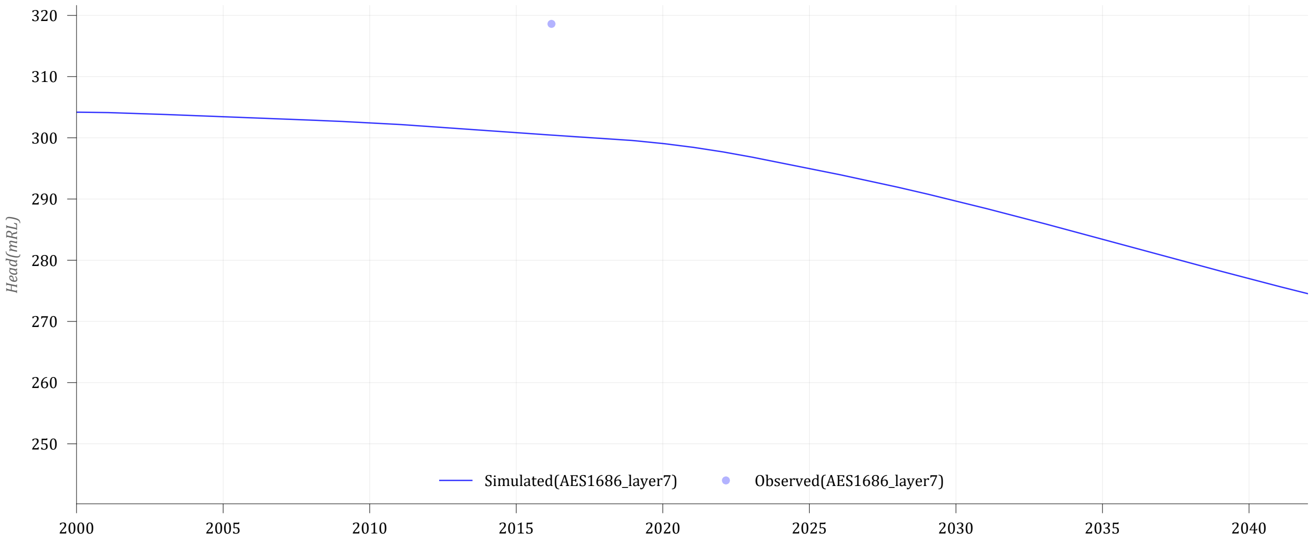
AES1436



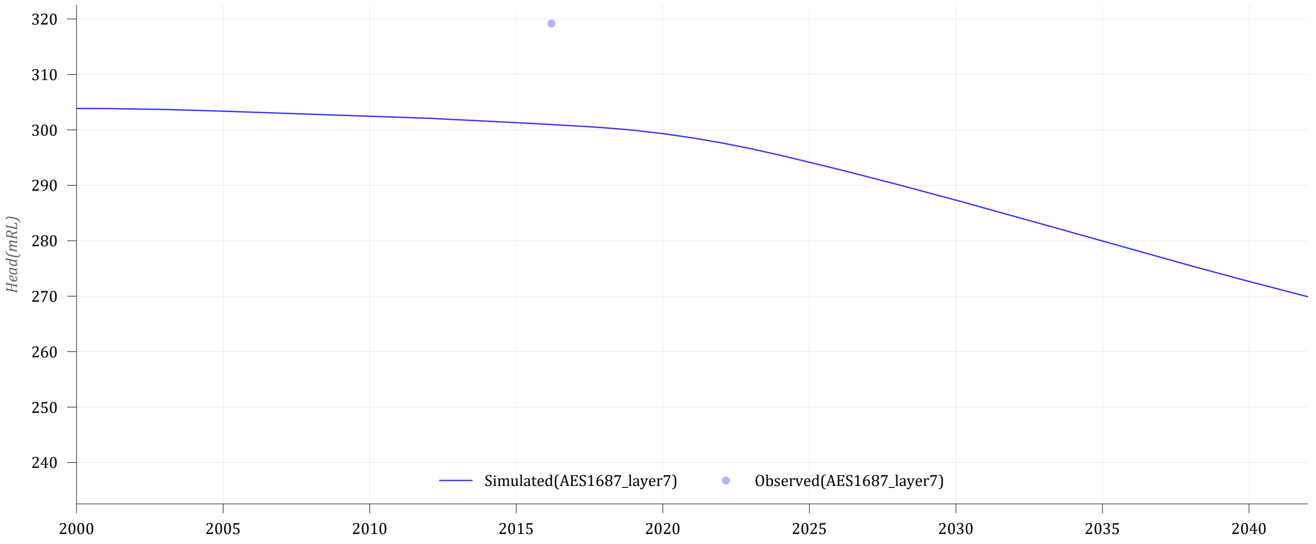
AES1524

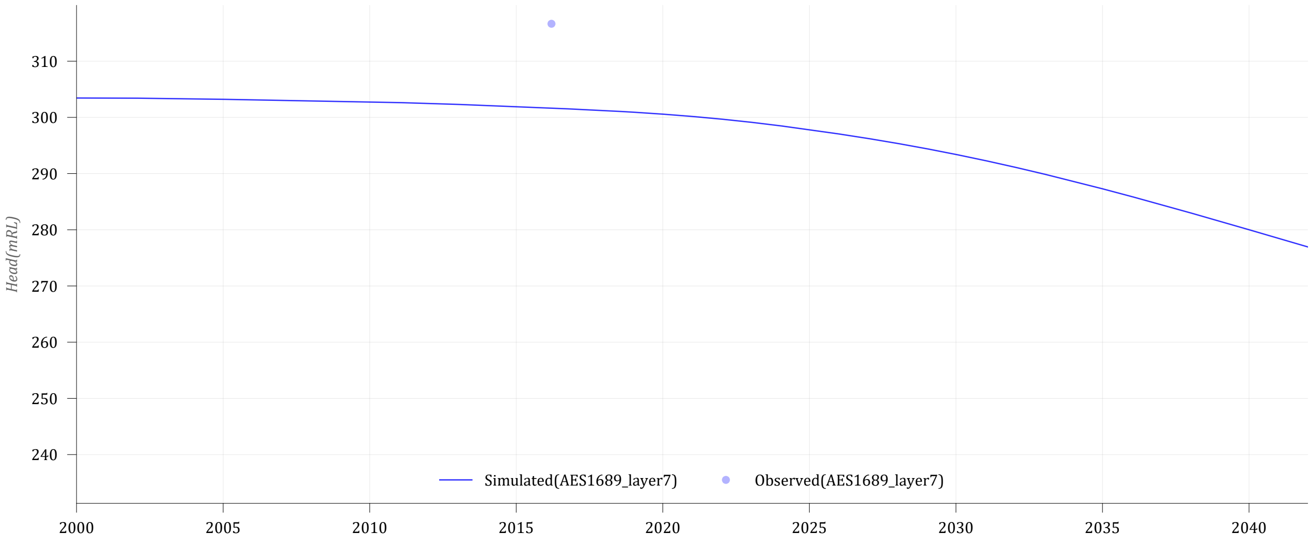


AES1686

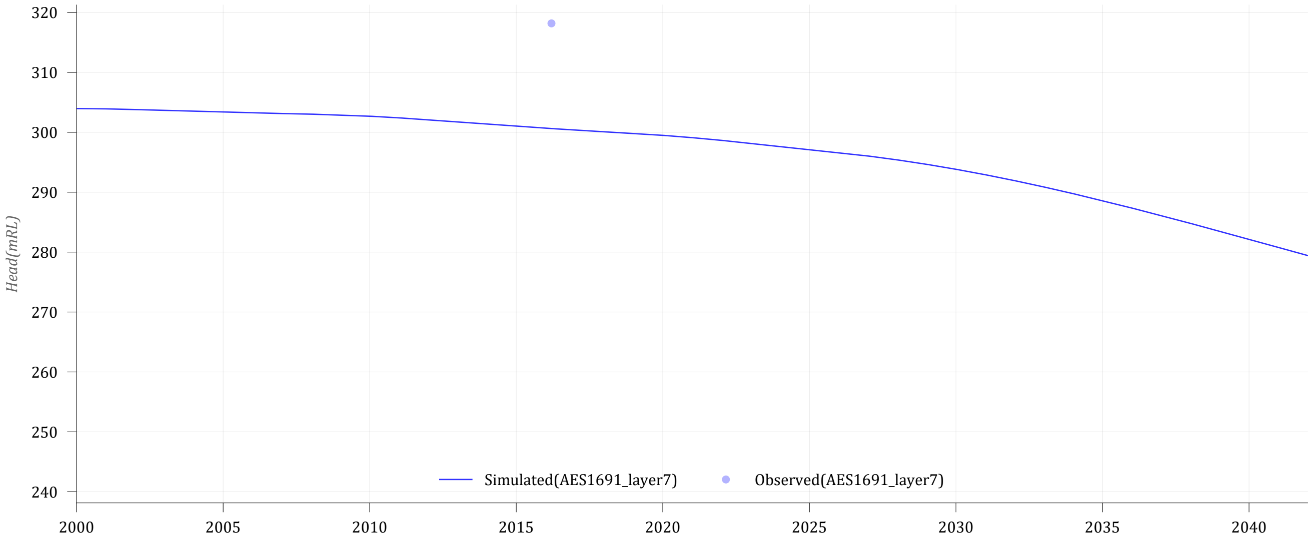


AES1687

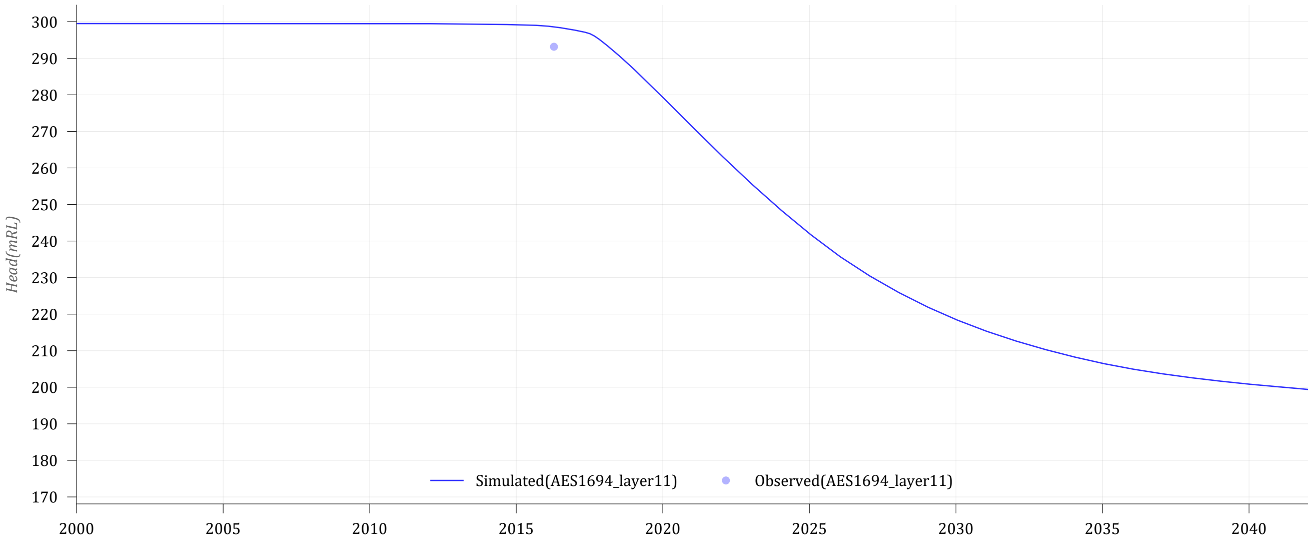




AES1689

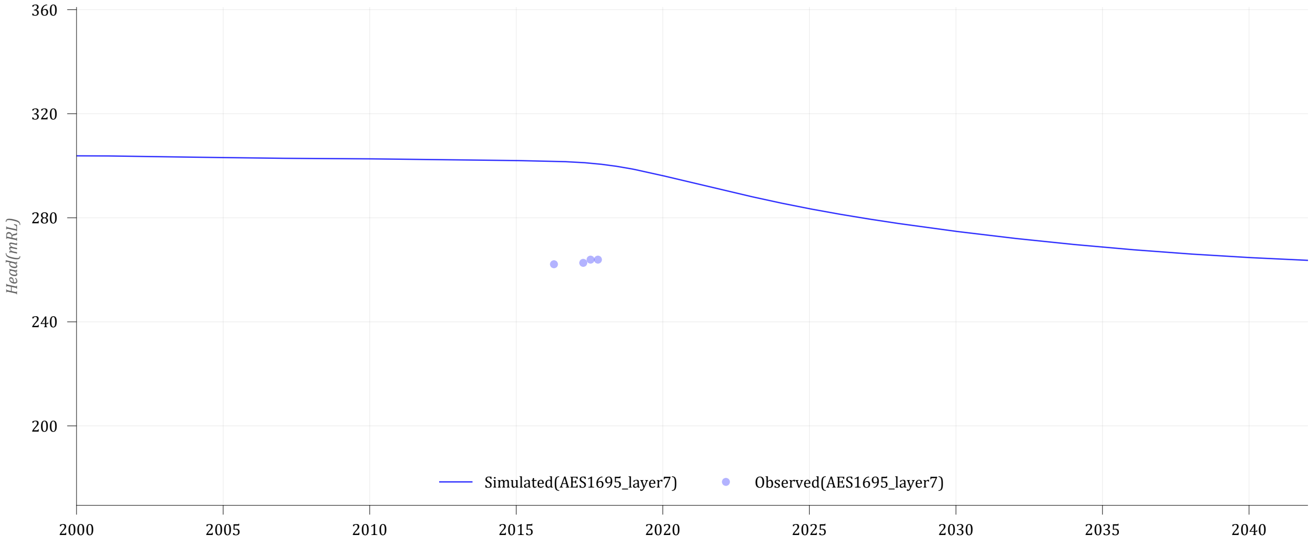


AES1691

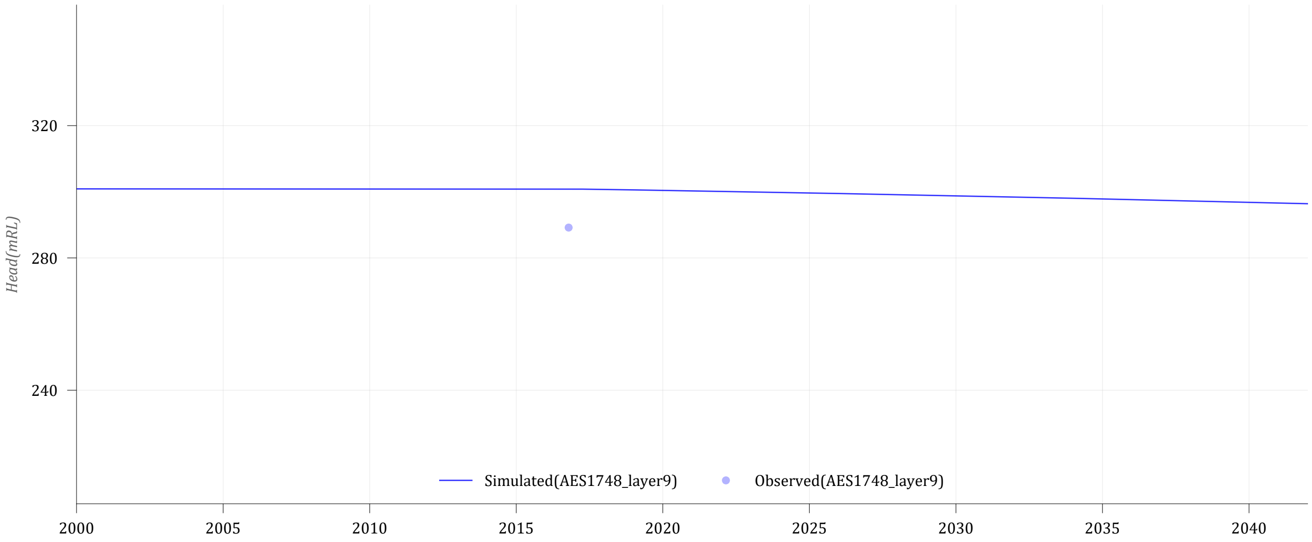


AES1694

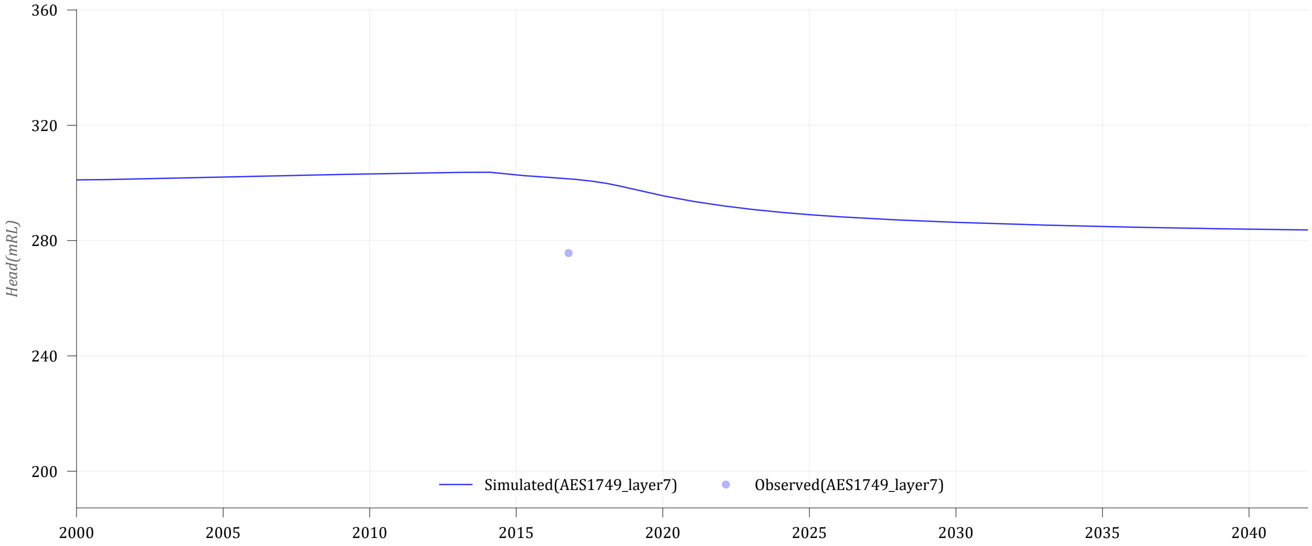
AES1695



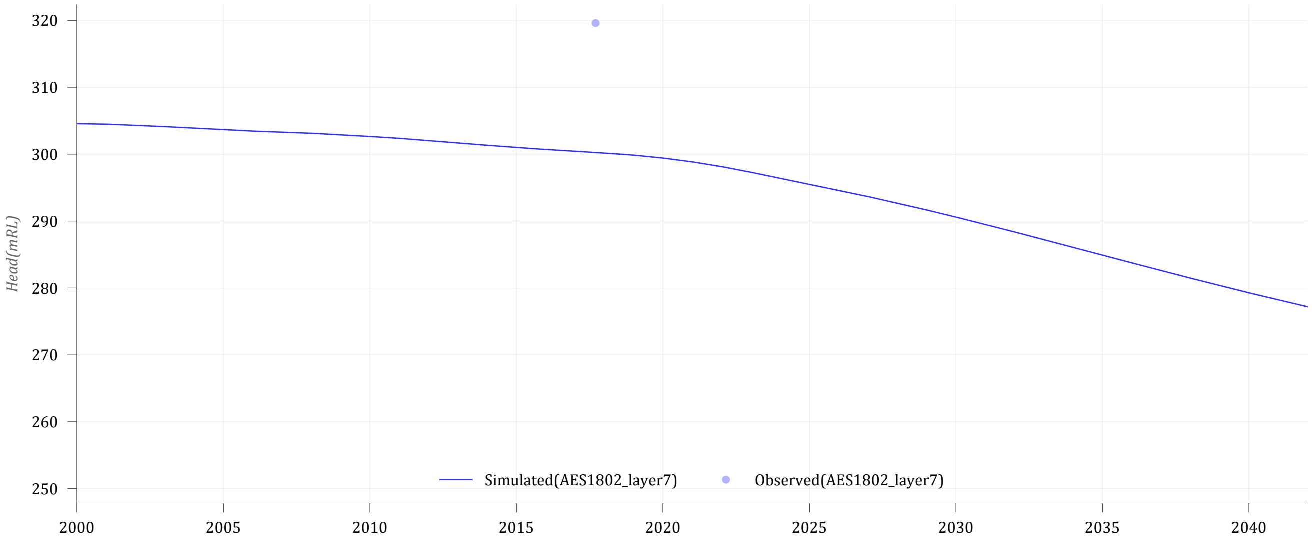
AES1748



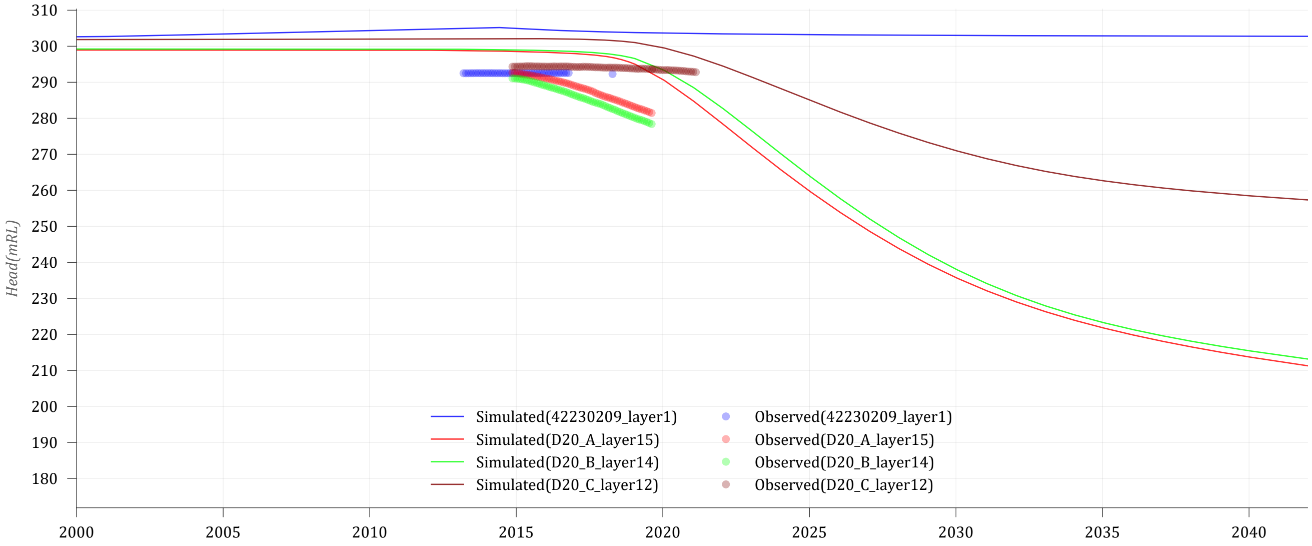
AES1749



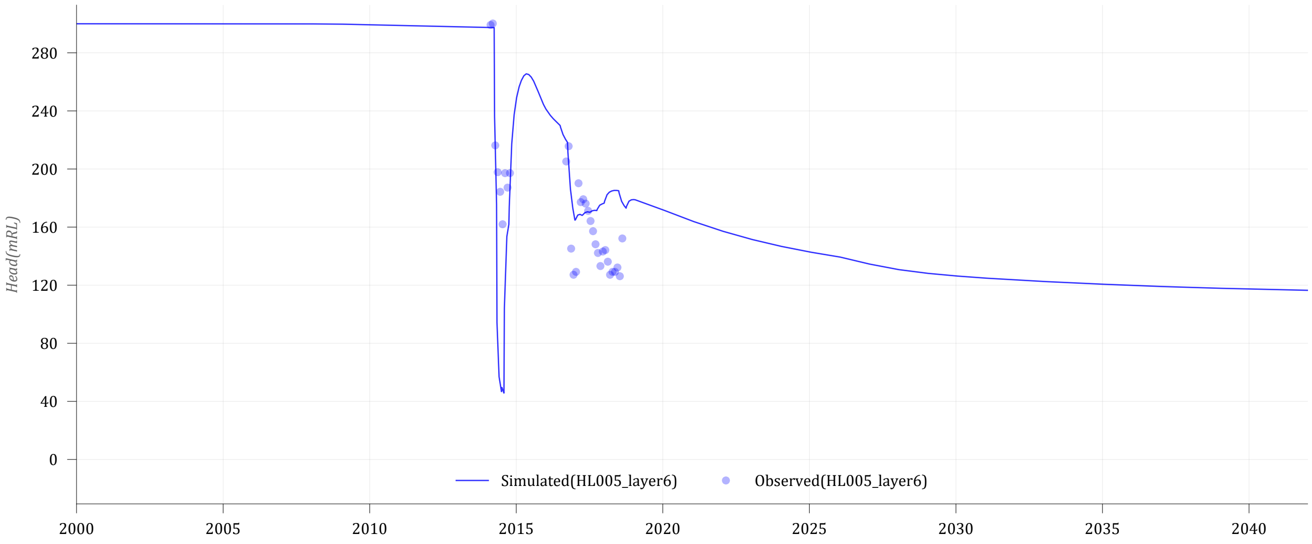
AES1802

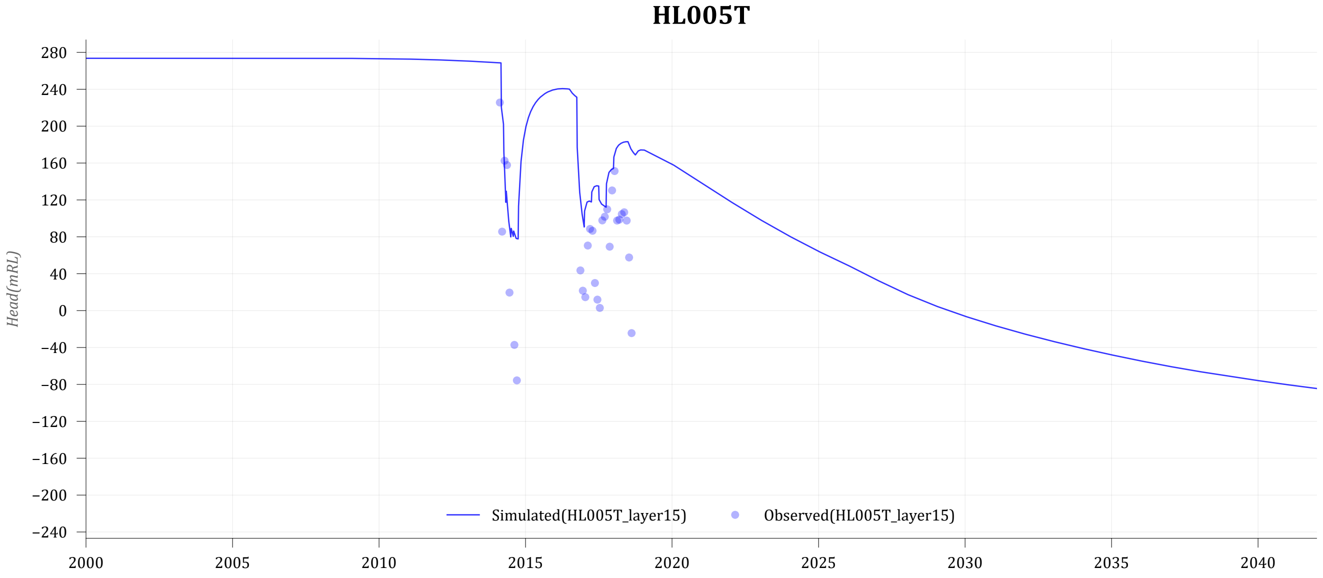


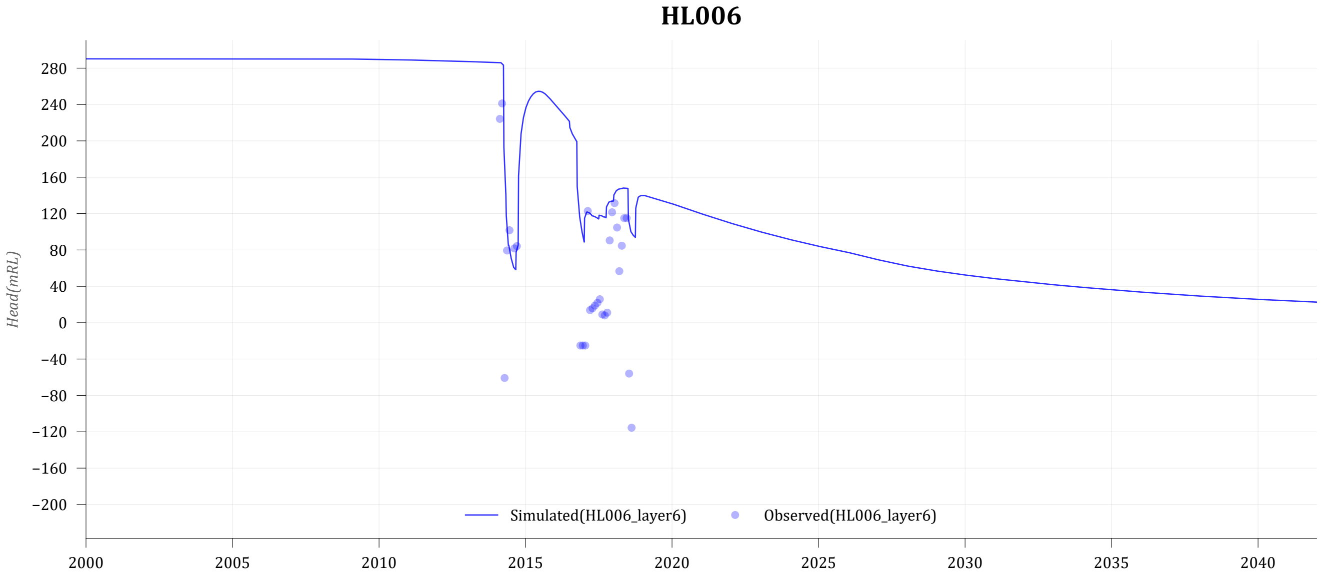
D20

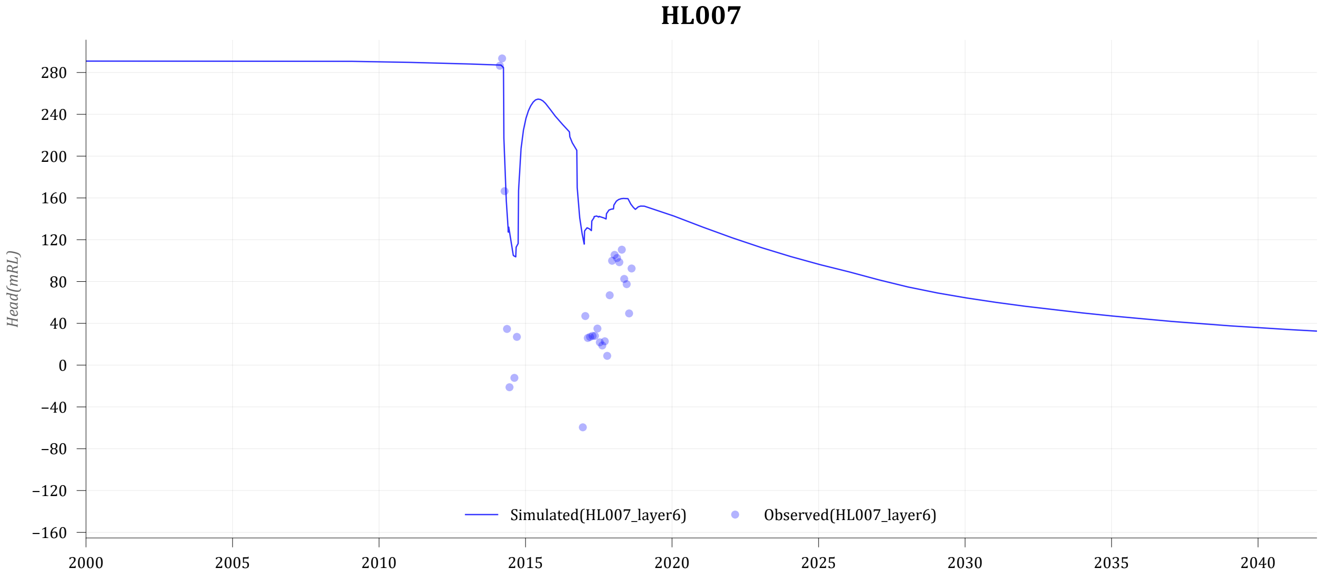


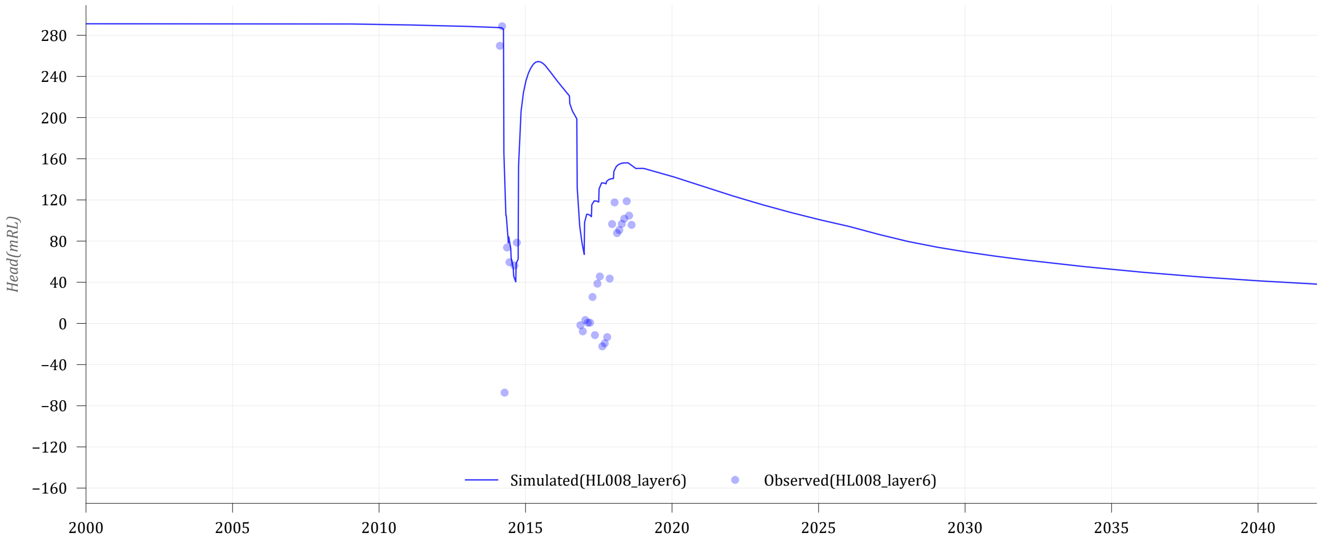
HL005

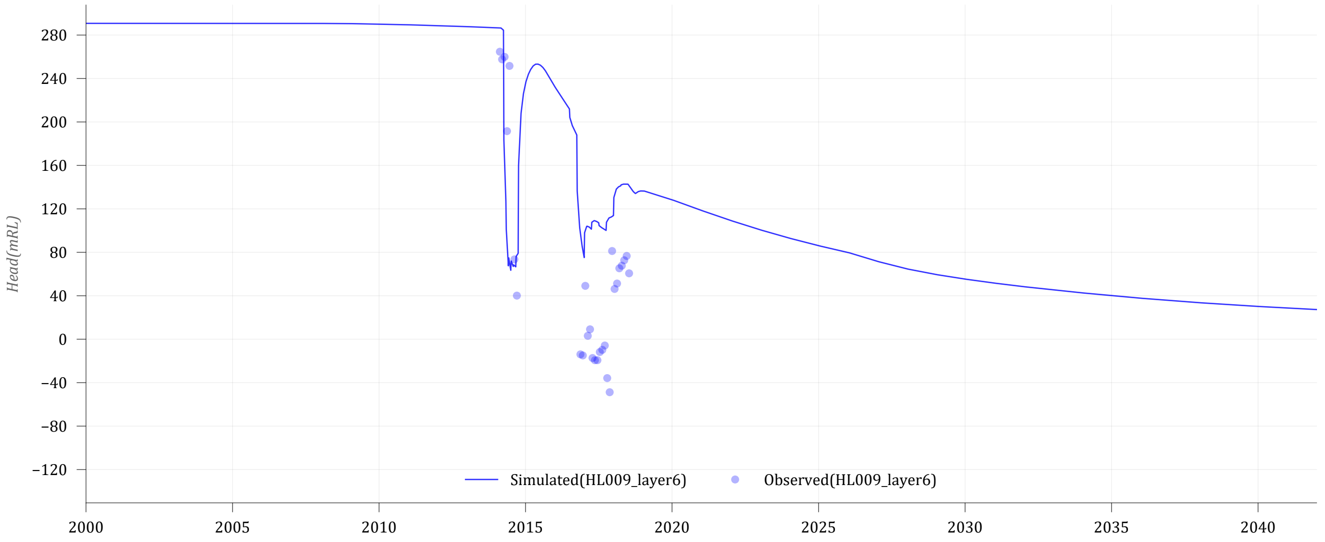


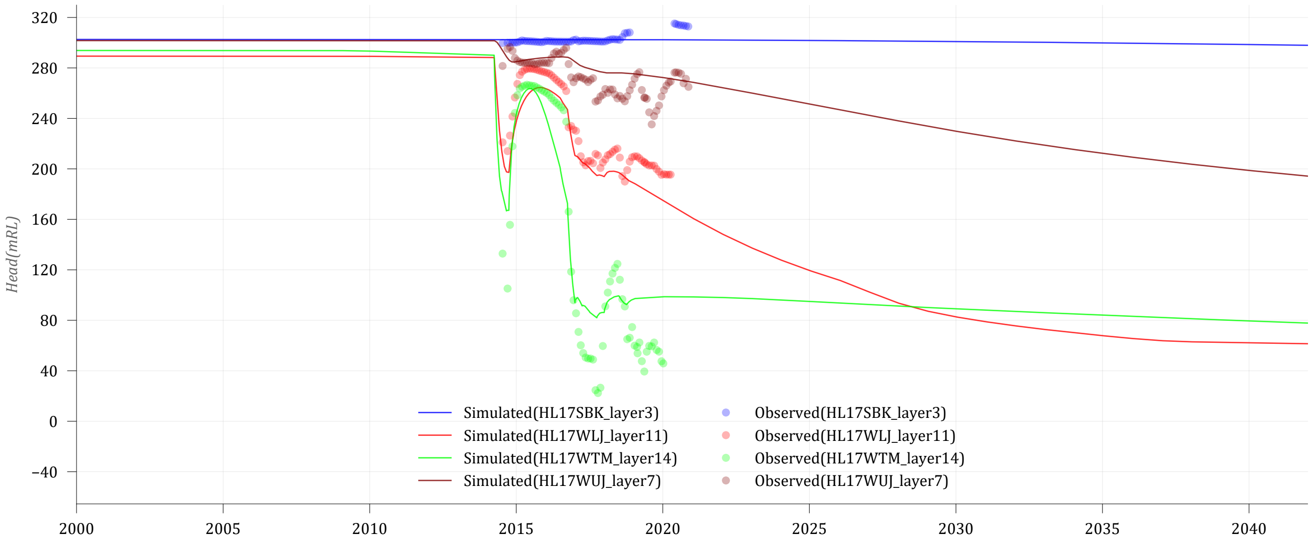

HL005T
Head(mRL)
280
240
200
160
120
80
40
0
−40
−80
−120
−160
−200
−240
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HL005T_layer15)
Observed(HL005T_layer15)


HL006
Head(mRL)
280
240
200
160
120
80
40
0
−40
−80
−120
−160
−200
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HL006_layer6)
Observed(HL006_layer6)

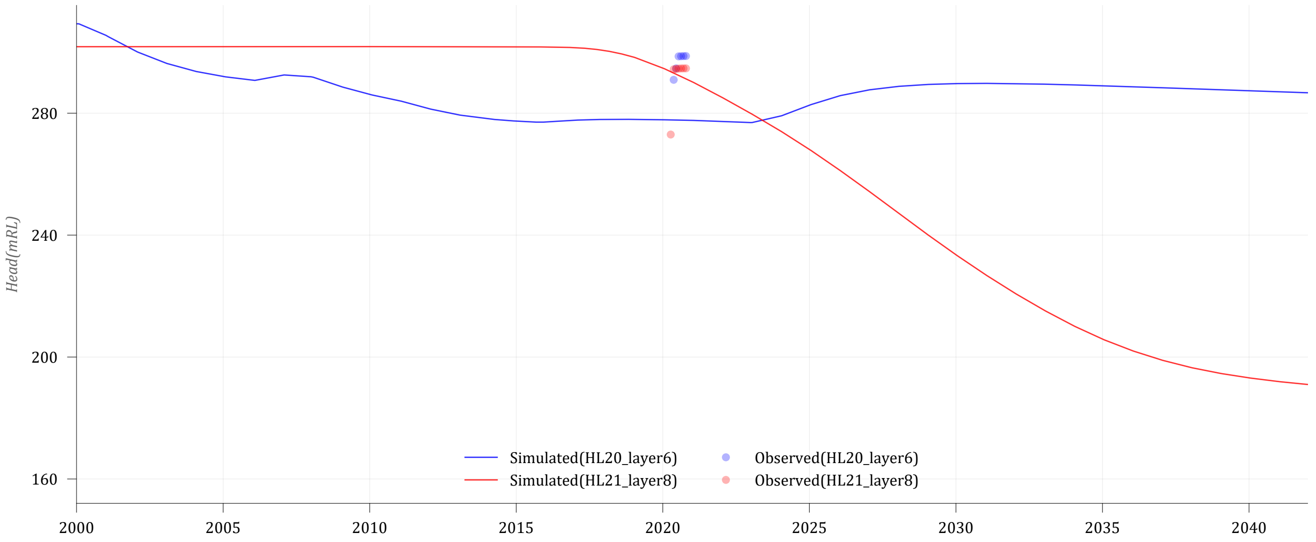

HL007
Head(mRL)
280
240
200
160
120
80
40
0
−40
−80
−120
−160
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HL007_layer6)
Observed(HL007_layer6)


HL008

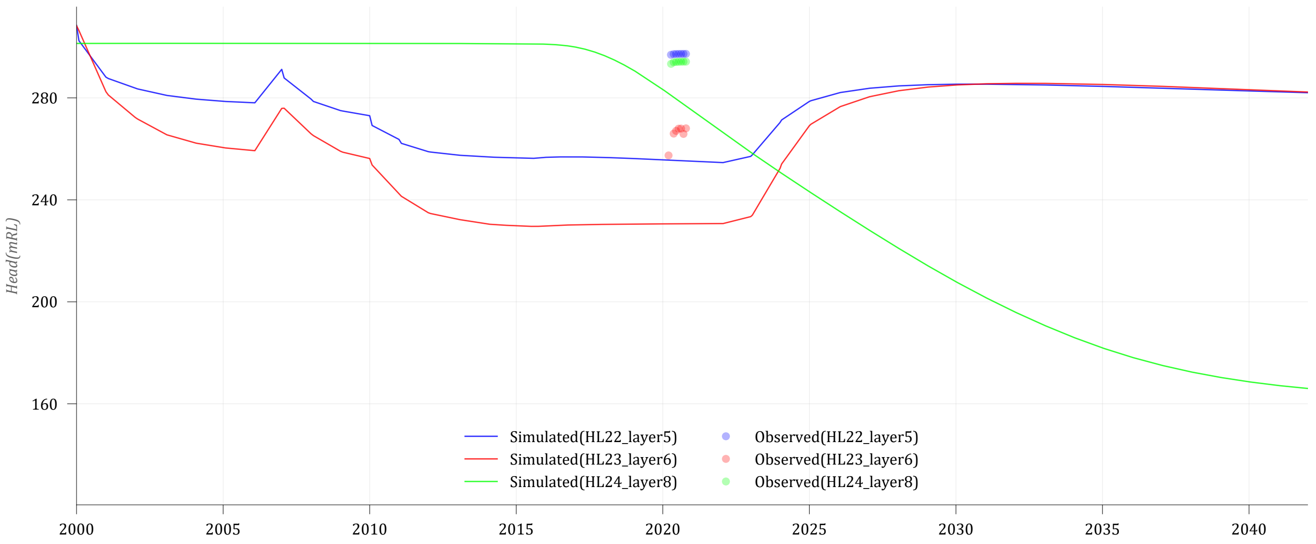

HL009


HL17

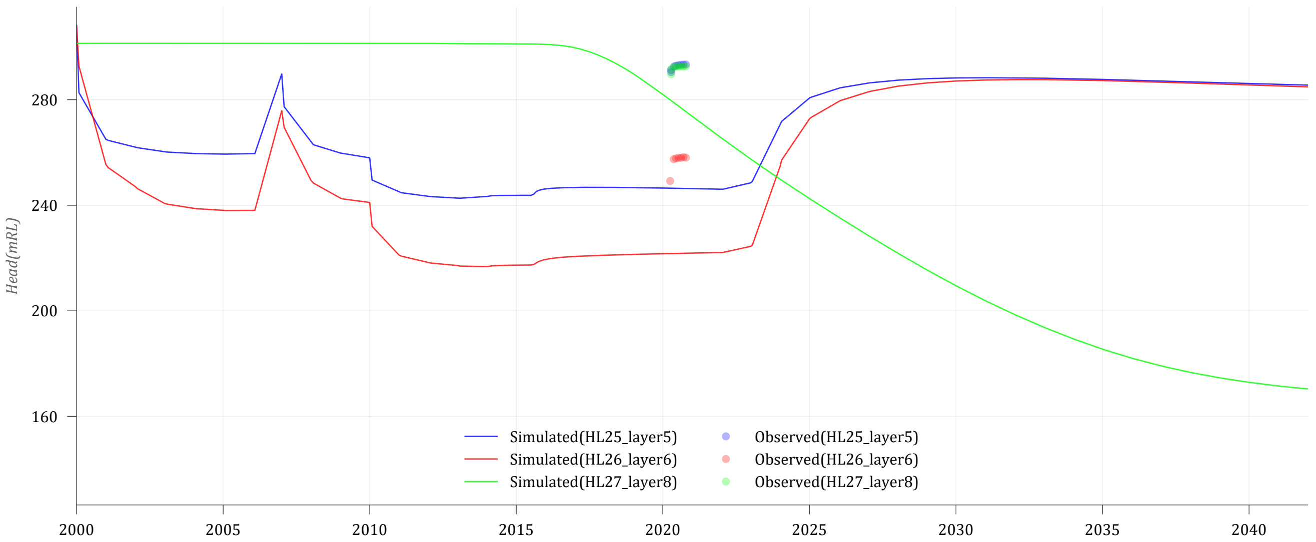
HL20-21

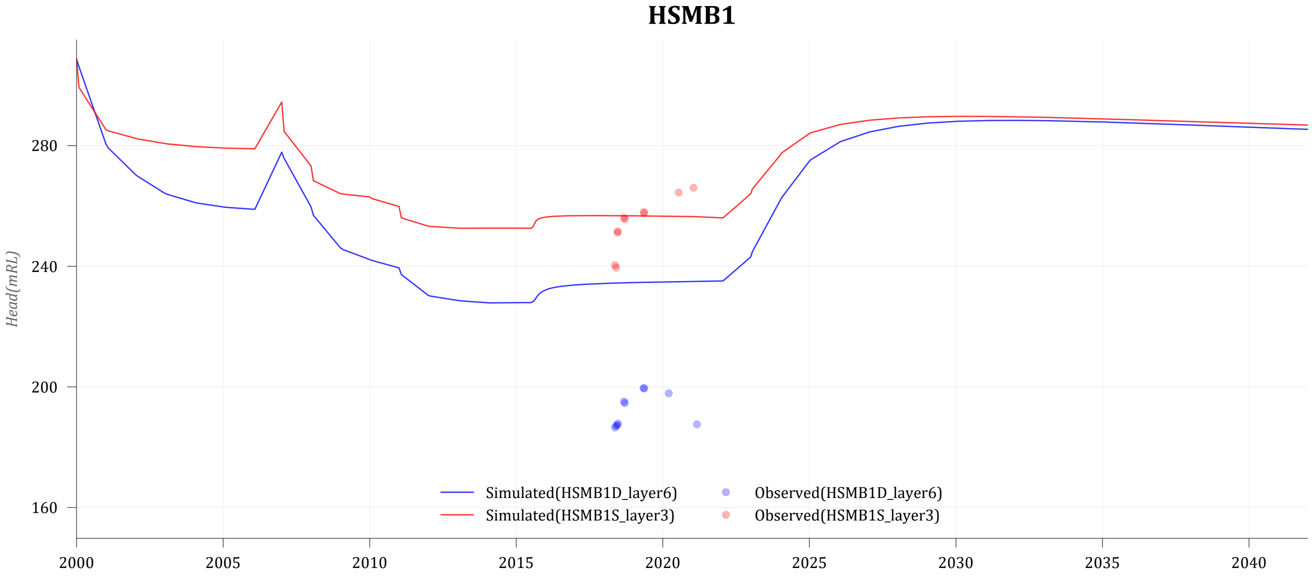


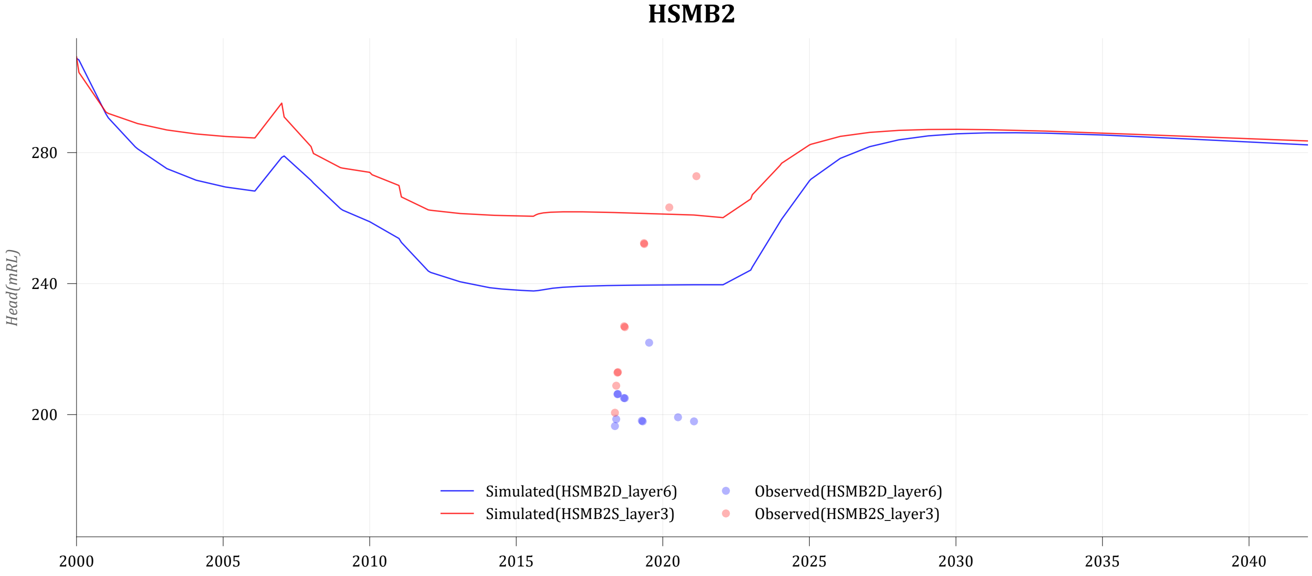
HL22-24

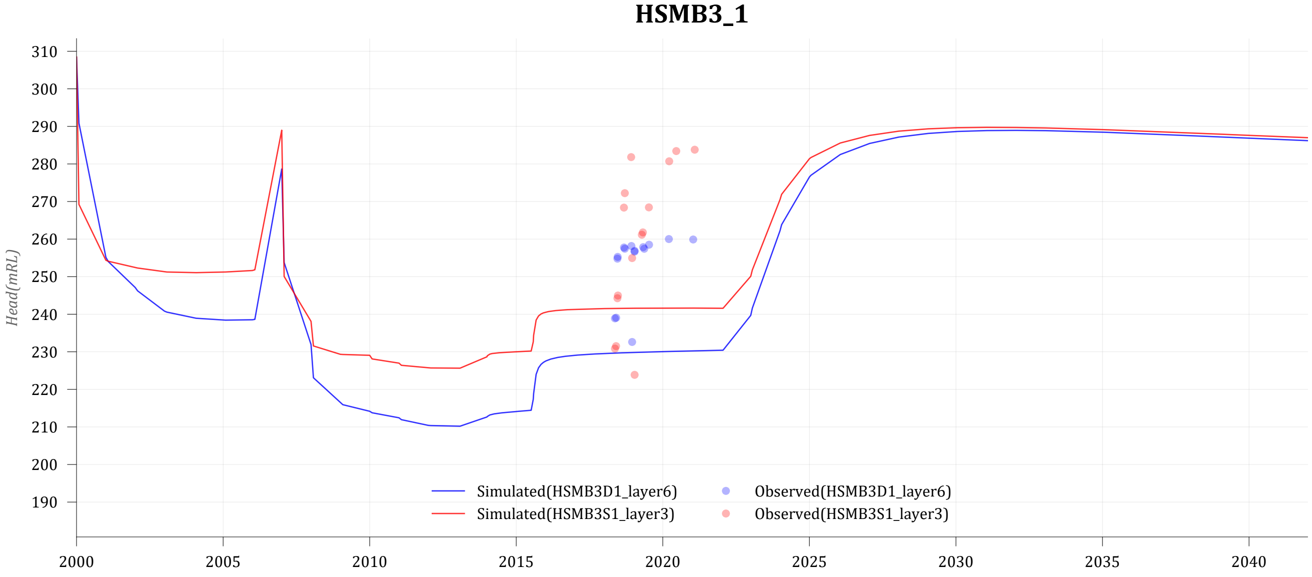


HL25-27

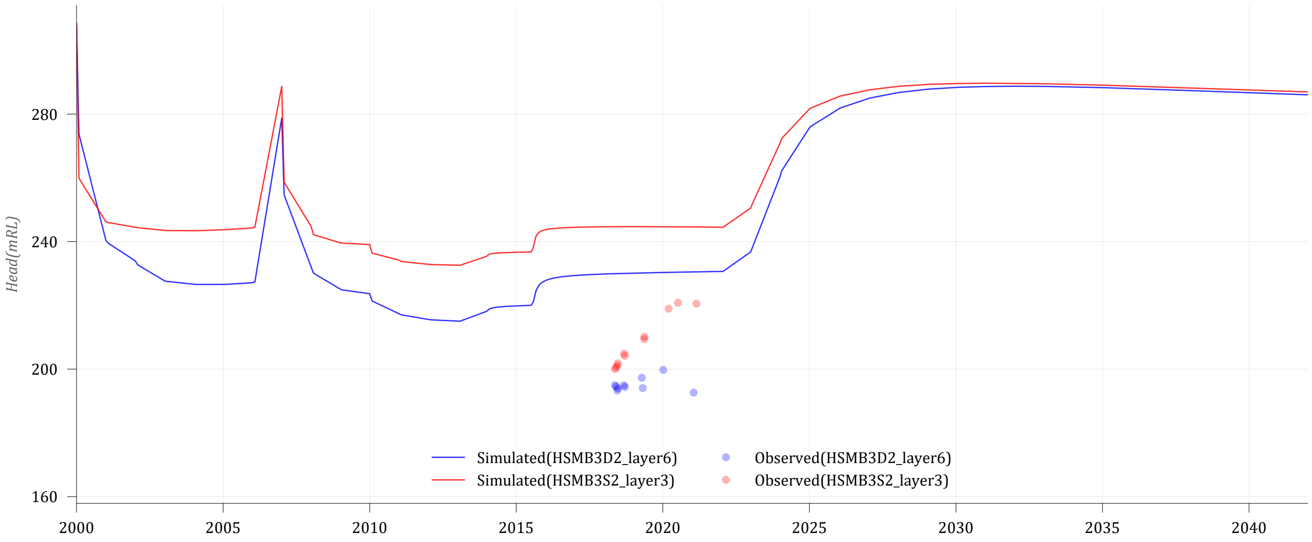



HSMB1
Head(mRL)
160
200
240
280
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HSMB1D_layer6)
Simulated(HSMB1S_layer3)
Observed(HSMB1D_layer6)
Observed(HSMB1S_layer3)

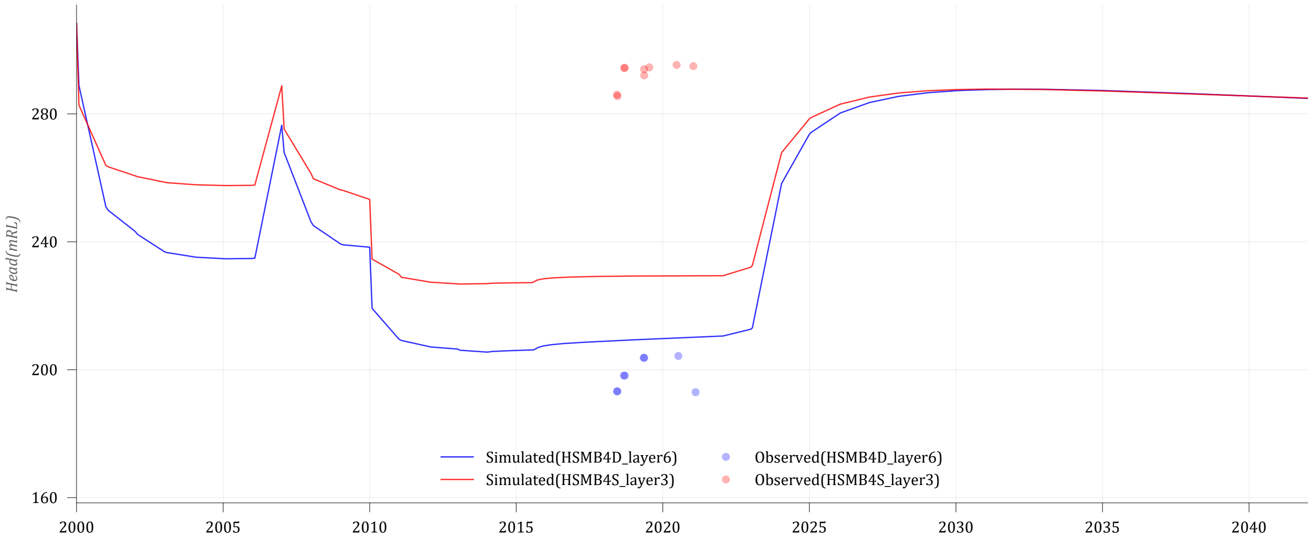

HSMB2
Head(mRL)
200
240
280
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HSMB2D_layer6)
Simulated(HSMB2S_layer3)
Observed(HSMB2D_layer6)
Observed(HSMB2S_layer3)


HSMB3_1
Head(mRL)
190
200
210
220
230
240
250
260
270
280
290
300
310
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(HSMB3D1_layer6)
Simulated(HSMB3S1_layer3)
Observed(HSMB3D1_layer6)
Observed(HSMB3S1_layer3)

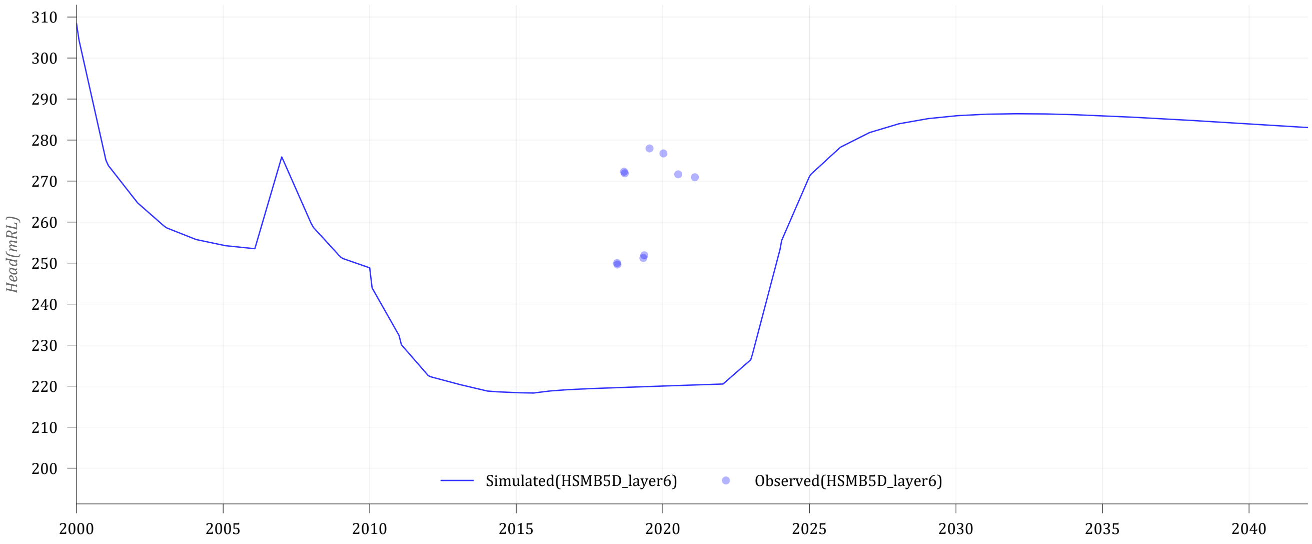
HSMB3_2



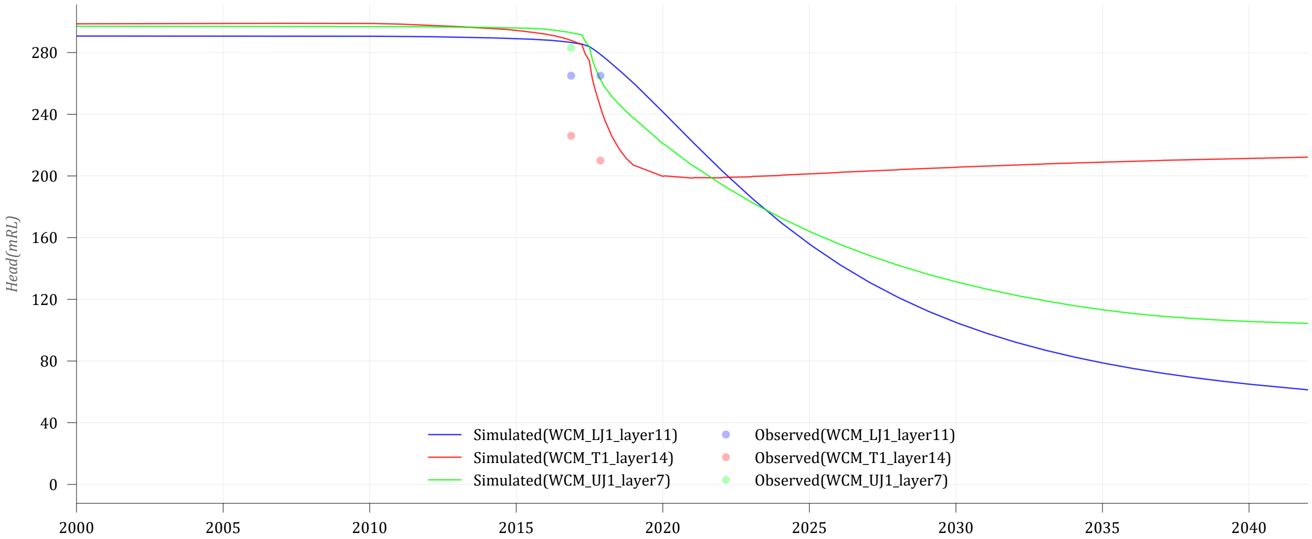
HSMB4



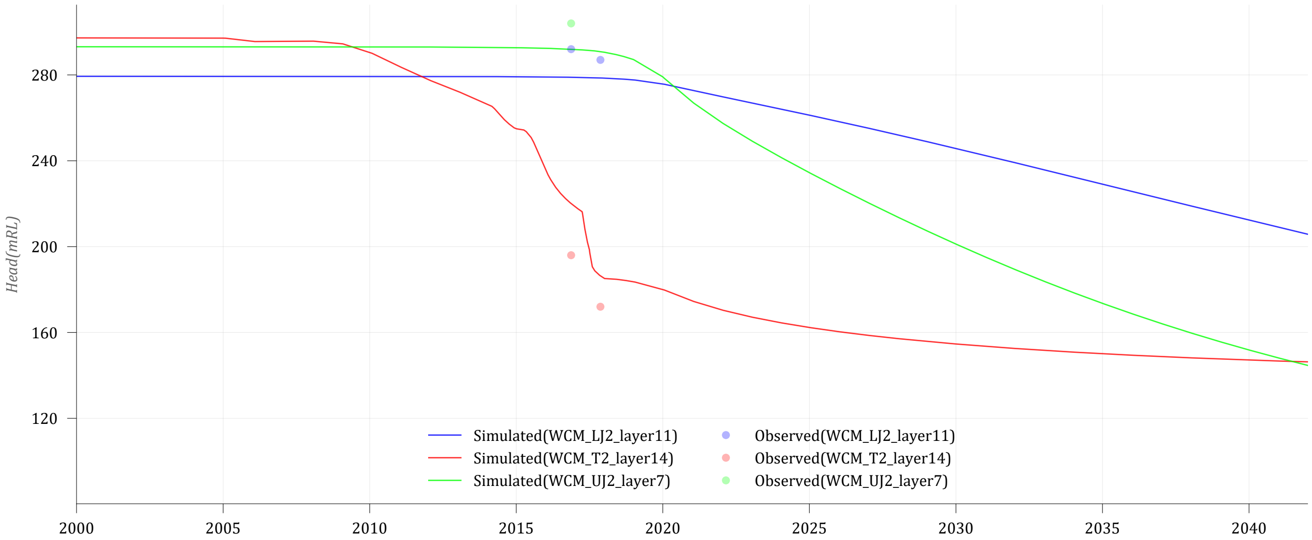
HSMB5D



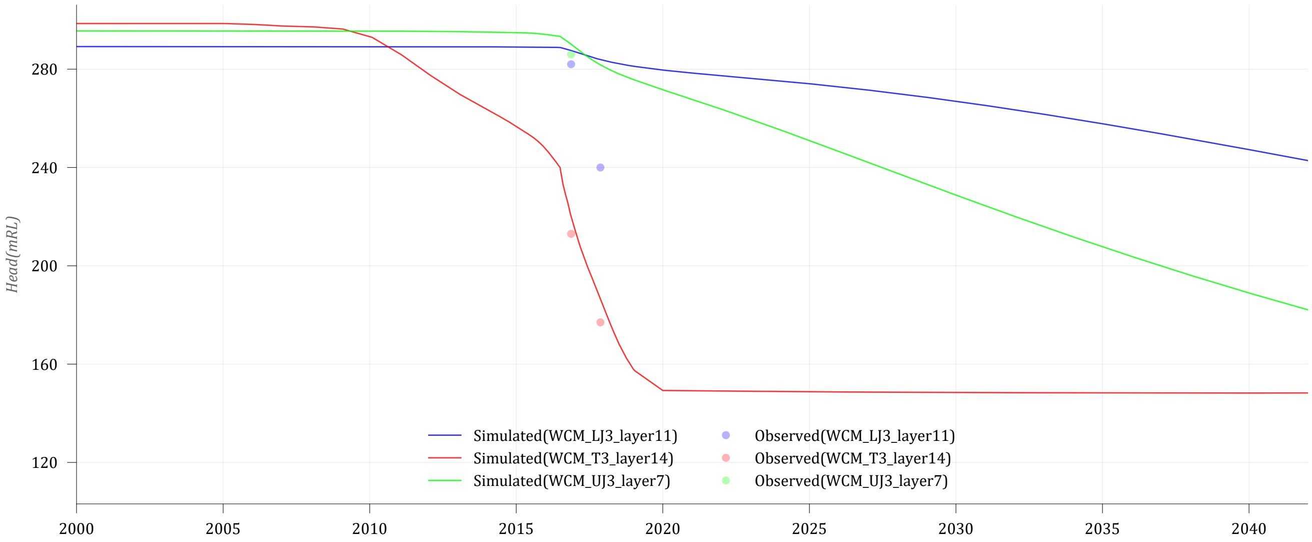
WCM1

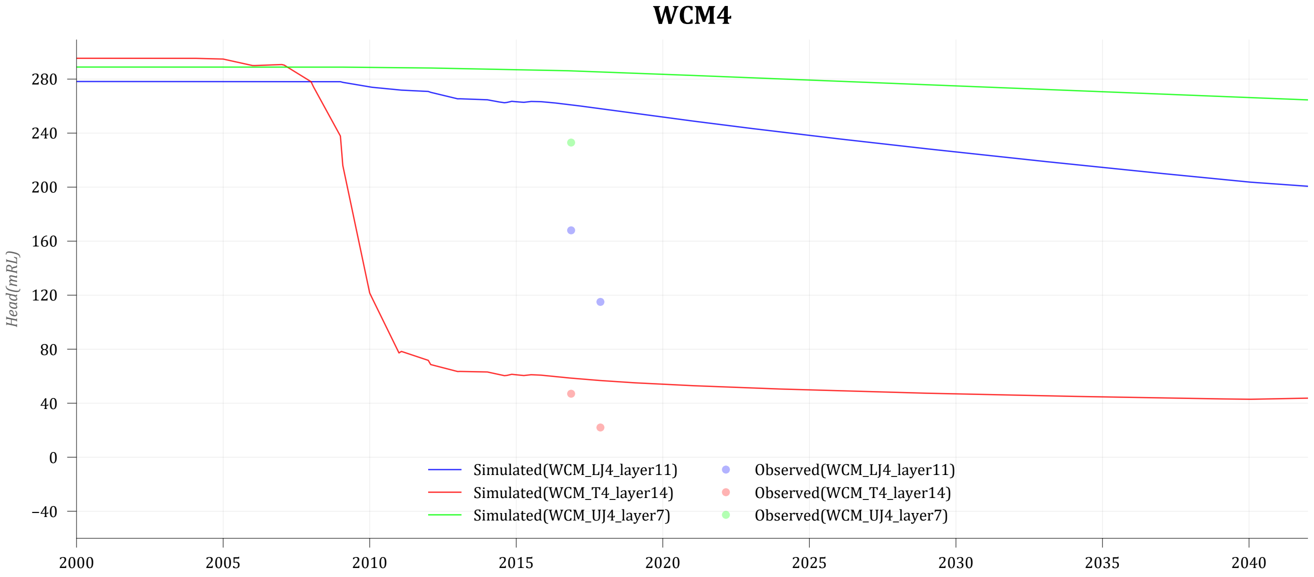


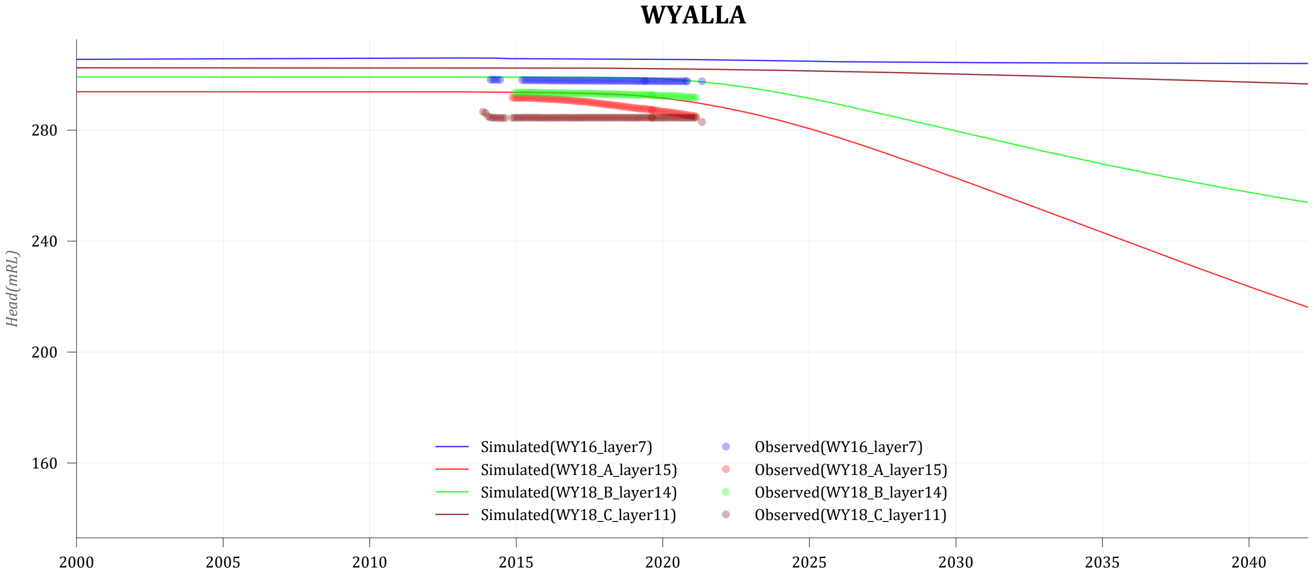
WCM2



WCM3

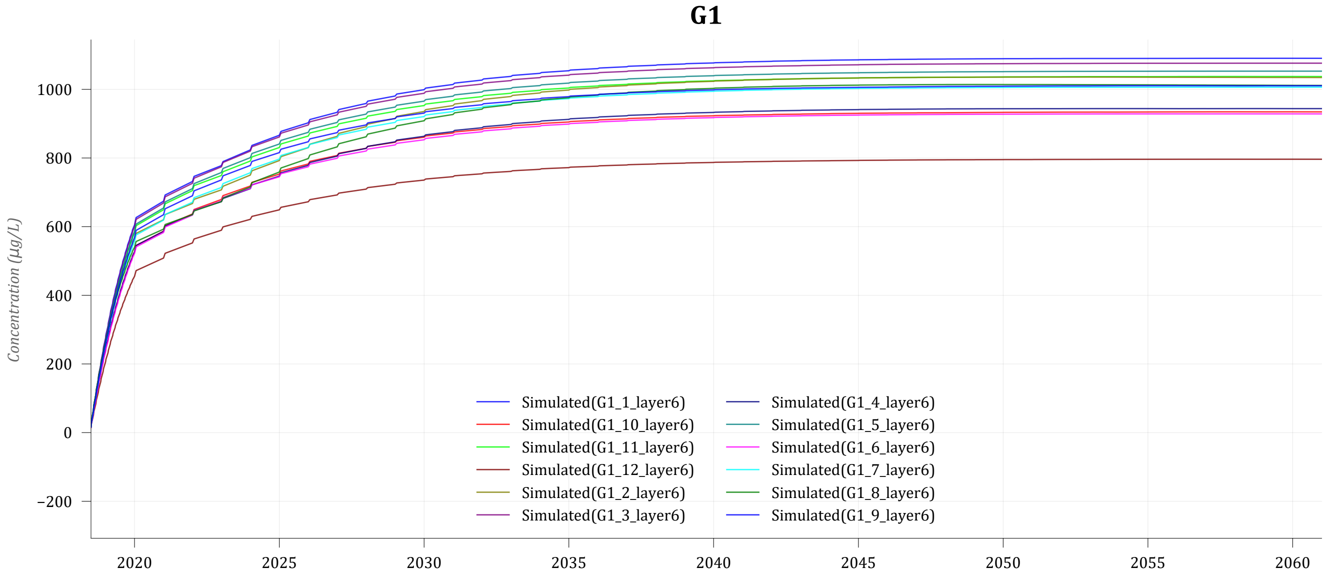


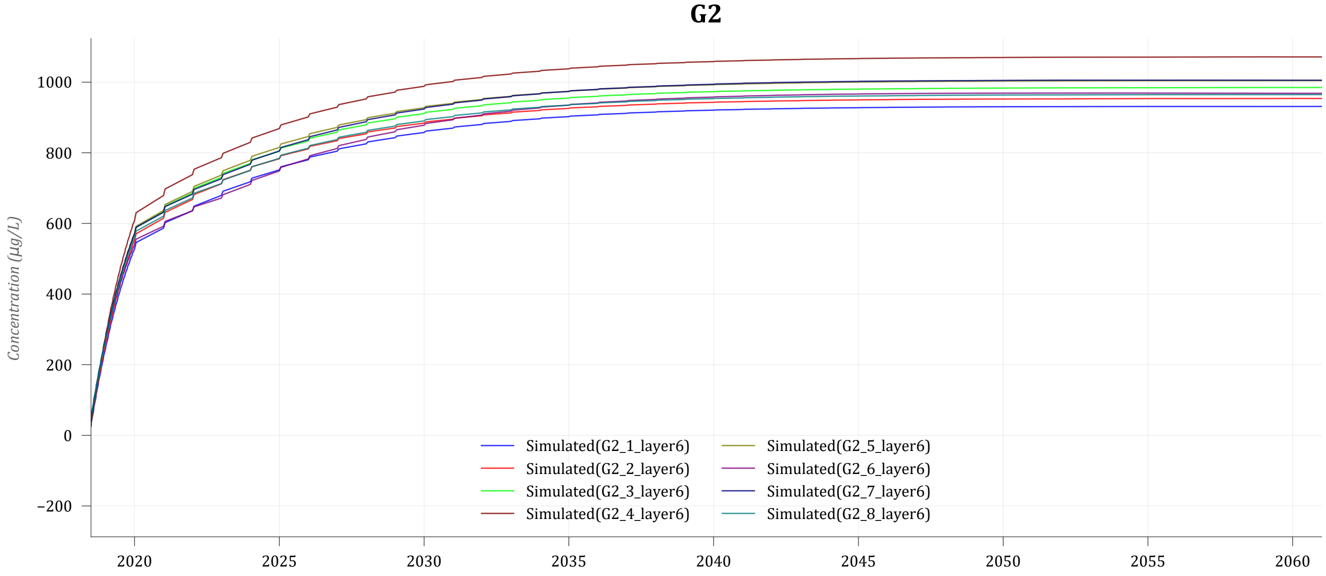

WCM4
Head(mRL)
280
240
200
160
120
80
40
0
−40
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(WCM_LJ4_layer11)
Simulated(WCM_T4_layer14)
Simulated(WCM_UJ4_layer7)
Observed(WCM_LJ4_layer11)
Observed(WCM_T4_layer14)
Observed(WCM_UJ4_layer7)

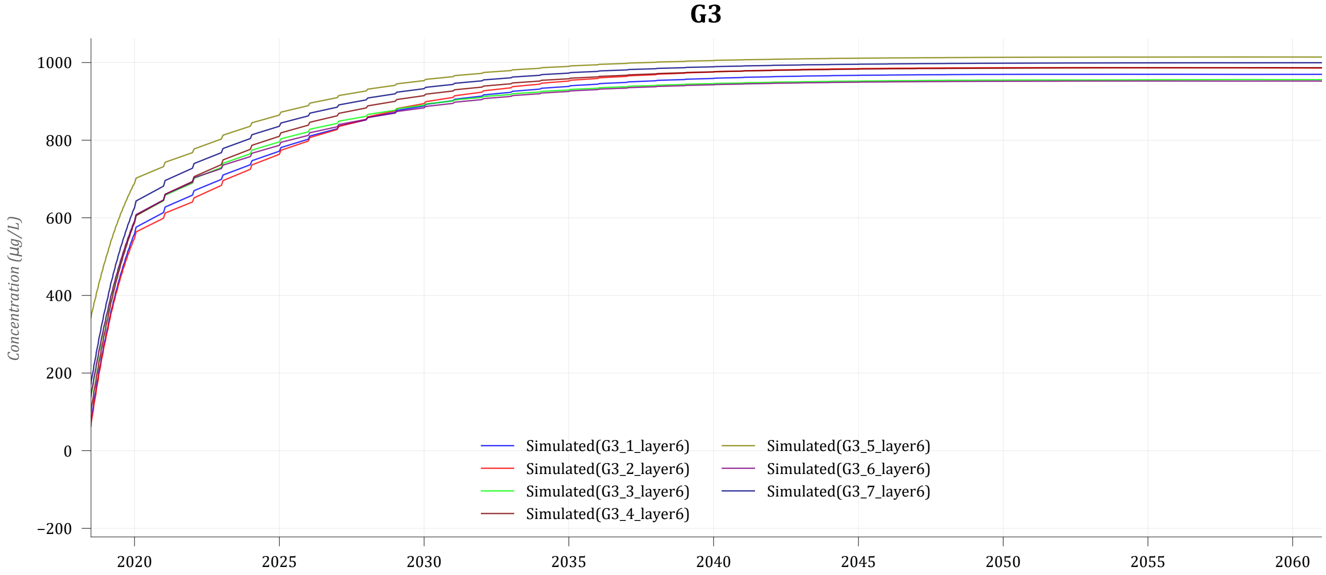

WYALLA
Head(mRL)
280
240
200
160
2000
2005
2010
2015
2020
2025
2030
2035
2040
Simulated(WY16_layer7)
Simulated(WY18_A_layer15)
Simulated(WY18_B_layer14)
Simulated(WY18_C_layer11)
Observed(WY16_layer7)
Observed(WY18_A_layer15)
Observed(WY18_B_layer14)
Observed(WY18_C_layer11)

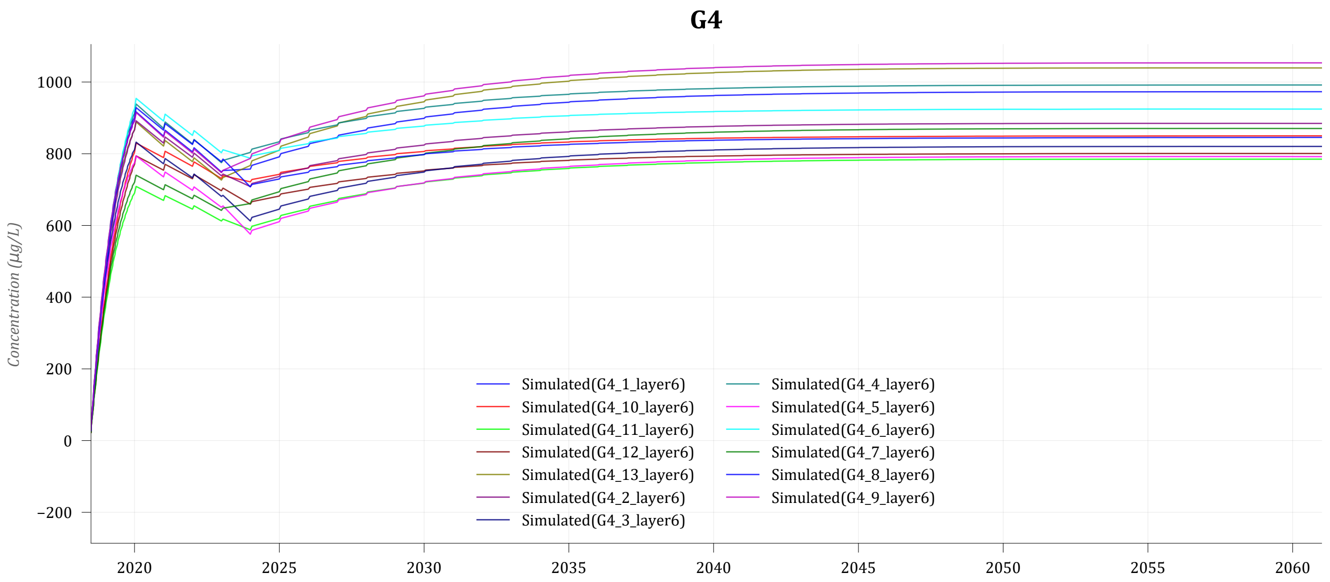
Appendix B

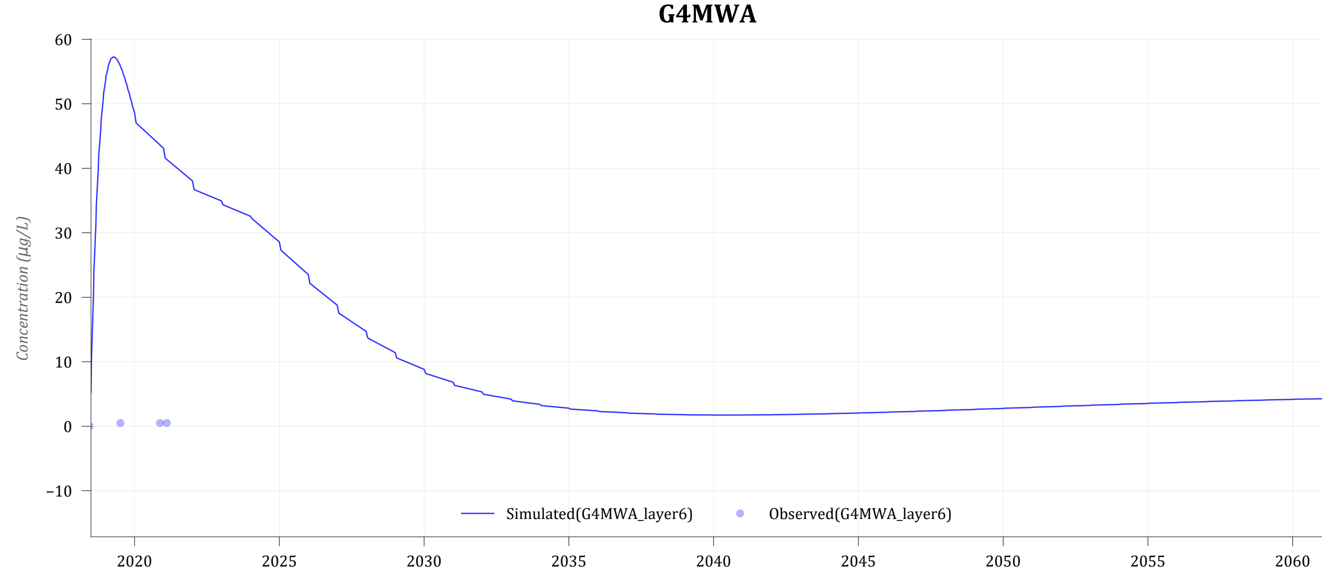
Concentration hydrographs – Benzene

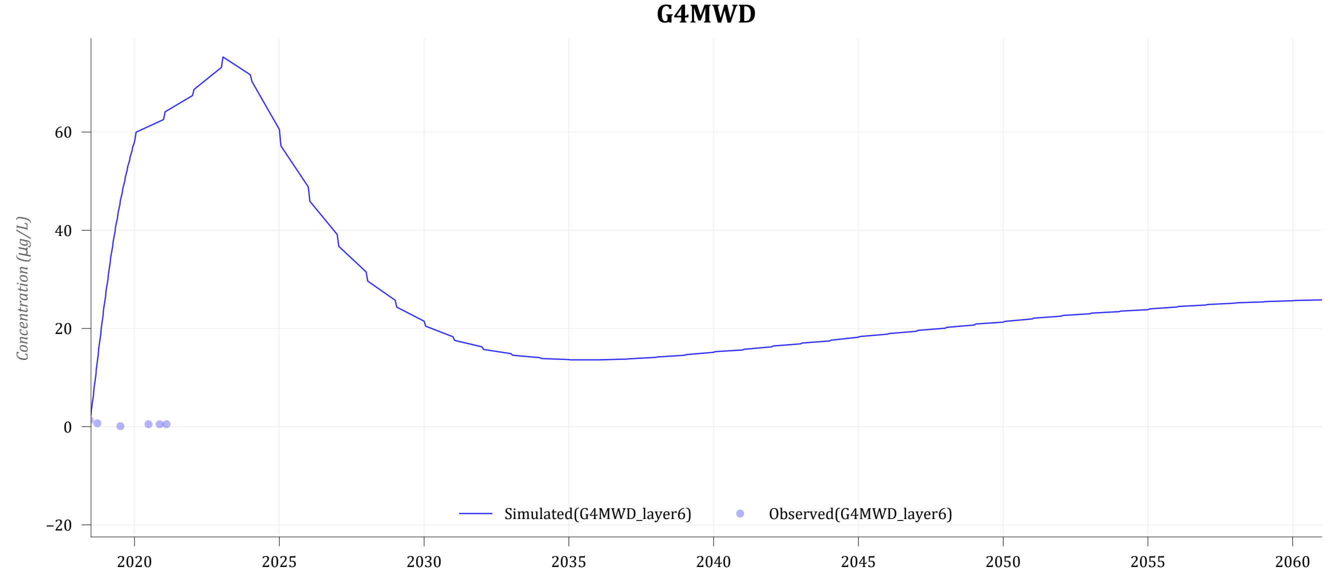

G1
Concentration (µg/L)
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G1_1_layer6)
Simulated(G1_10_layer6)
Simulated(G1_11_layer6)
Simulated(G1_12_layer6)
Simulated(G1_2_layer6)
Simulated(G1_3_layer6)
Simulated(G1_4_layer6)
Simulated(G1_5_layer6)
Simulated(G1_6_layer6)
Simulated(G1_7_layer6)
Simulated(G1_8_layer6)
Simulated(G1_9_layer6)

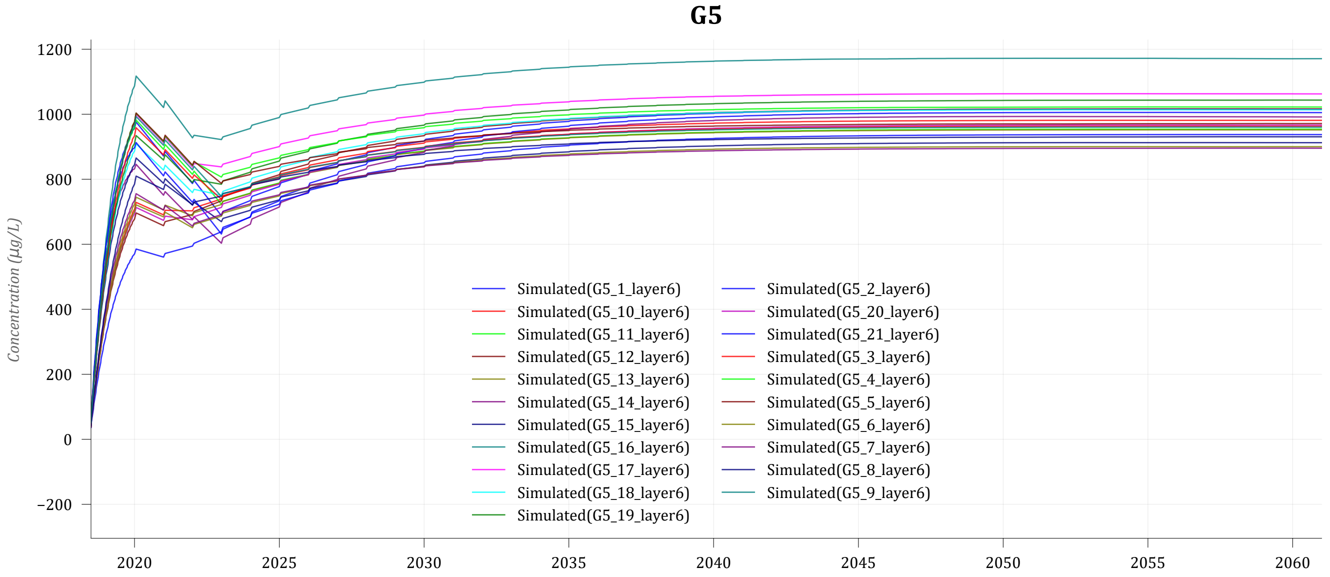

G2
Concentration (µg/L)
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G2_1_layer6)
Simulated(G2_2_layer6)
Simulated(G2_3_layer6)
Simulated(G2_4_layer6)
Simulated(G2_5_layer6)
Simulated(G2_6_layer6)
Simulated(G2_7_layer6)
Simulated(G2_8_layer6)

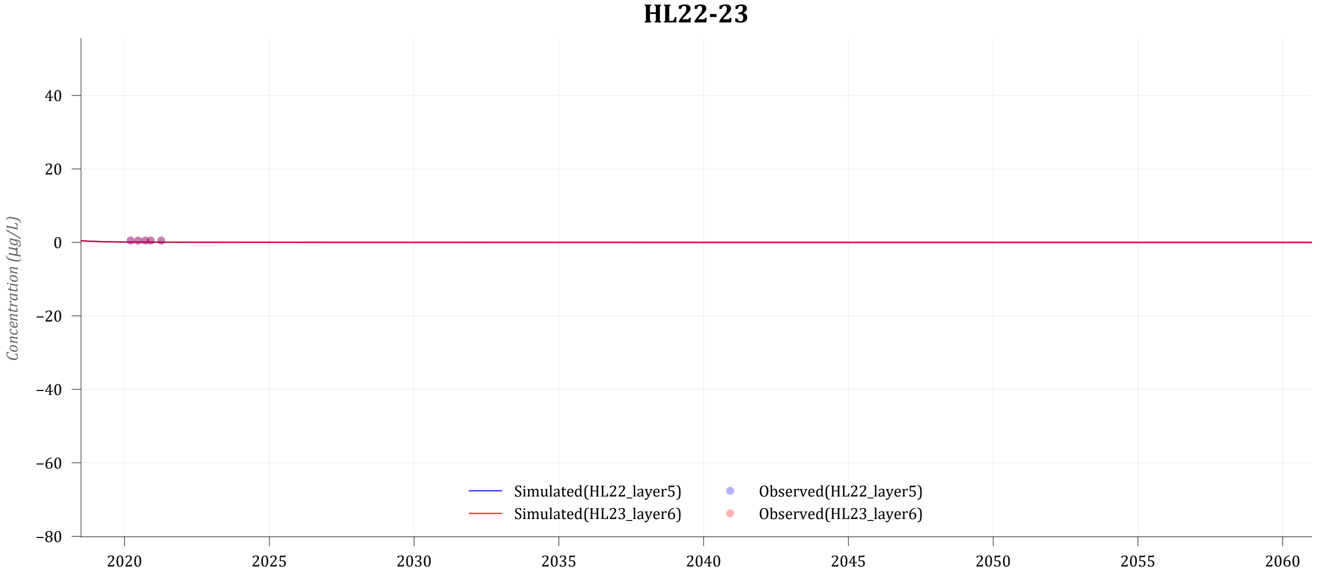

G3
Concentration (µg/L)
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G3_1_layer6)
Simulated(G3_2_layer6)
Simulated(G3_3_layer6)
Simulated(G3_4_layer6)
Simulated(G3_5_layer6)
Simulated(G3_6_layer6)
Simulated(G3_7_layer6)

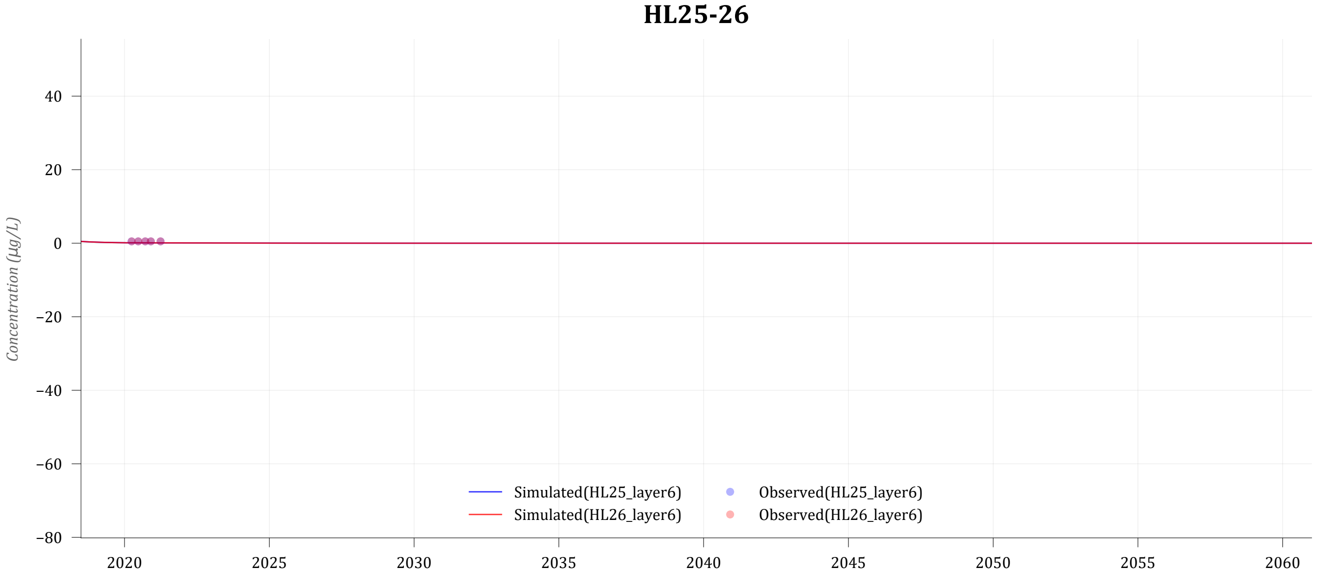

G4
Concentration (µg/L)
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4_1_layer6)
Simulated(G4_10_layer6)
Simulated(G4_11_layer6)
Simulated(G4_12_layer6)
Simulated(G4_13_layer6)
Simulated(G4_2_layer6)
Simulated(G4_3_layer6)
Simulated(G4_4_layer6)
Simulated(G4_5_layer6)
Simulated(G4_6_layer6)
Simulated(G4_7_layer6)
Simulated(G4_8_layer6)
Simulated(G4_9_layer6)


G4MWA
Concentration (µg/L)
60
50
40
30
20
10
0
−10
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4MWA_layer6)
Observed(G4MWA_layer6)

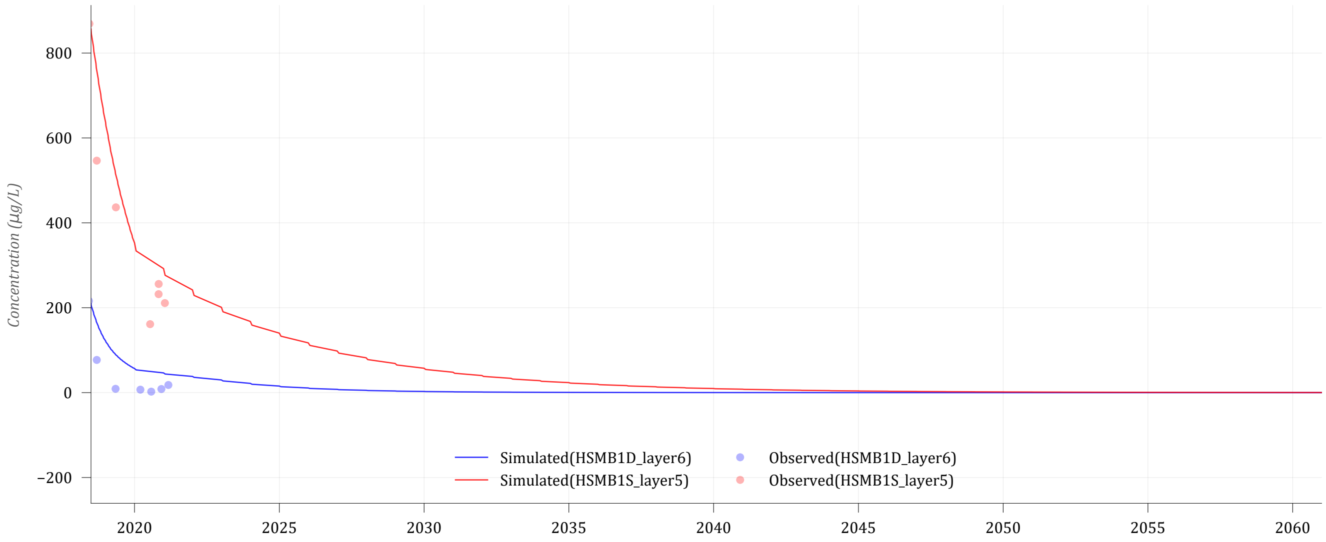

G4MWD
Concentration (µg/L)
60
40
20
0
−20
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4MWD_layer6)
Observed(G4MWD_layer6)


G5
Concentration (µg/L)
1200
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G5_1_layer6)
Simulated(G5_10_layer6)
Simulated(G5_11_layer6)
Simulated(G5_12_layer6)
Simulated(G5_13_layer6)
Simulated(G5_14_layer6)
Simulated(G5_15_layer6)
Simulated(G5_16_layer6)
Simulated(G5_17_layer6)
Simulated(G5_18_layer6)
Simulated(G5_19_layer6)
Simulated(G5_2_layer6)
Simulated(G5_20_layer6)
Simulated(G5_21_layer6)
Simulated(G5_3_layer6)
Simulated(G5_4_layer6)
Simulated(G5_5_layer6)
Simulated(G5_6_layer6)
Simulated(G5_7_layer6)
Simulated(G5_8_layer6)
Simulated(G5_9_layer6)

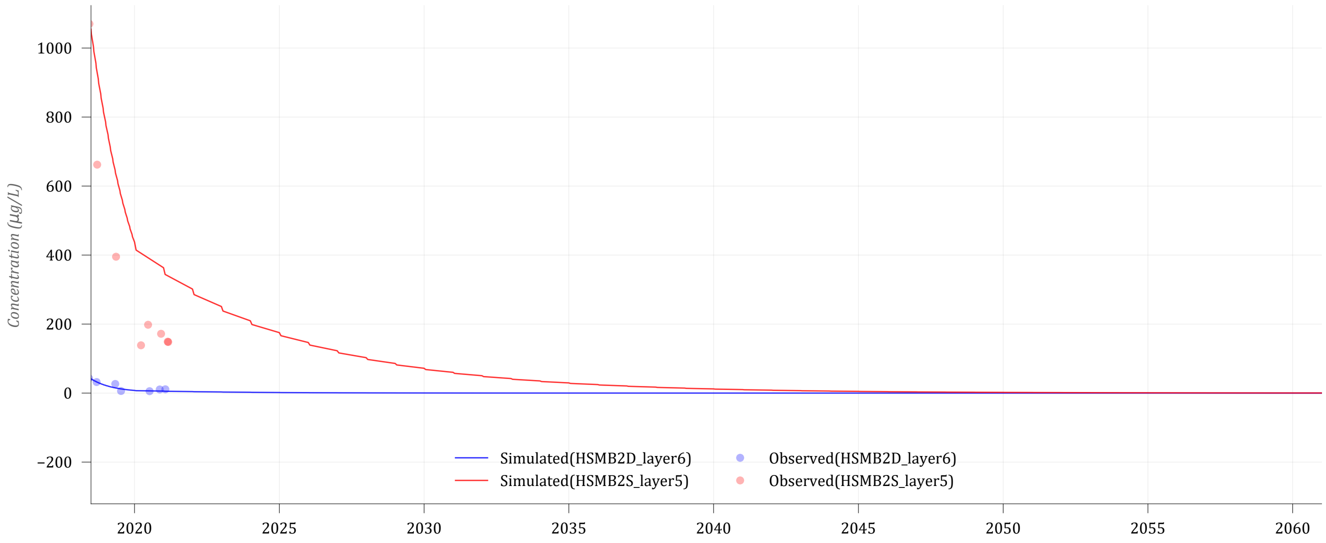

HL22-23
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HL22_layer5)
Simulated(HL23_layer6)
Observed(HL22_layer5)
Observed(HL23_layer6)


HL25-26
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HL25_layer6)
Simulated(HL26_layer6)
Observed(HL25_layer6)
Observed(HL26_layer6)

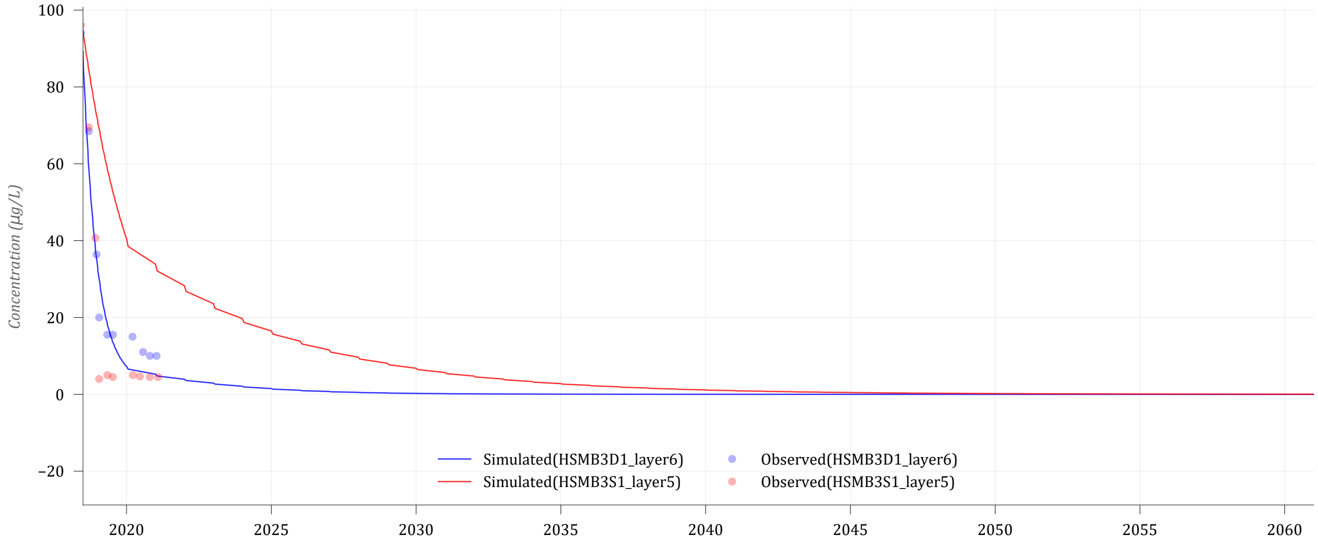
HSMB1

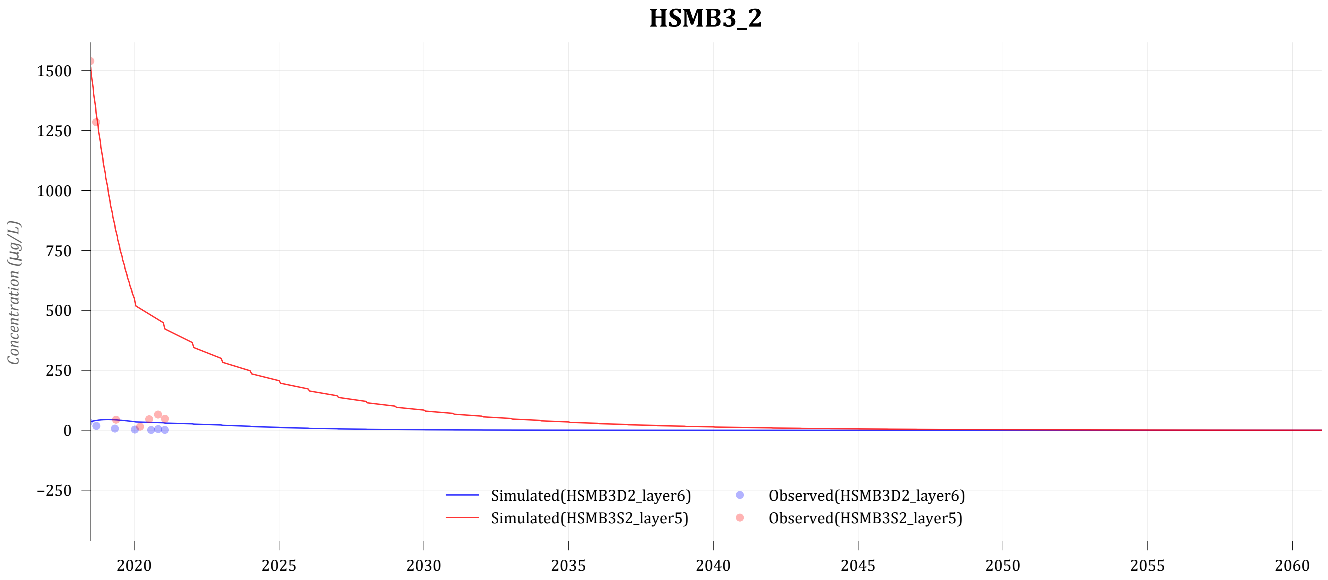


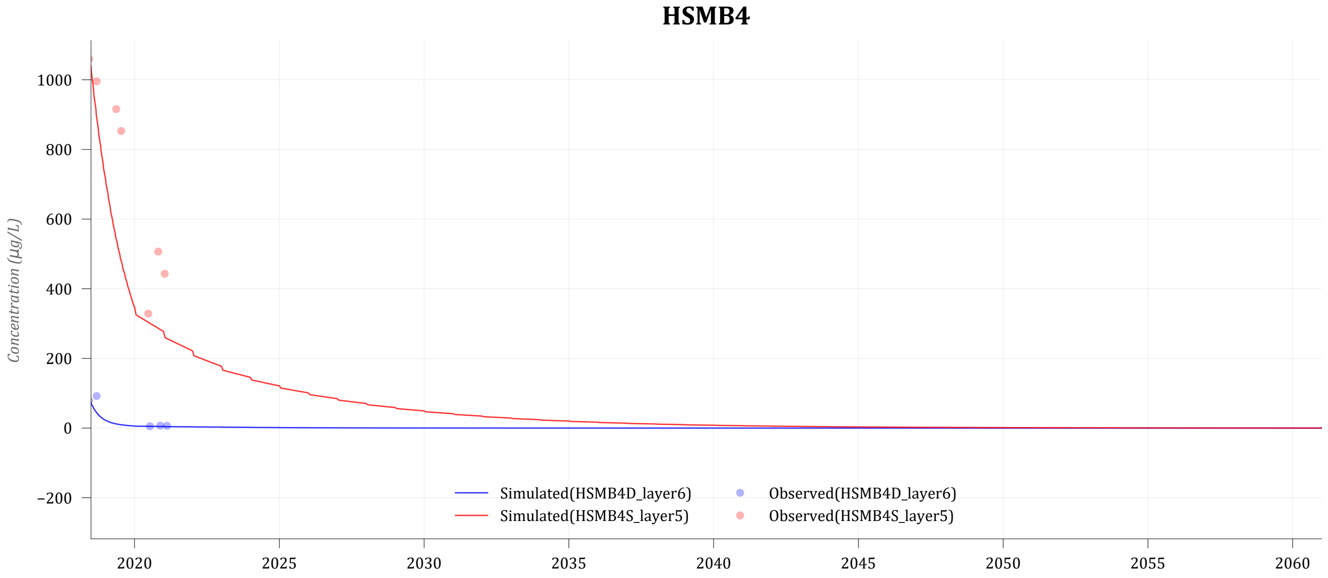
HSMB2

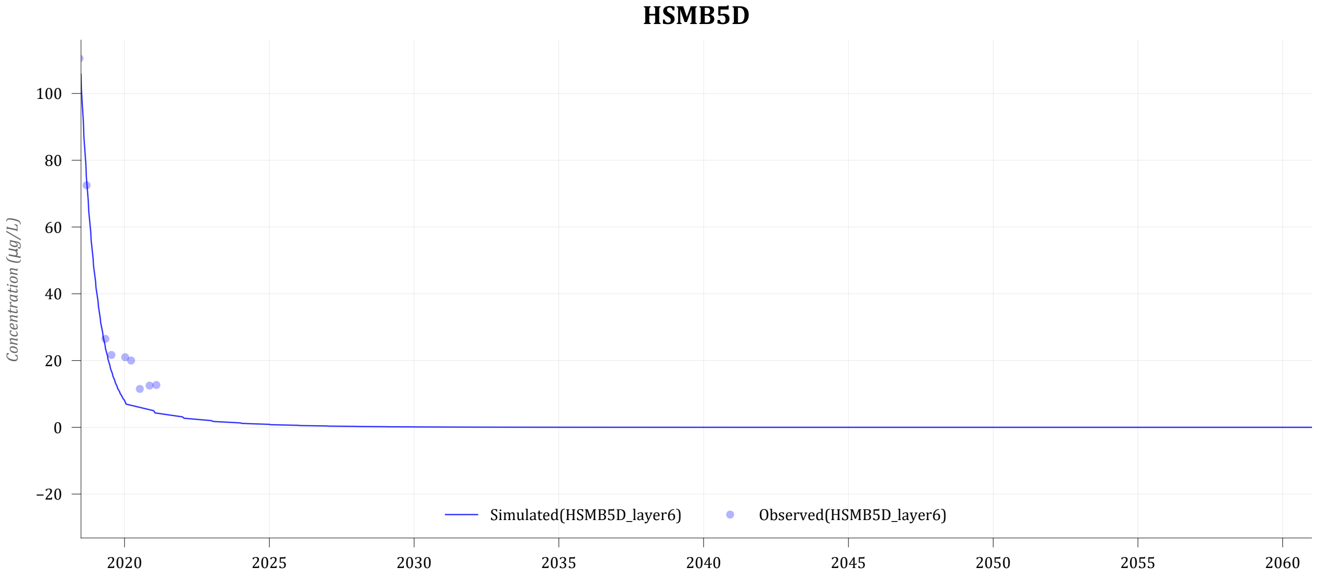


HSMB3_1

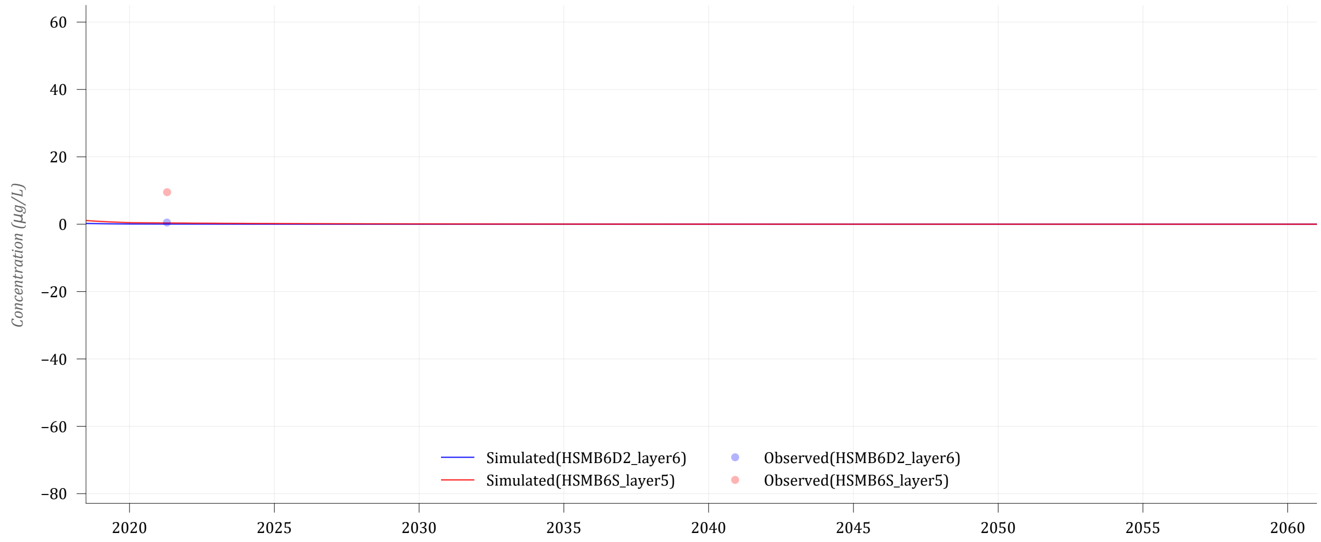



HSMB3_2
Concentration (µg/L)
1500
1250
1000
750
500
250
0
−250
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB3D2_layer6)
Simulated(HSMB3S2_layer5)
Observed(HSMB3D2_layer6)
Observed(HSMB3S2_layer5)

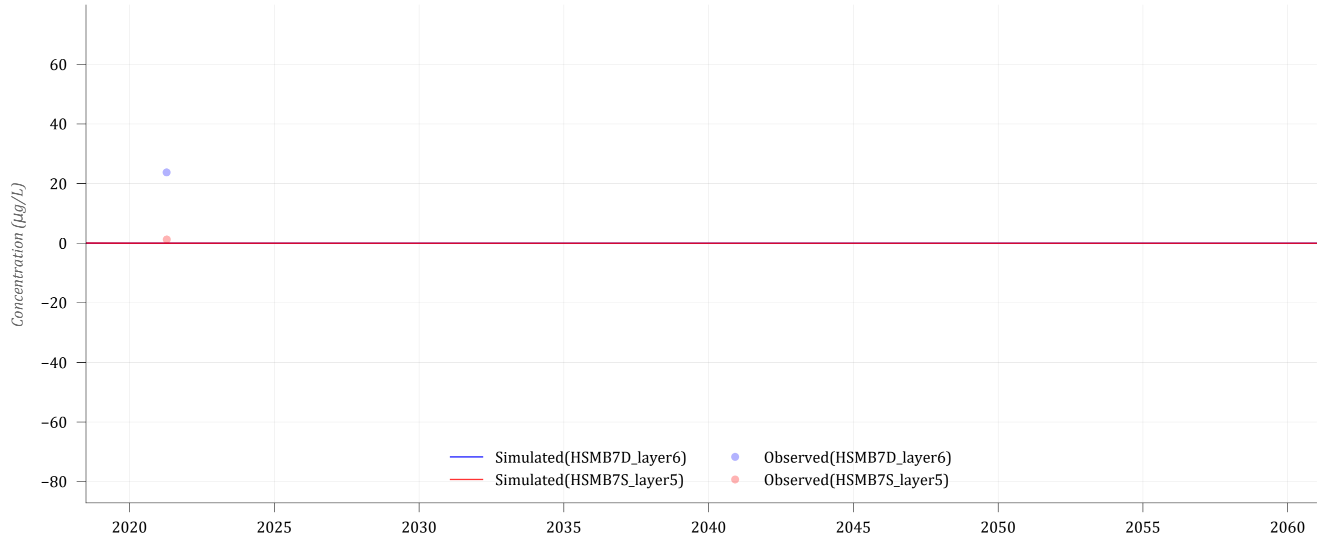

HSMB4
Concentration (µg/L)
1000
800
600
400
200
0
−200
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB4D_layer6)
Simulated(HSMB4S_layer5)
Observed(HSMB4D_layer6)
Observed(HSMB4S_layer5)


HSMB5D
Concentration (µg/L)
100
80
60
40
20
0
−20
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB5D_layer6)
Observed(HSMB5D_layer6)

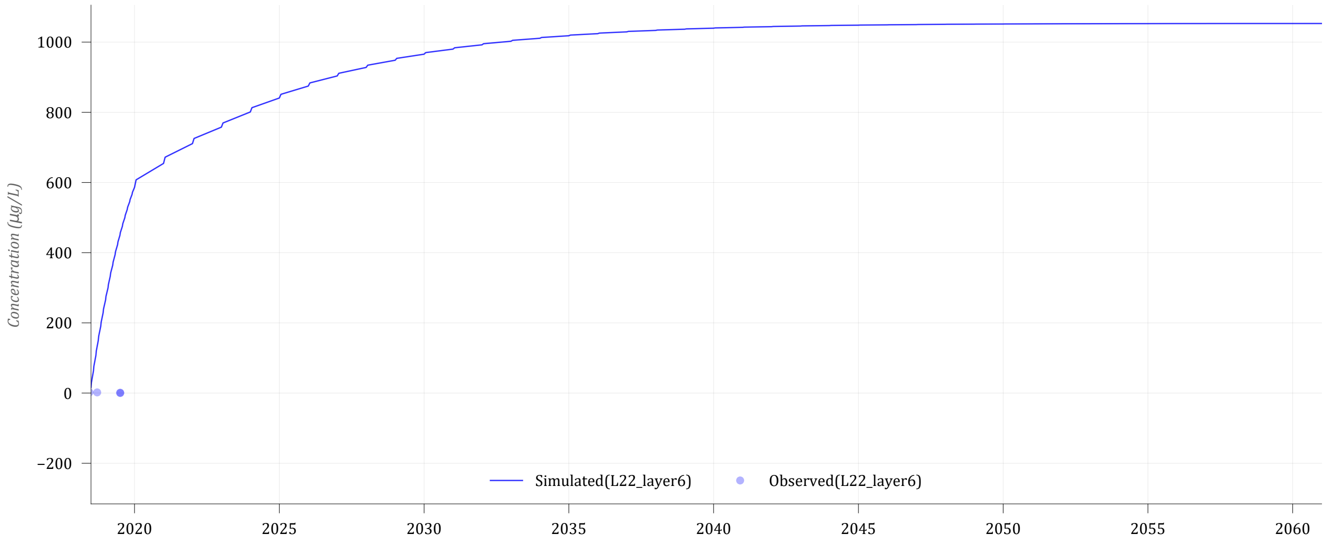
HSMB6

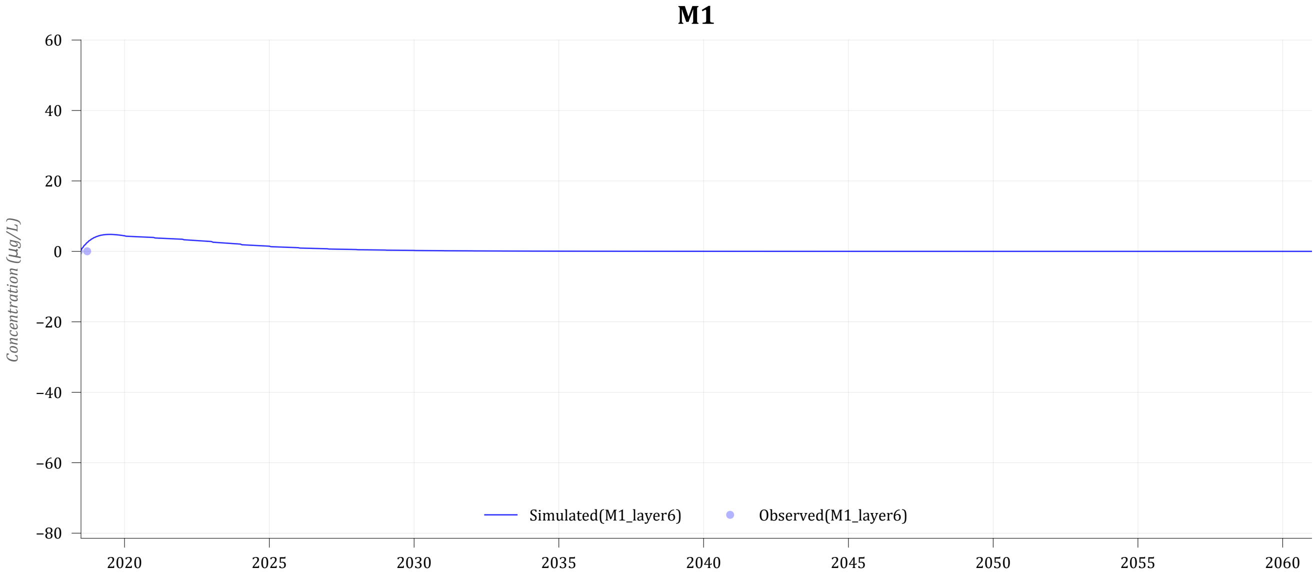


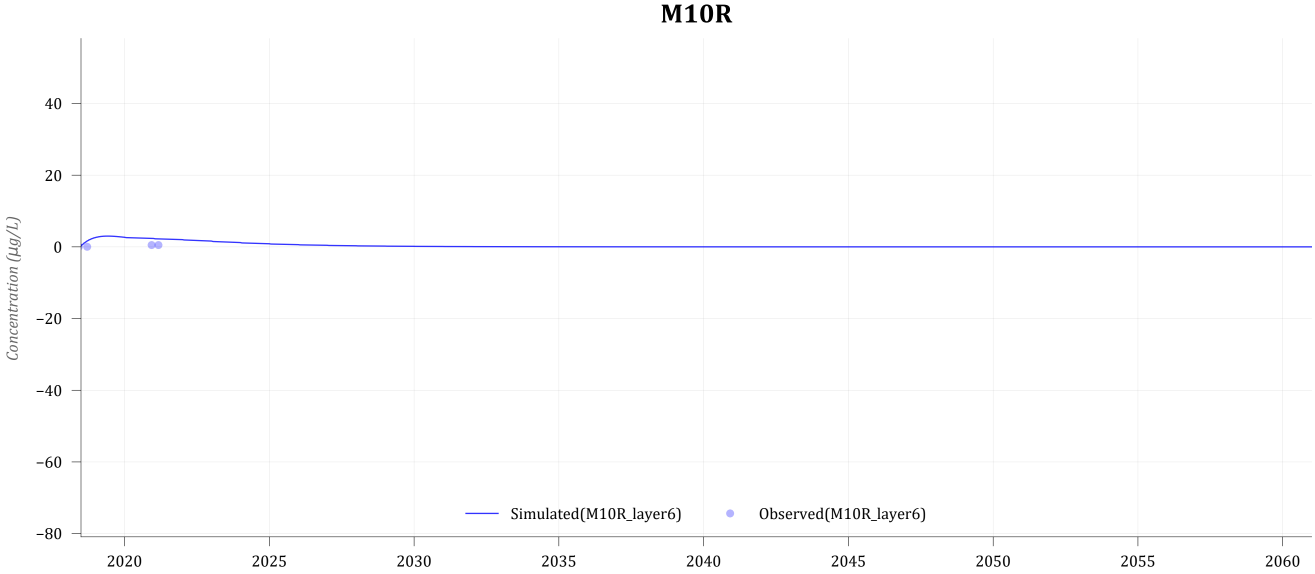
HSMB7

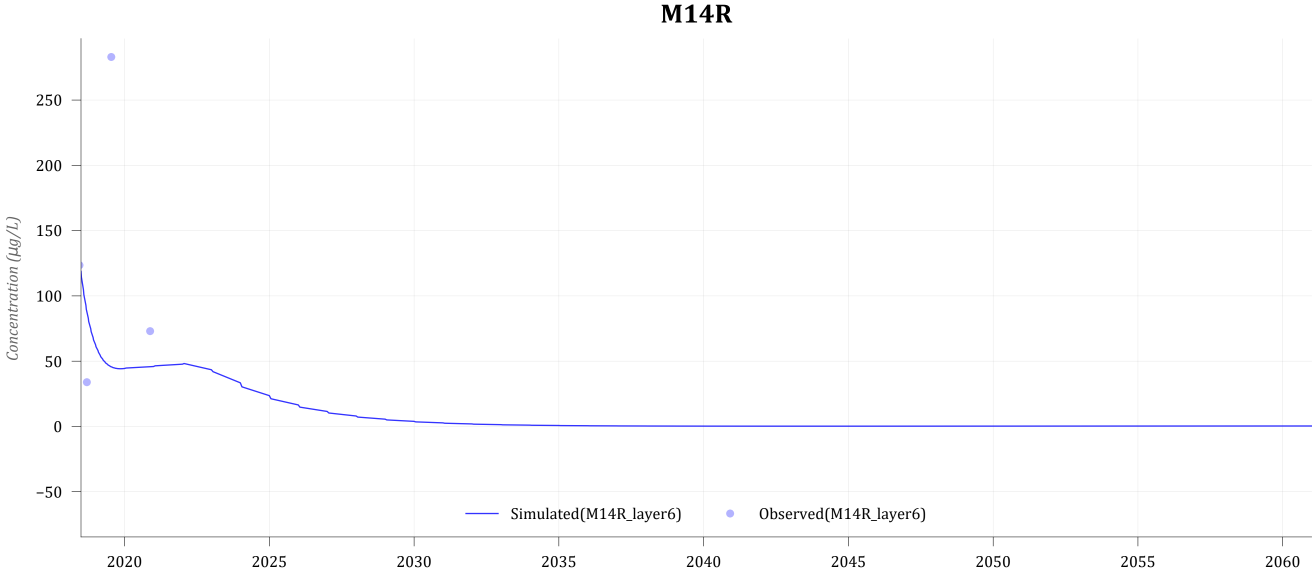


L22

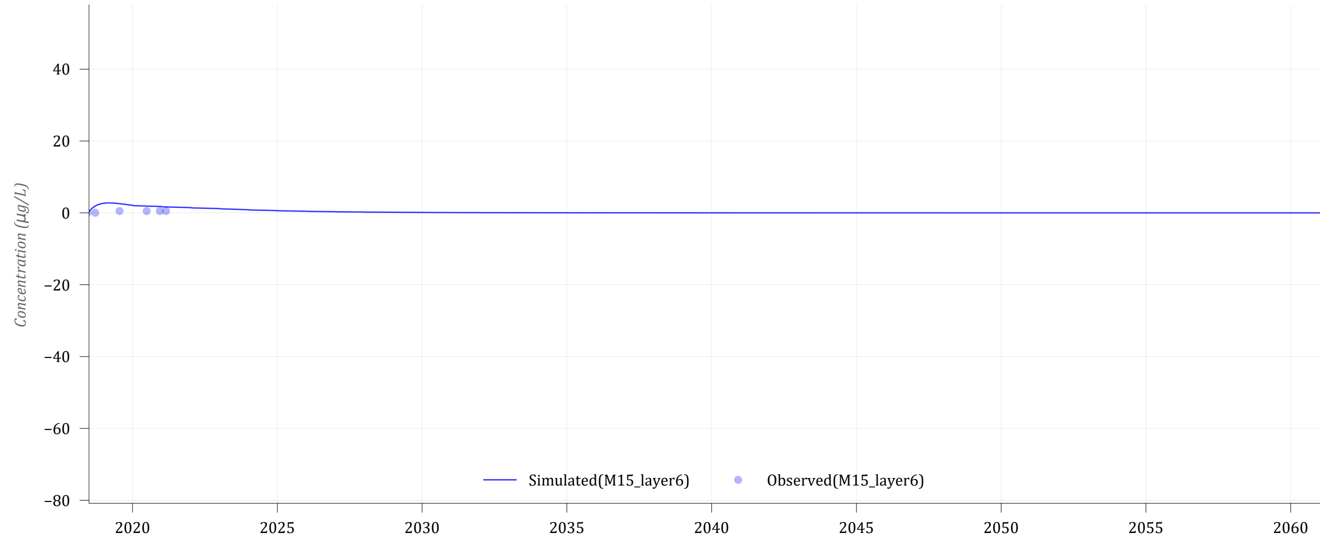



M1
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M1_layer6)
Observed(M1_layer6)


M10R
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M10R_layer6)
Observed(M10R_layer6)

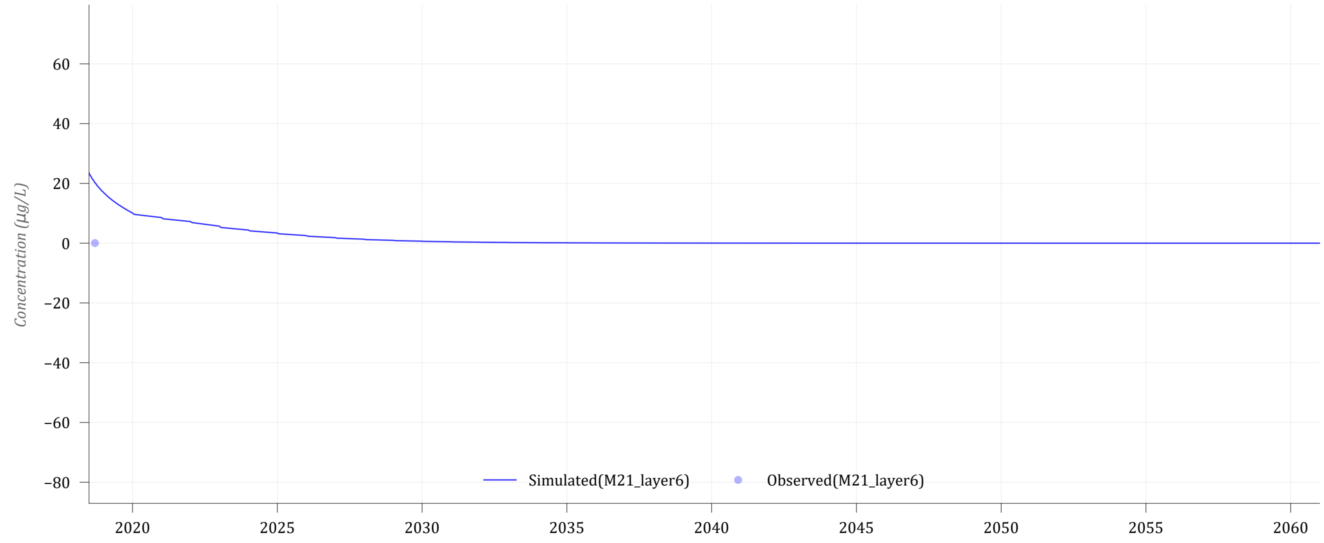

M14R
Concentration (µg/L)
250
200
150
100
50
0
−50
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M14R_layer6)
Observed(M14R_layer6)

M15



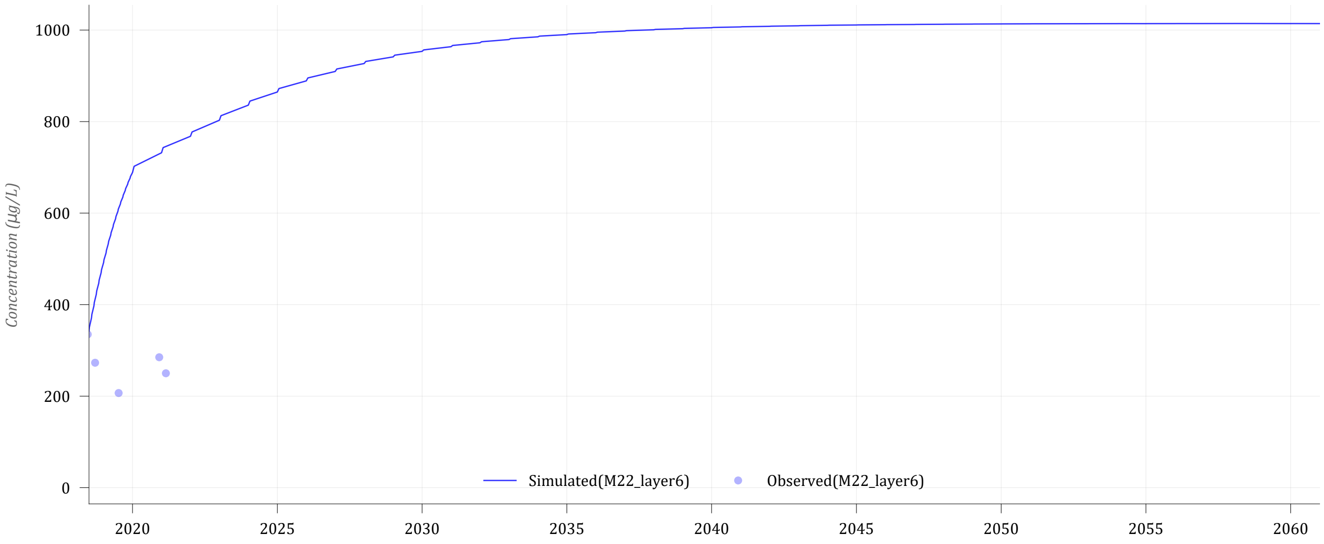
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M15_layer6)
Observed(M15_layer6)

M21



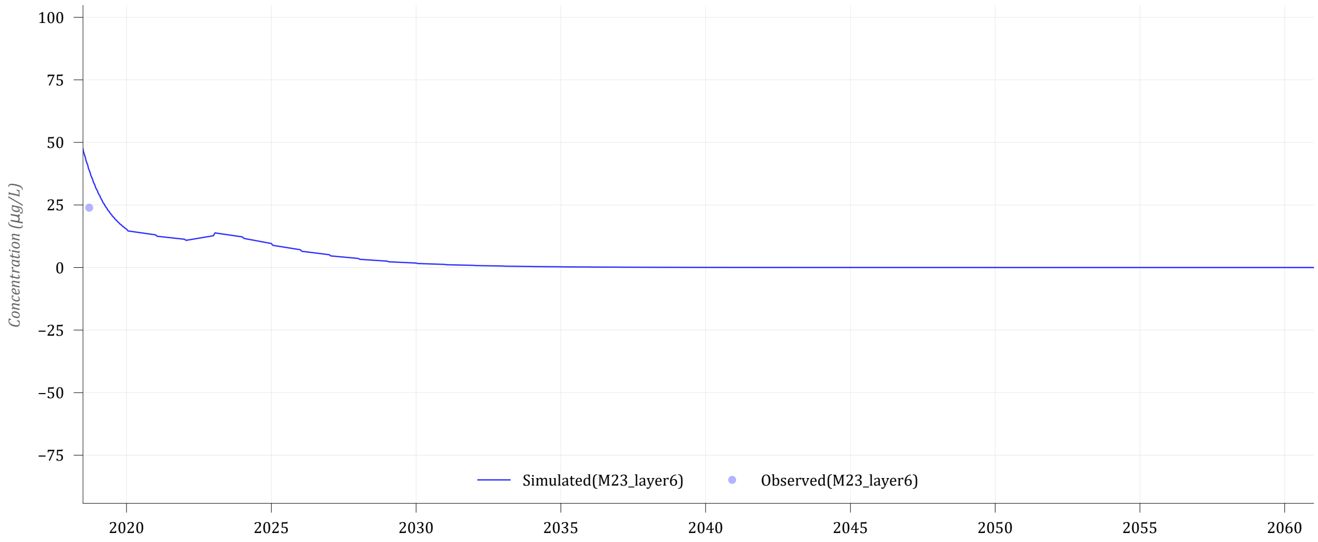
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M21_layer6)
Observed(M21_layer6)

M22

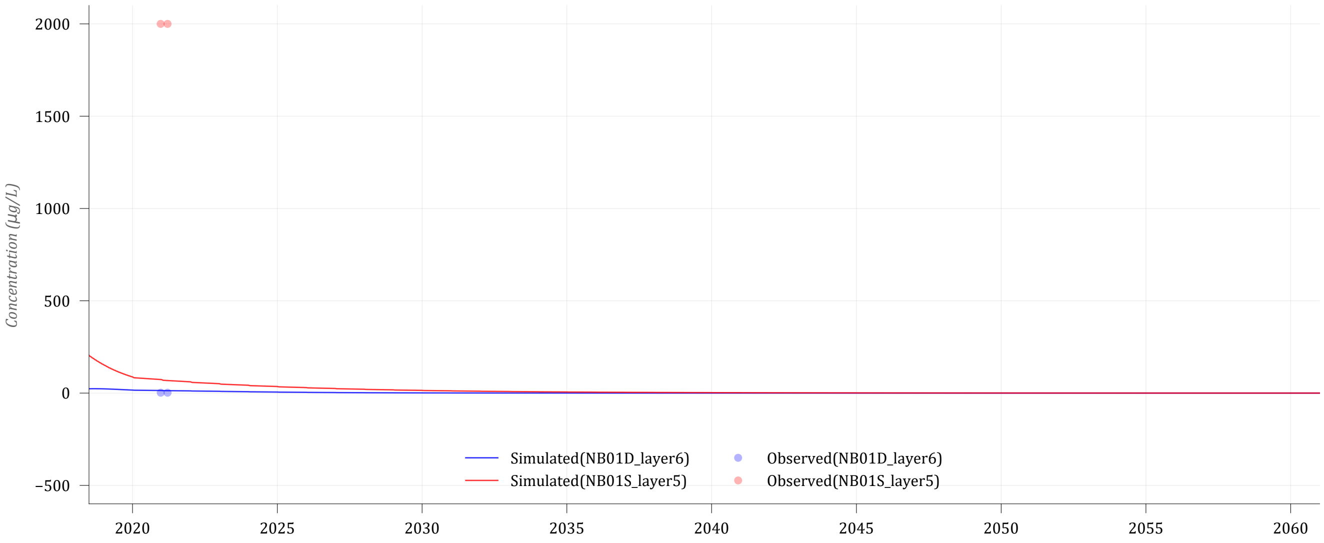


Concentration (µg/L)
1000
800
600
400
200
0
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M22_layer6)
Observed(M22_layer6)

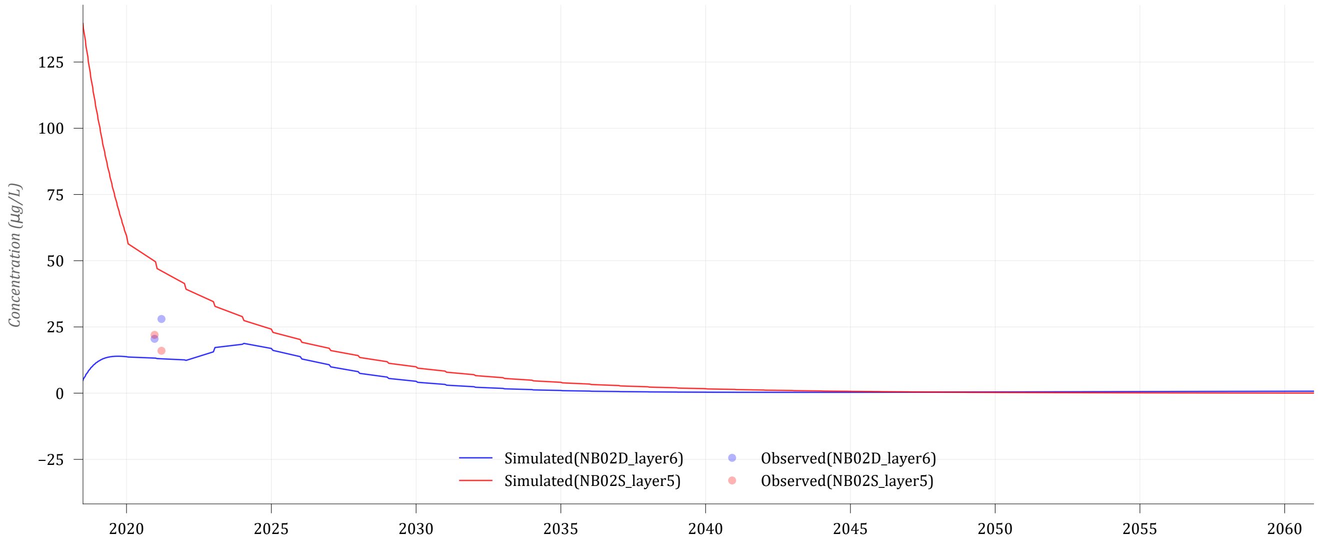
M23



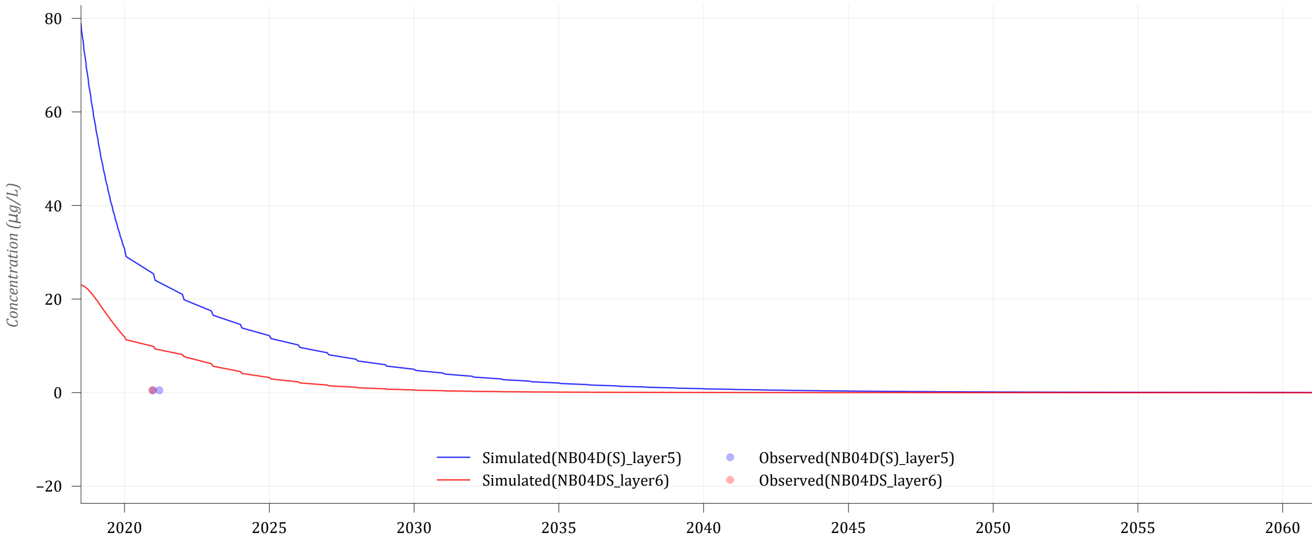
NB01



NB02

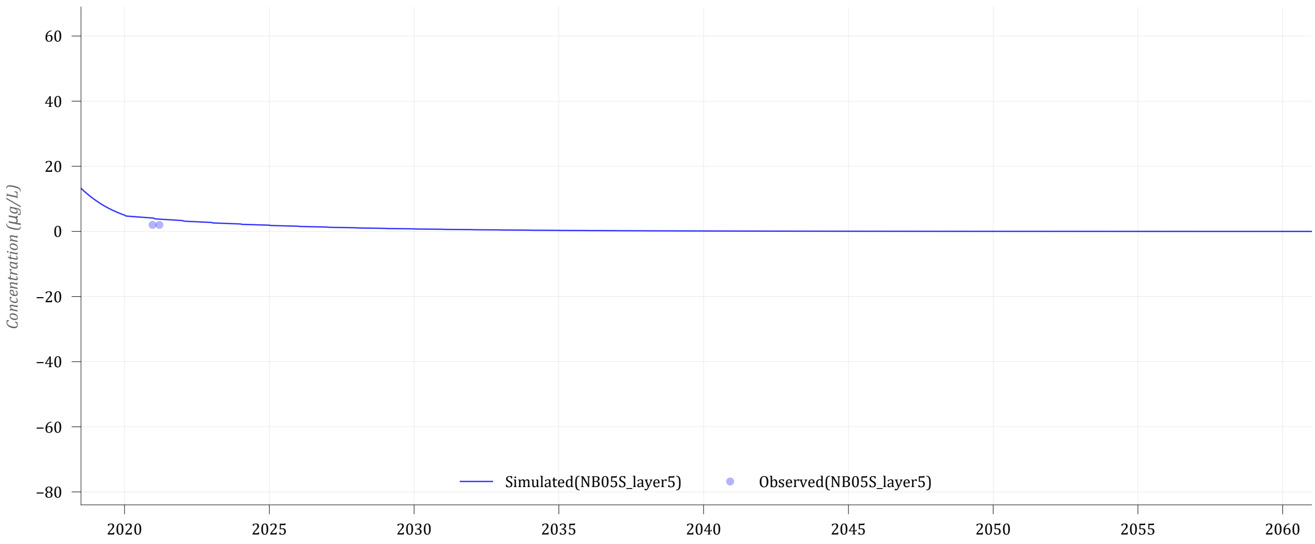


NB04



Concentration (µg/L)
80
60
40
20
0
−20
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(NB04D(S)_layer5)
Simulated(NB04DS_layer6)
Observed(NB04D(S)_layer5)
Observed(NB04DS_layer6)

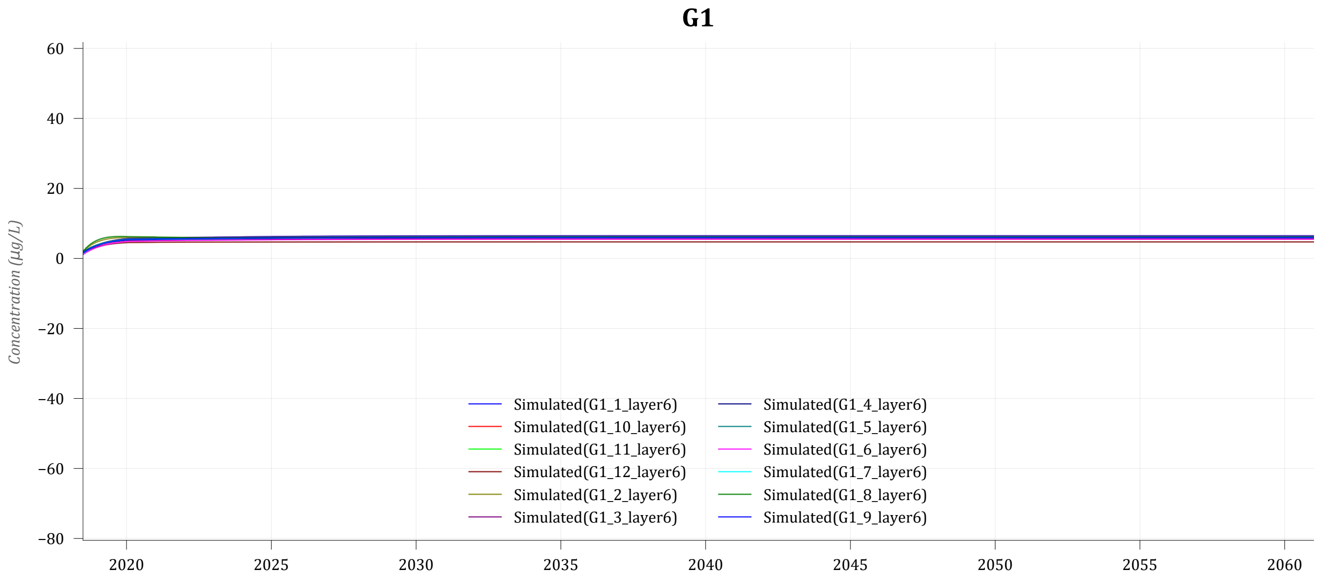
NB05S

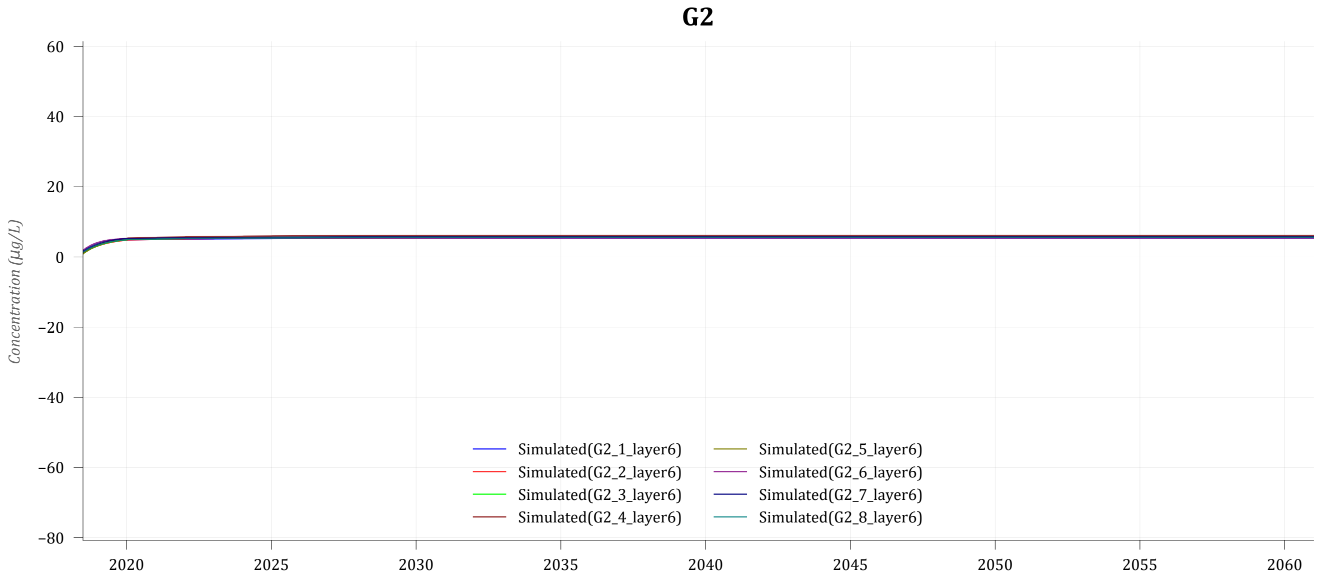


Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(NB05S_layer5)
Observed(NB05S_layer5)

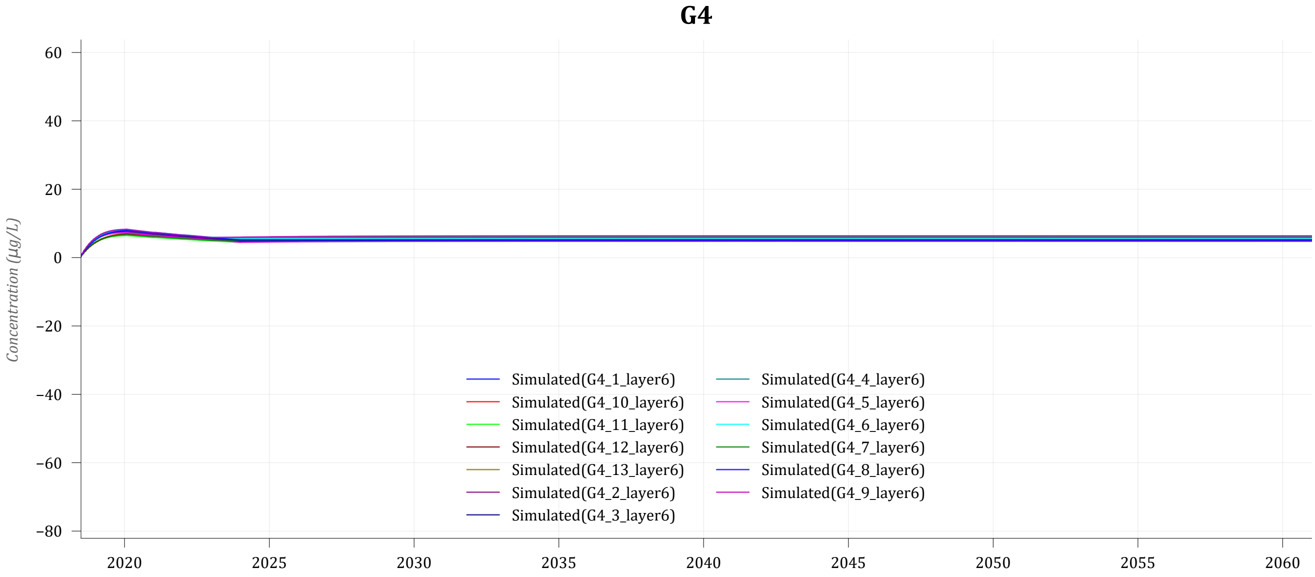
Appendix C

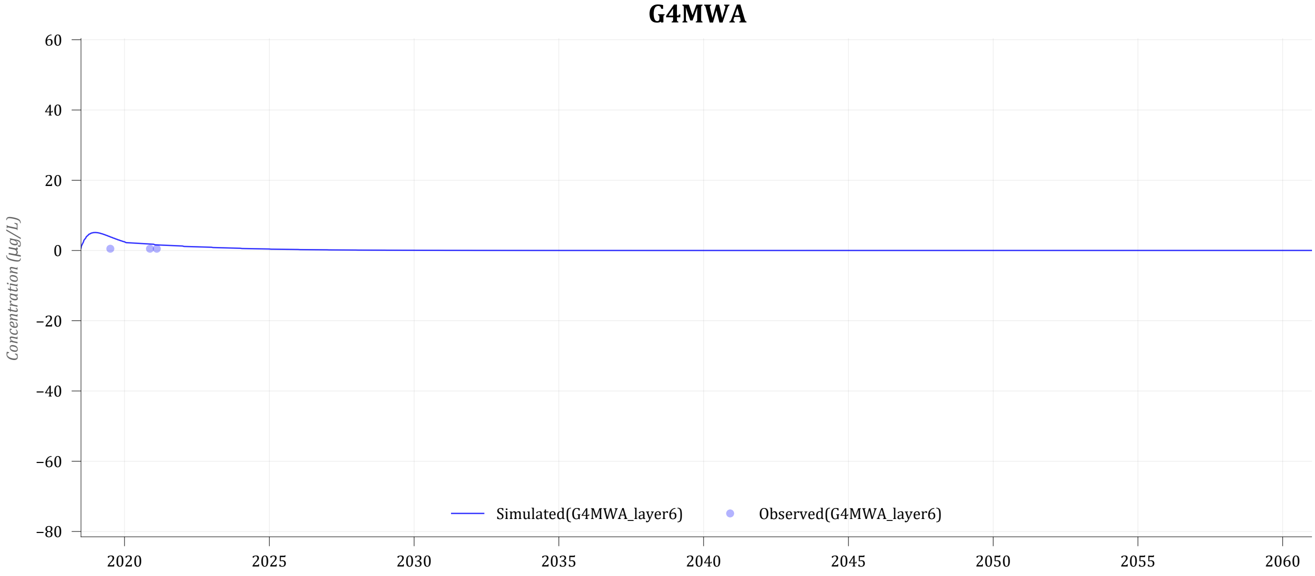
Concentration hydrographs – Naphthalene

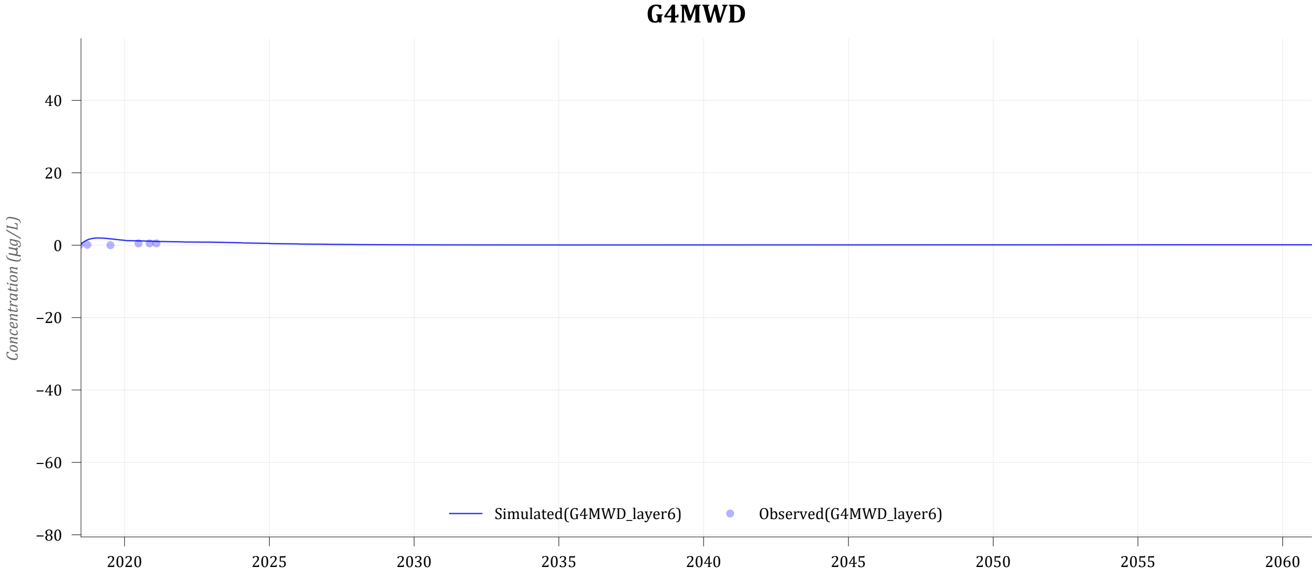

G1
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G1_1_layer6)
Simulated(G1_10_layer6)
Simulated(G1_11_layer6)
Simulated(G1_12_layer6)
Simulated(G1_2_layer6)
Simulated(G1_3_layer6)
Simulated(G1_4_layer6)
Simulated(G1_5_layer6)
Simulated(G1_6_layer6)
Simulated(G1_7_layer6)
Simulated(G1_8_layer6)
Simulated(G1_9_layer6)

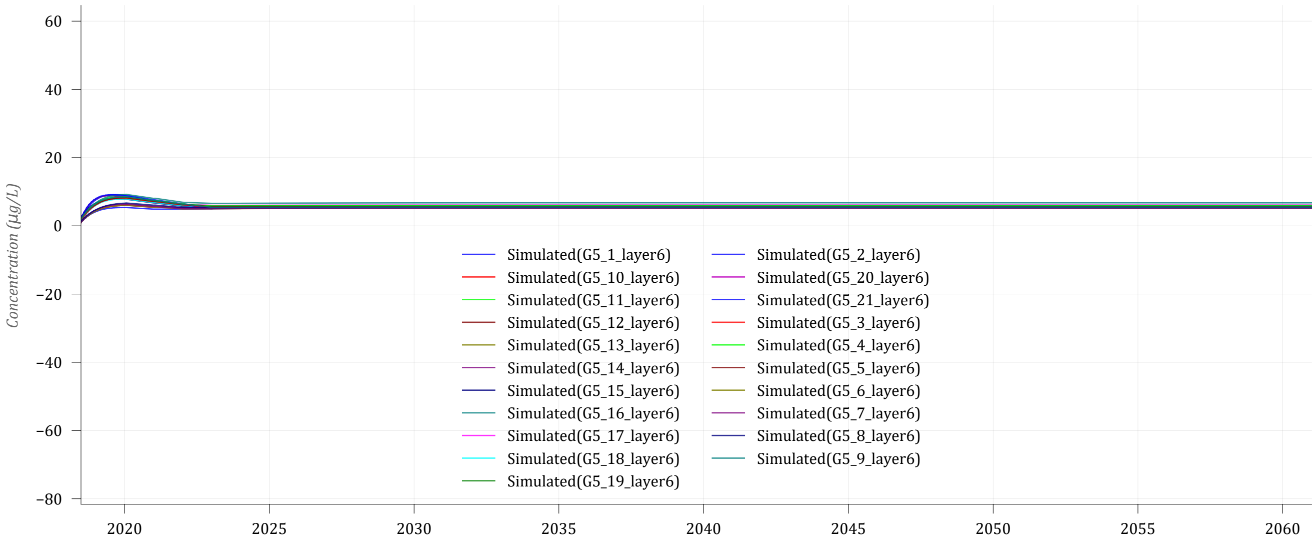

G2
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G2_1_layer6)
Simulated(G2_2_layer6)
Simulated(G2_3_layer6)
Simulated(G2_4_layer6)
Simulated(G2_5_layer6)
Simulated(G2_6_layer6)
Simulated(G2_7_layer6)
Simulated(G2_8_layer6)


G3
Concentration (µg/L)
100
75
50
25
0
−25
−50
−75
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G3_1_layer6)
Simulated(G3_2_layer6)
Simulated(G3_3_layer6)
Simulated(G3_4_layer6)
Simulated(G3_5_layer6)
Simulated(G3_6_layer6)
Simulated(G3_7_layer6)

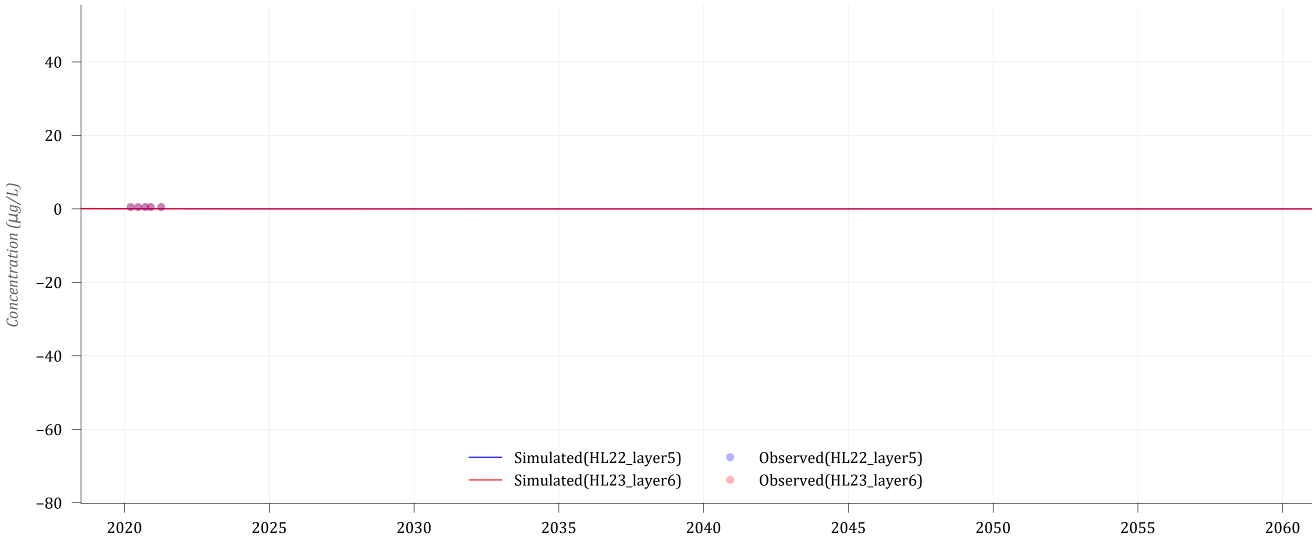

G4
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4_1_layer6)
Simulated(G4_10_layer6)
Simulated(G4_11_layer6)
Simulated(G4_12_layer6)
Simulated(G4_13_layer6)
Simulated(G4_2_layer6)
Simulated(G4_3_layer6)
Simulated(G4_4_layer6)
Simulated(G4_5_layer6)
Simulated(G4_6_layer6)
Simulated(G4_7_layer6)
Simulated(G4_8_layer6)
Simulated(G4_9_layer6)


G4MWA
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4MWA_layer6)
Observed(G4MWA_layer6)

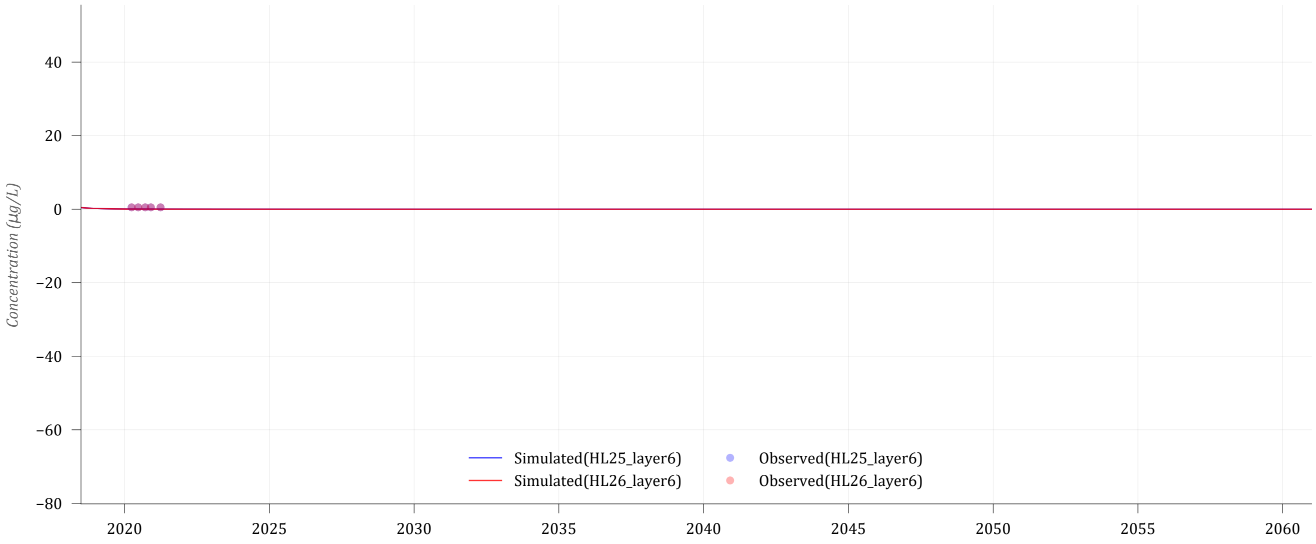

G4MWD
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(G4MWD_layer6)
Observed(G4MWD_layer6)



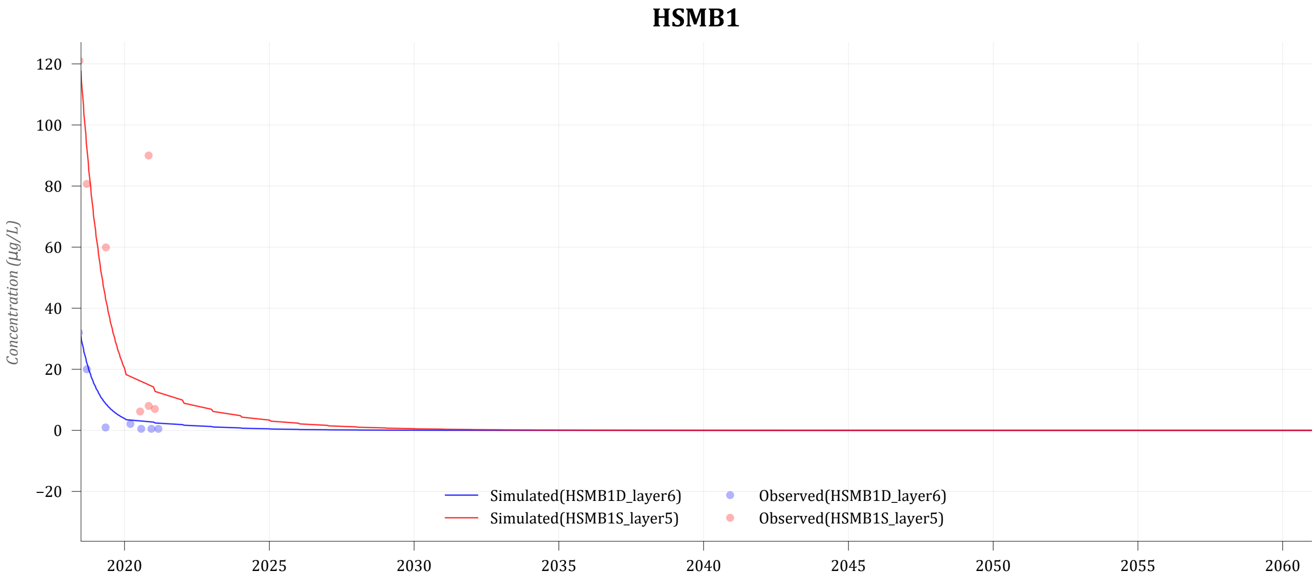
G5

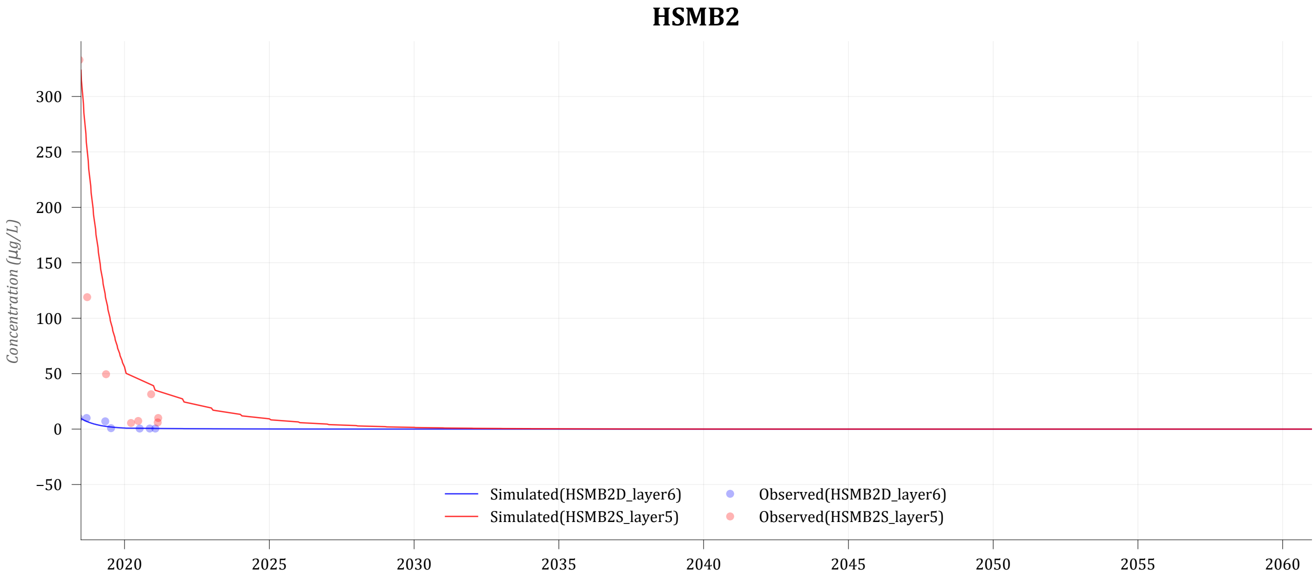


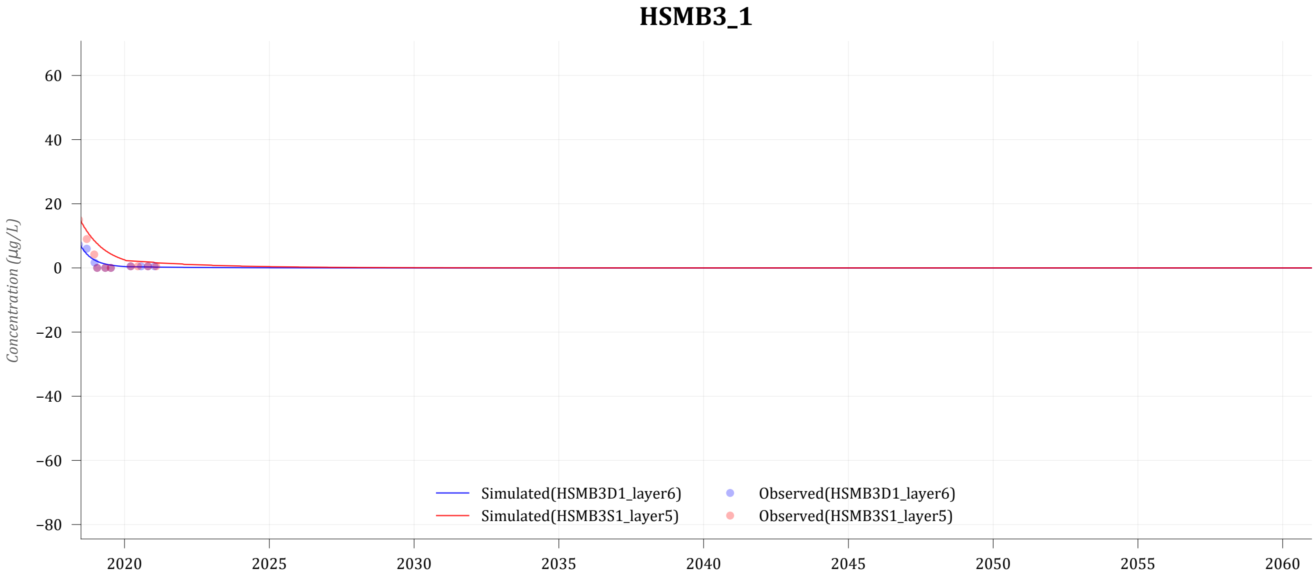
HL22-23

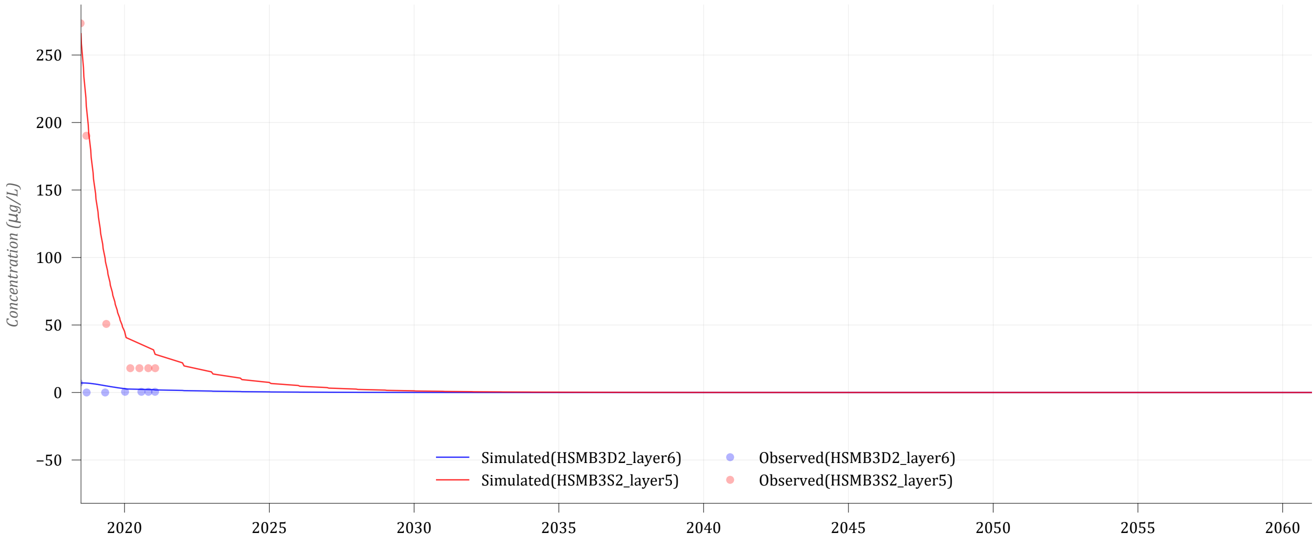


HL25-26

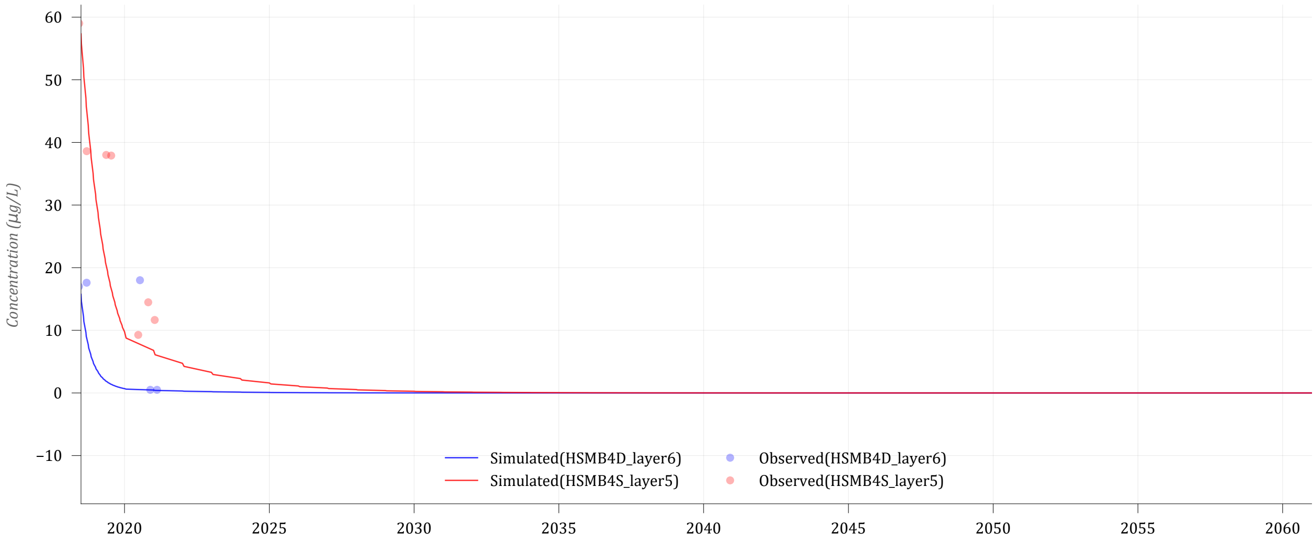

HSMB1
Concentration (μg/L)
120
100
80
60
40
20
0
−20
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB1D_layer6)
Simulated(HSMB1S_layer5)
Observed(HSMB1D_layer6)
Observed(HSMB1S_layer5)


HSMB2
Concentration (μg/L)
300
250
200
150
100
50
0
−50
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB2D_layer6)
Simulated(HSMB2S_layer5)
Observed(HSMB2D_layer6)
Observed(HSMB2S_layer5)

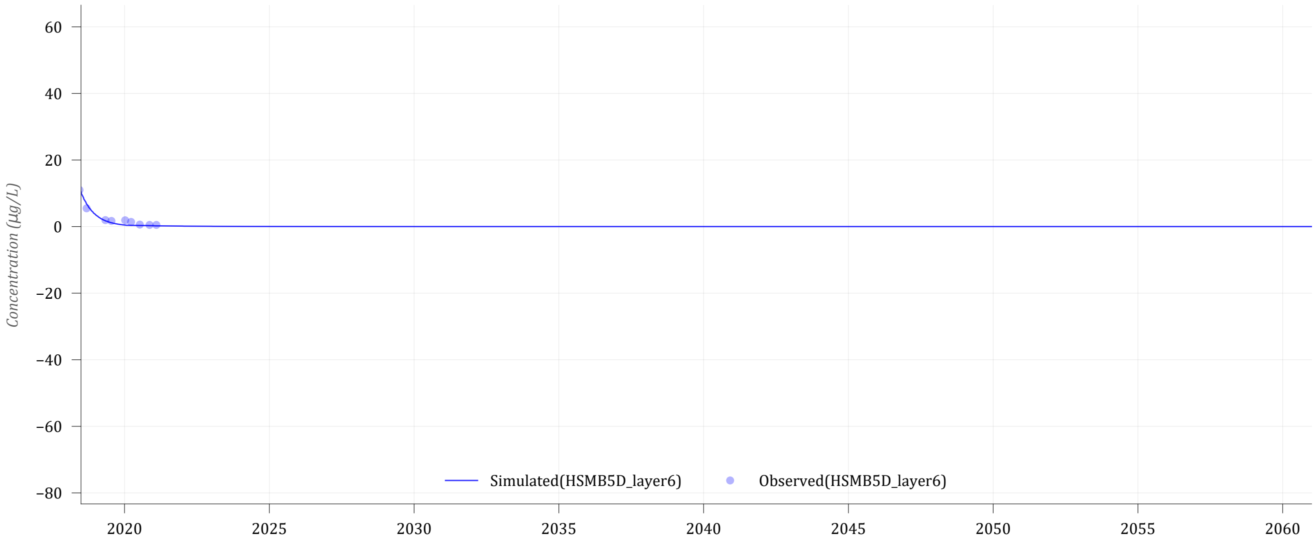

HSMB3_1
Concentration (μg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB3D1_layer6)
Simulated(HSMB3S1_layer5)
Observed(HSMB3D1_layer6)
Observed(HSMB3S1_layer5)



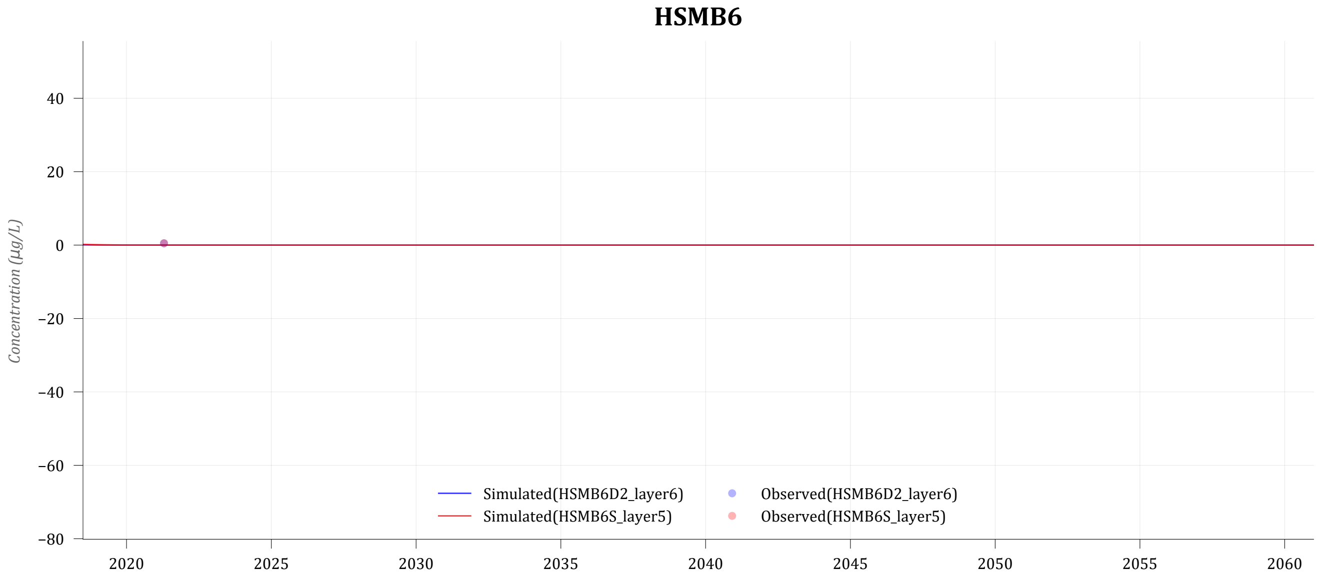
HSMB3_2

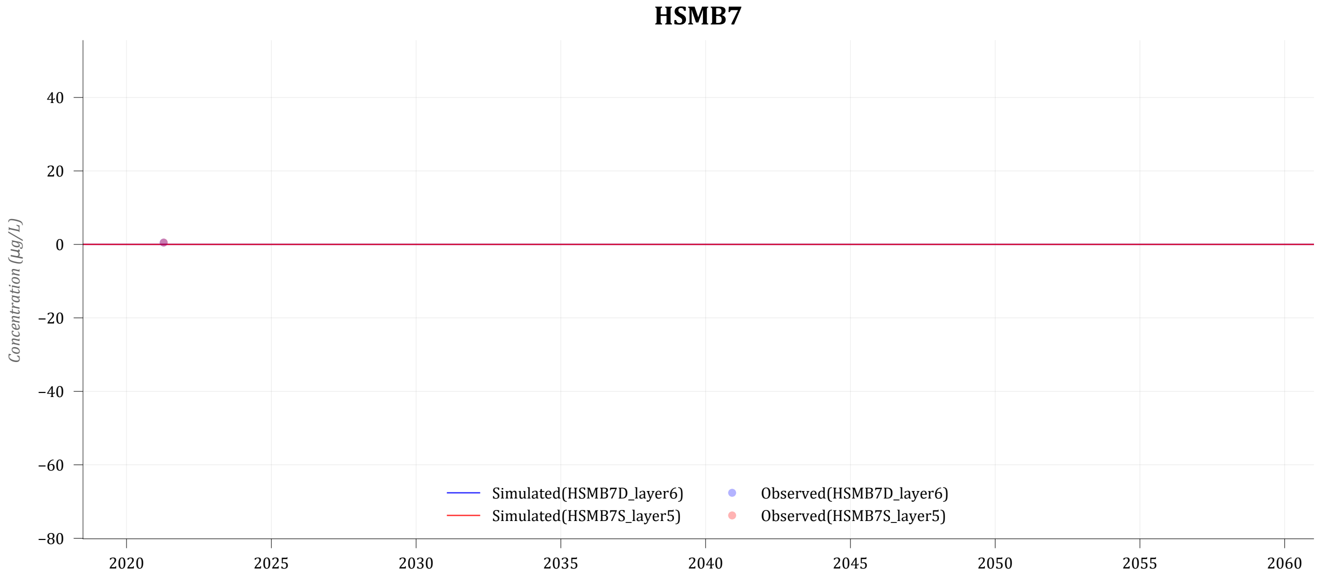


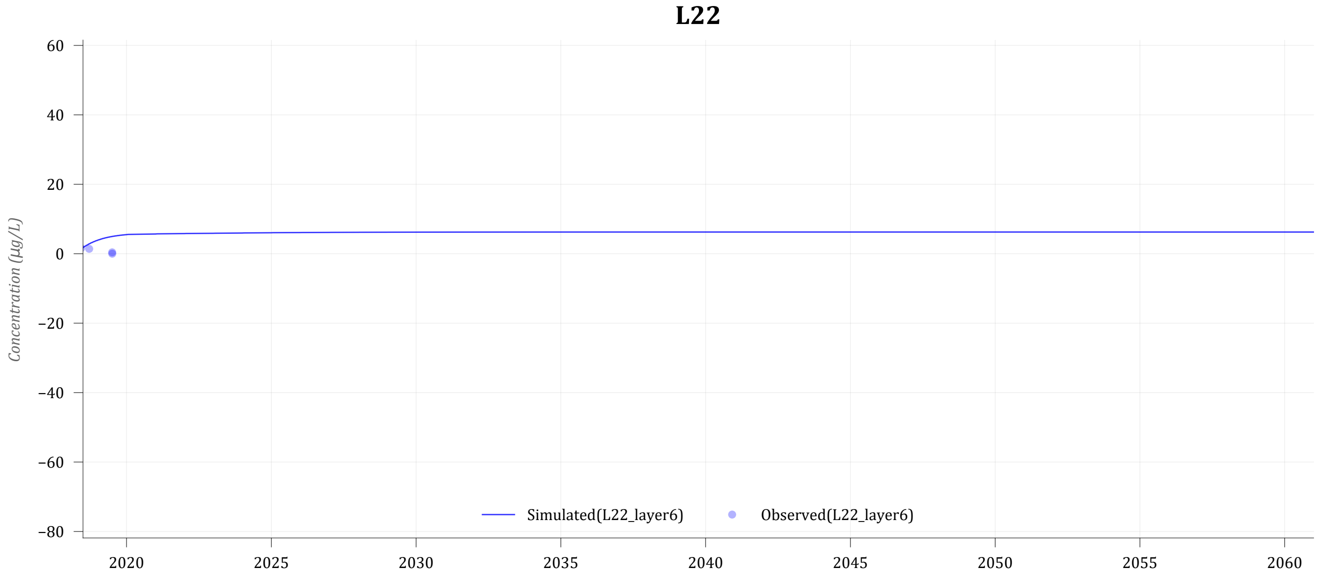
HSMB4

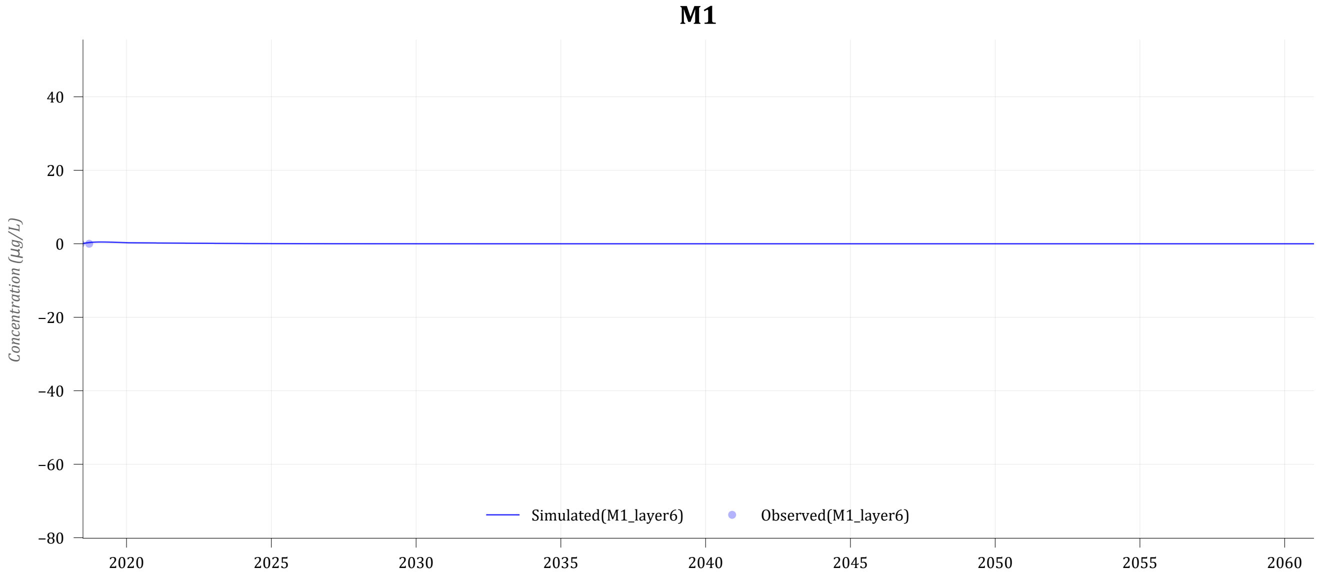


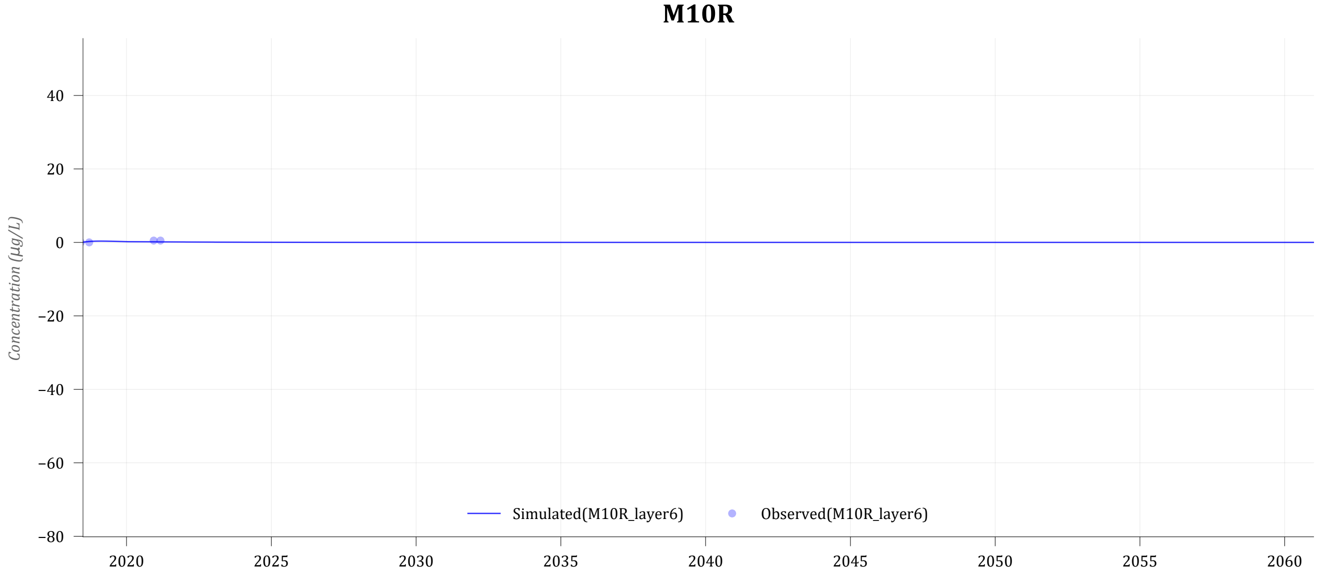
HSMB5D

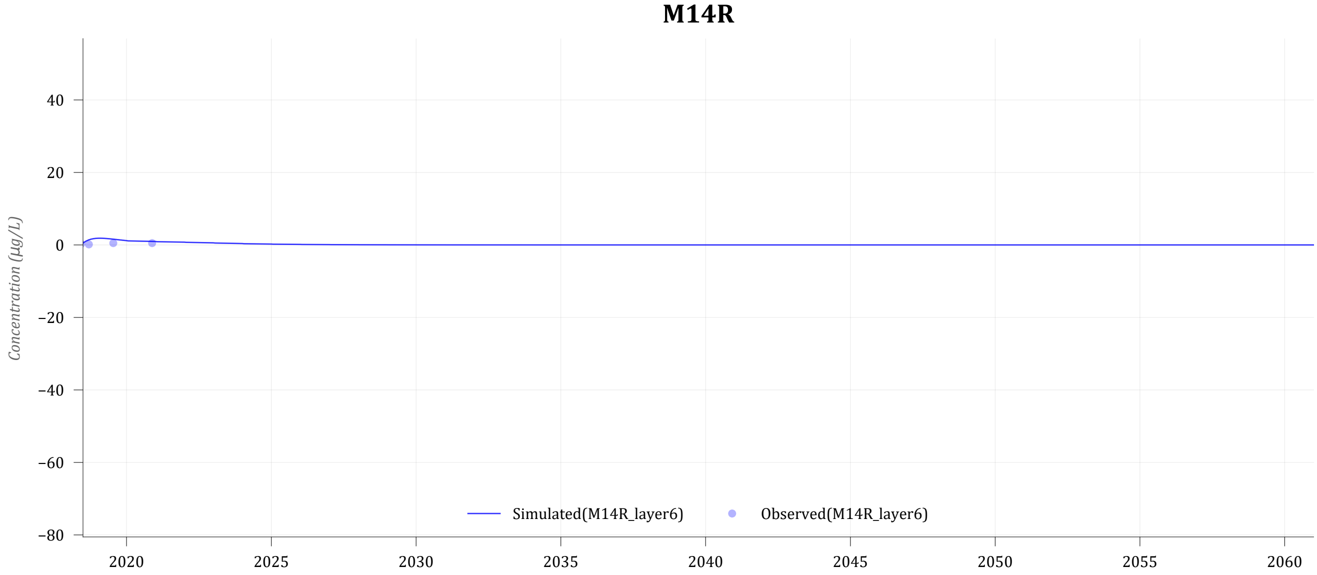

HSMB6
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB6D2_layer6)
Simulated(HSMB6S_layer5)
Observed(HSMB6D2_layer6)
Observed(HSMB6S_layer5)


HSMB7
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(HSMB7D_layer6)
Simulated(HSMB7S_layer5)
Observed(HSMB7D_layer6)
Observed(HSMB7S_layer5)

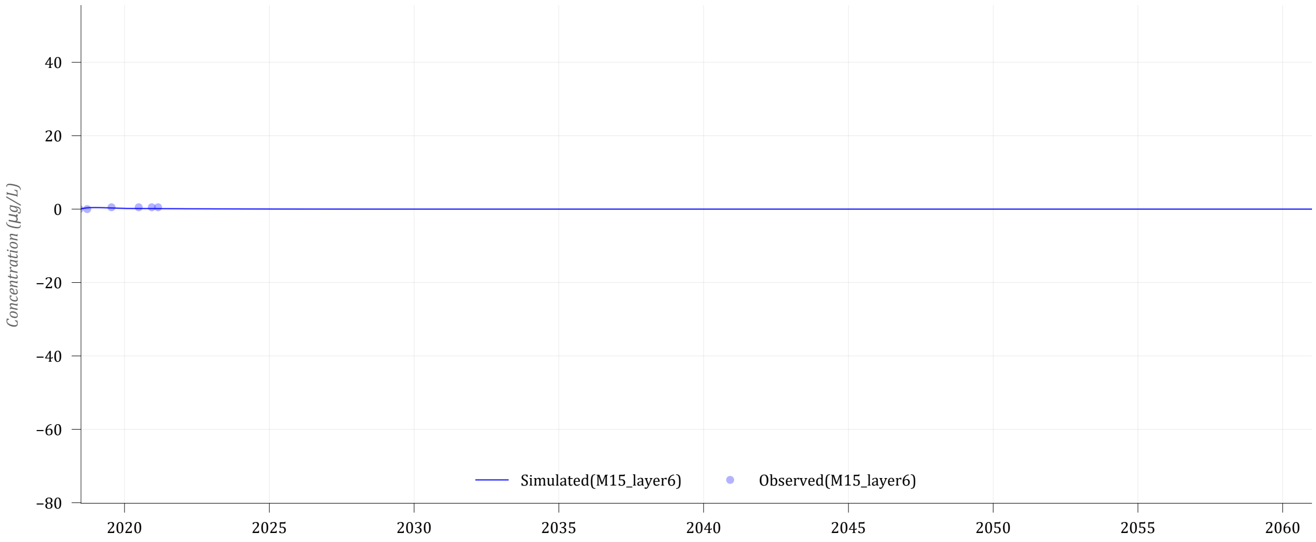

L22
Concentration (µg/L)
60
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(L22_layer6)
Observed(L22_layer6)


M1
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M1_layer6)
Observed(M1_layer6)

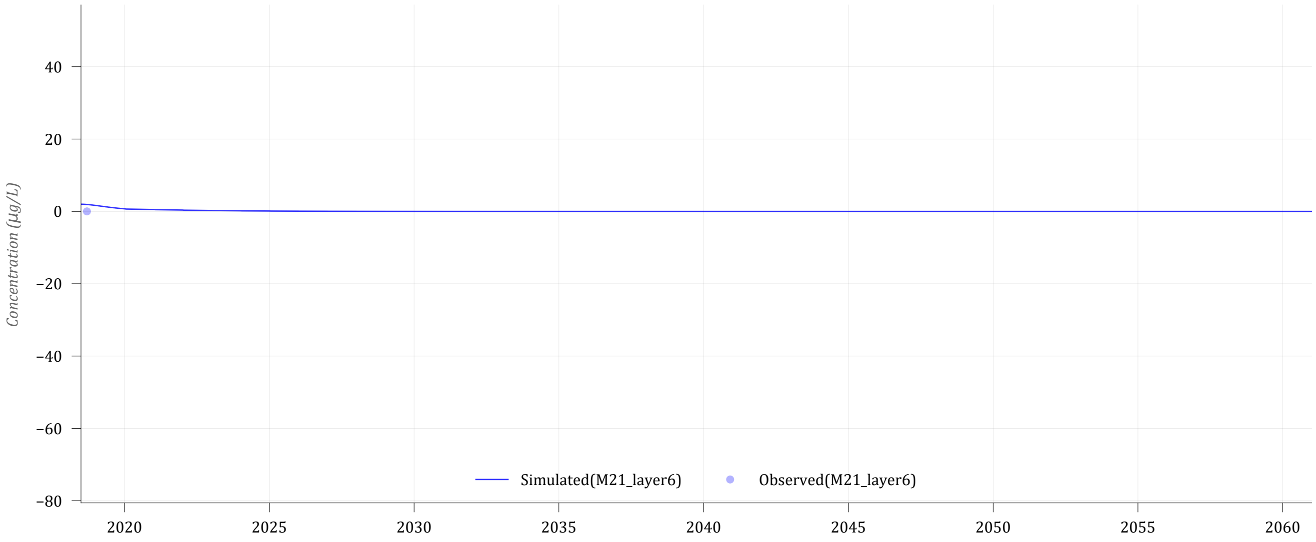

M10R
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M10R_layer6)
Observed(M10R_layer6)


M14R
Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M14R_layer6)
Observed(M14R_layer6)

M15


Concentration (µg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M15_layer6)
Observed(M15_layer6)

M21


Concentration (µg/L)
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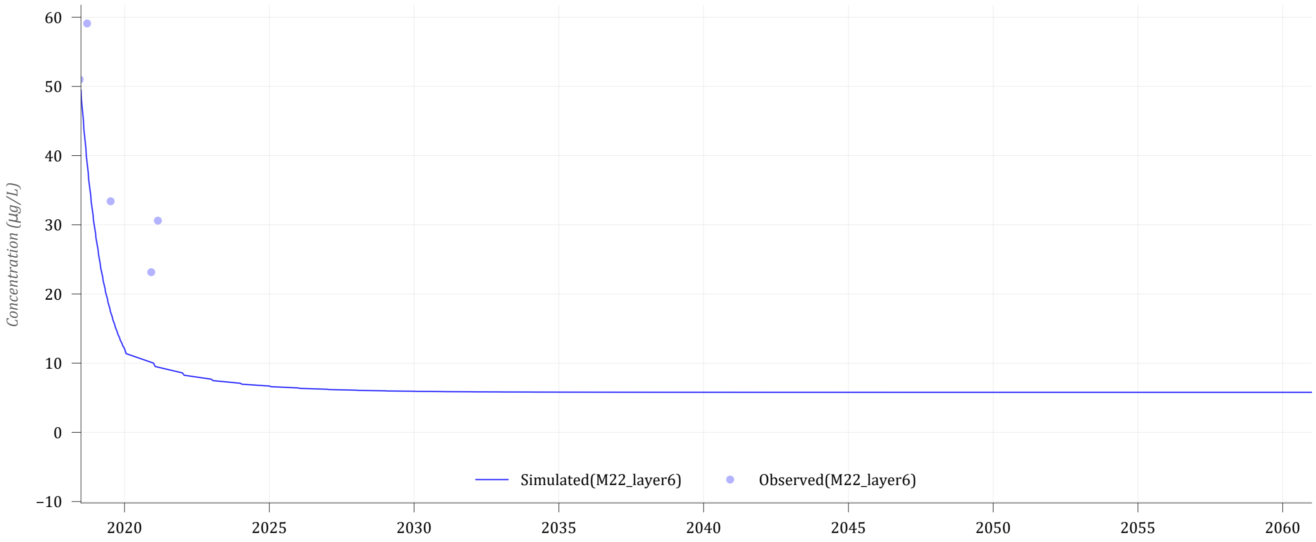
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(M21_layer6)
Observed(M21_layer6)

M22


Concentration (µg/L)
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50
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30
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10
0
−10
2020
2025
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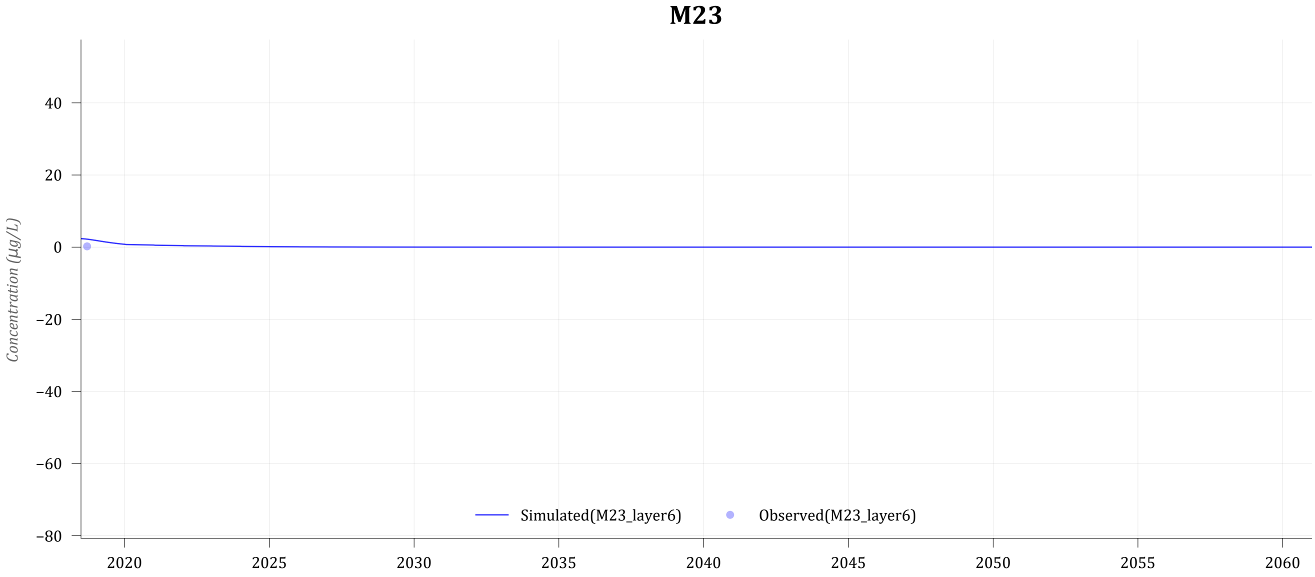
Observed(M22_layer6)


M23
Concentration (µg/L)
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−60
−80
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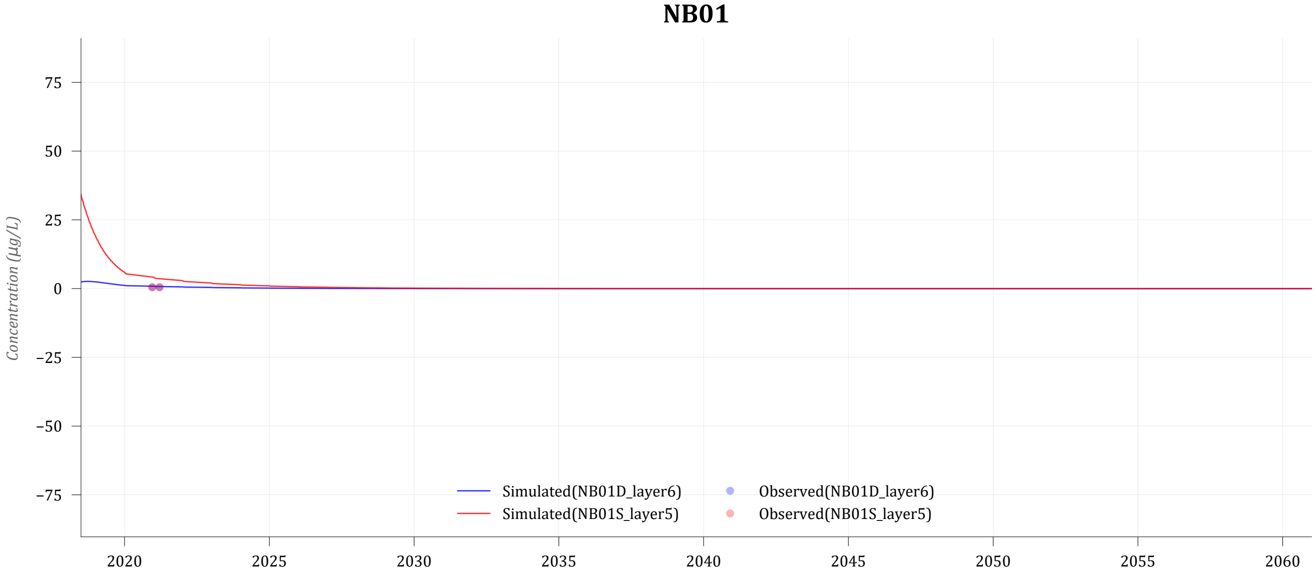
Observed(M23_layer6)


NB01
Concentration (µg/L)
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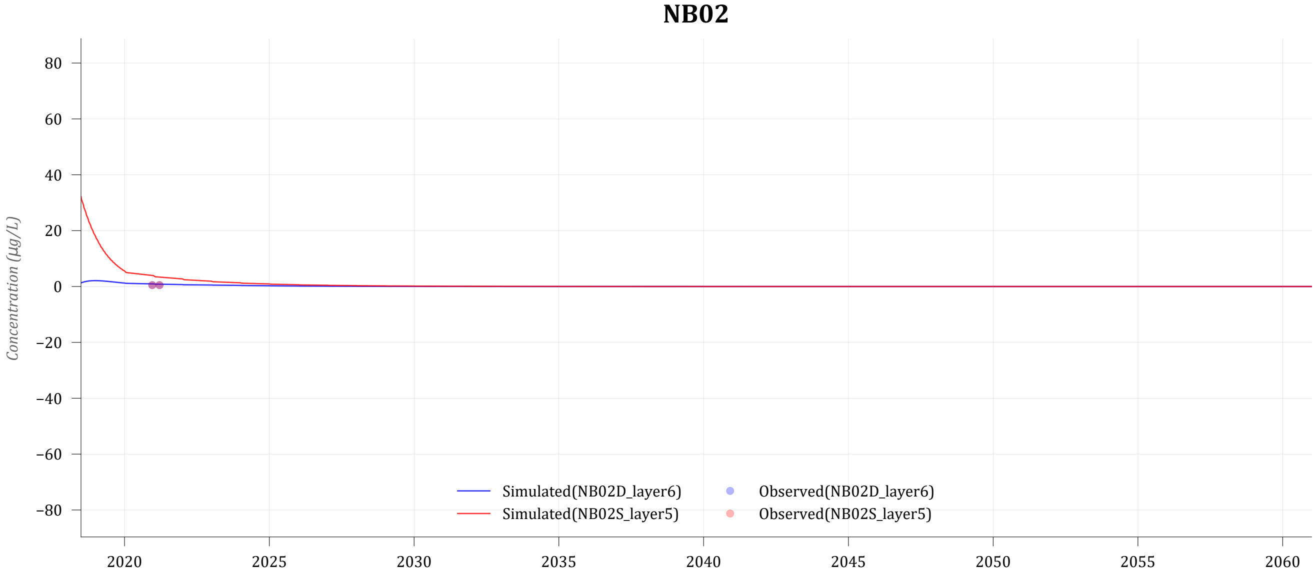
50
25
0
−25
−50
−75
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(NB01D_layer6)
Simulated(NB01S_layer5)
Observed(NB01D_layer6)
Observed(NB01S_layer5)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Concentration (µg/L)
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−20
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−60
−80
2020
2025
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2040
2045
2050
2055
2060
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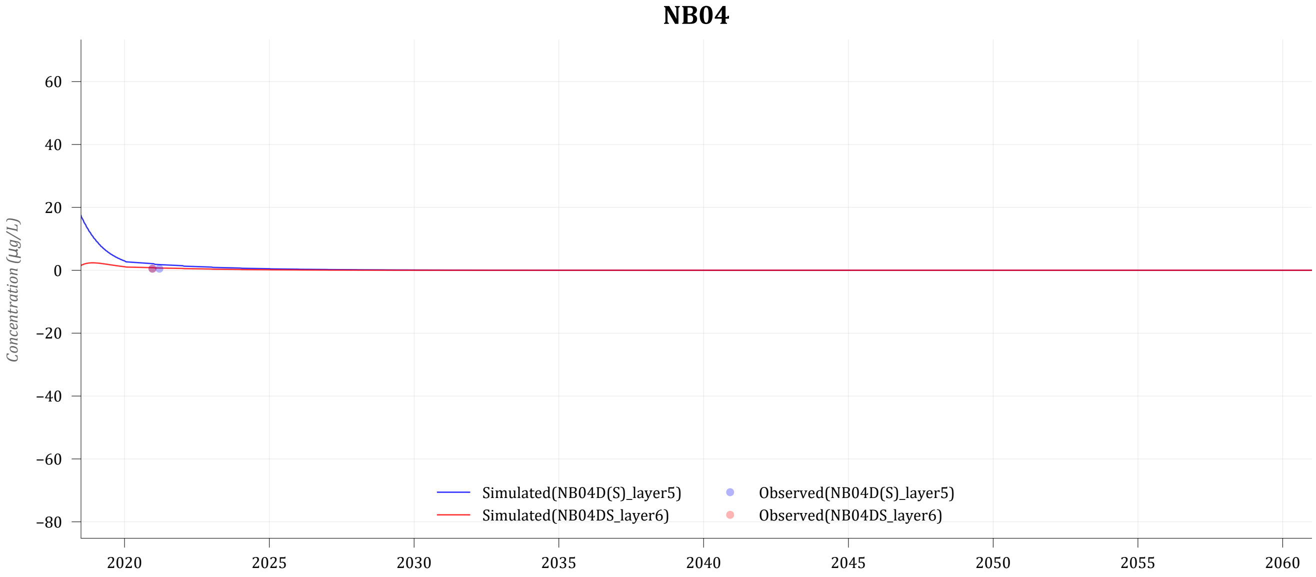
Simulated(NB02S_layer5)
Observed(NB02D_layer6)
Observed(NB02S_layer5)


NB04
Concentration (μg/L)
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−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
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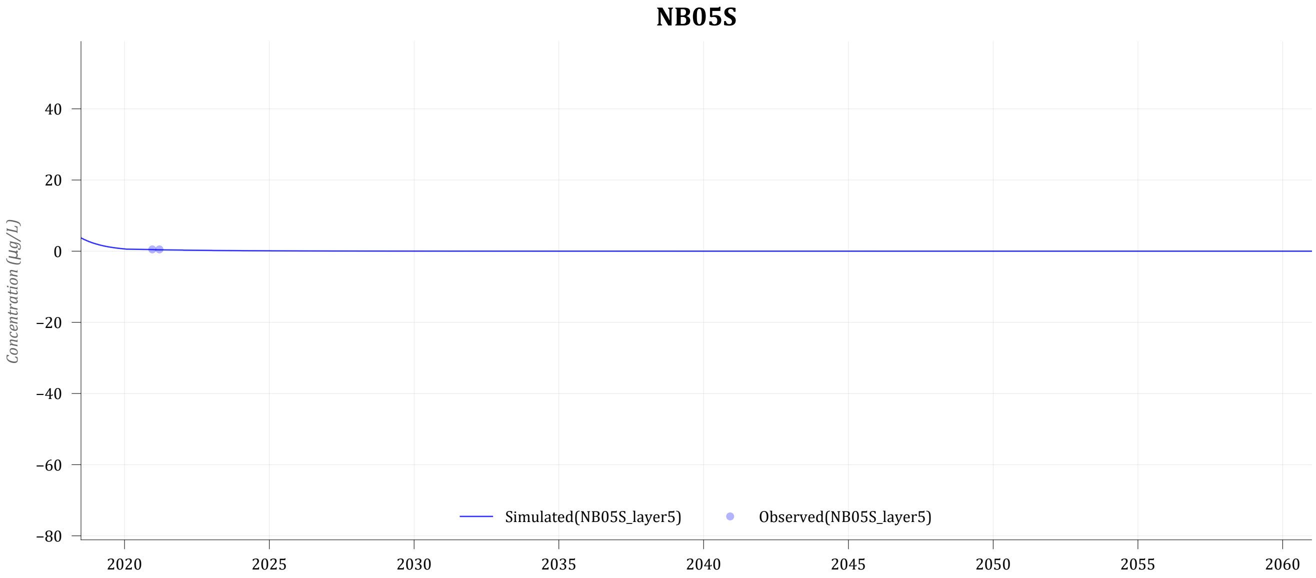
Simulated(NB04DS_layer6)
Observed(NB04D(S)_layer5)
Observed(NB04DS_layer6)


NB05S
Concentration (μg/L)
40
20
0
−20
−40
−60
−80
2020
2025
2030
2035
2040
2045
2050
2055
2060
Simulated(NB05S_layer5)
Observed(NB05S_layer5)

Appendix D

AGE/GHD 2020 report

Australasian Groundwater and
Environmental Consultants Pty Ltd

Report on

Production Licensing Modelling Support
Arrow Energy

Prepared for
Arrow Energy Pty Ltd

Project No. G2002 June 2020
www.ageconsultants.com.au ABN 64 080 238 642

Document details and history

Document details

Project number G2002
Document title Production Licensing Modelling Support – Arrow Energy
Site address Arrow Energy Pty Ltd
File name G2002.Arrow Production Licence Modelling and Reporting Support v04.01

Document status and review

Edition	Comments	Author	Authorised by	Date
v01.01	First draft	MA/NM/KP	KP	24/04/2020
v02.01	Revised reporting including CT model	MA/NM/KP	KP	19/05/2020
v03.01	Revised reporting as per comments from Arrow	MA/NM/KP	KP	2/06/2020
v04.01	Further minor revisions to address Arrow Comments	MA/NM/KP	KP	11/06/2020

Australasian Groundwater and Environmental Consultants Pty Ltd

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Page No.

List of appendices

Report on

Production Licensing Modelling Support
Arrow Energy

1 Introduction

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were commissioned in December 2019 to provide production licensing modelling support to Arrow Energy Pty Ltd (Arrow Energy). This report summarises the findings of numerical modelling work undertaken to assess the potential impact of CSG development around the former Linc Energy Site (Lot 40 DY 85 on ATP676) in the Hopelands area south west of Chinchilla (Figure 1.1).

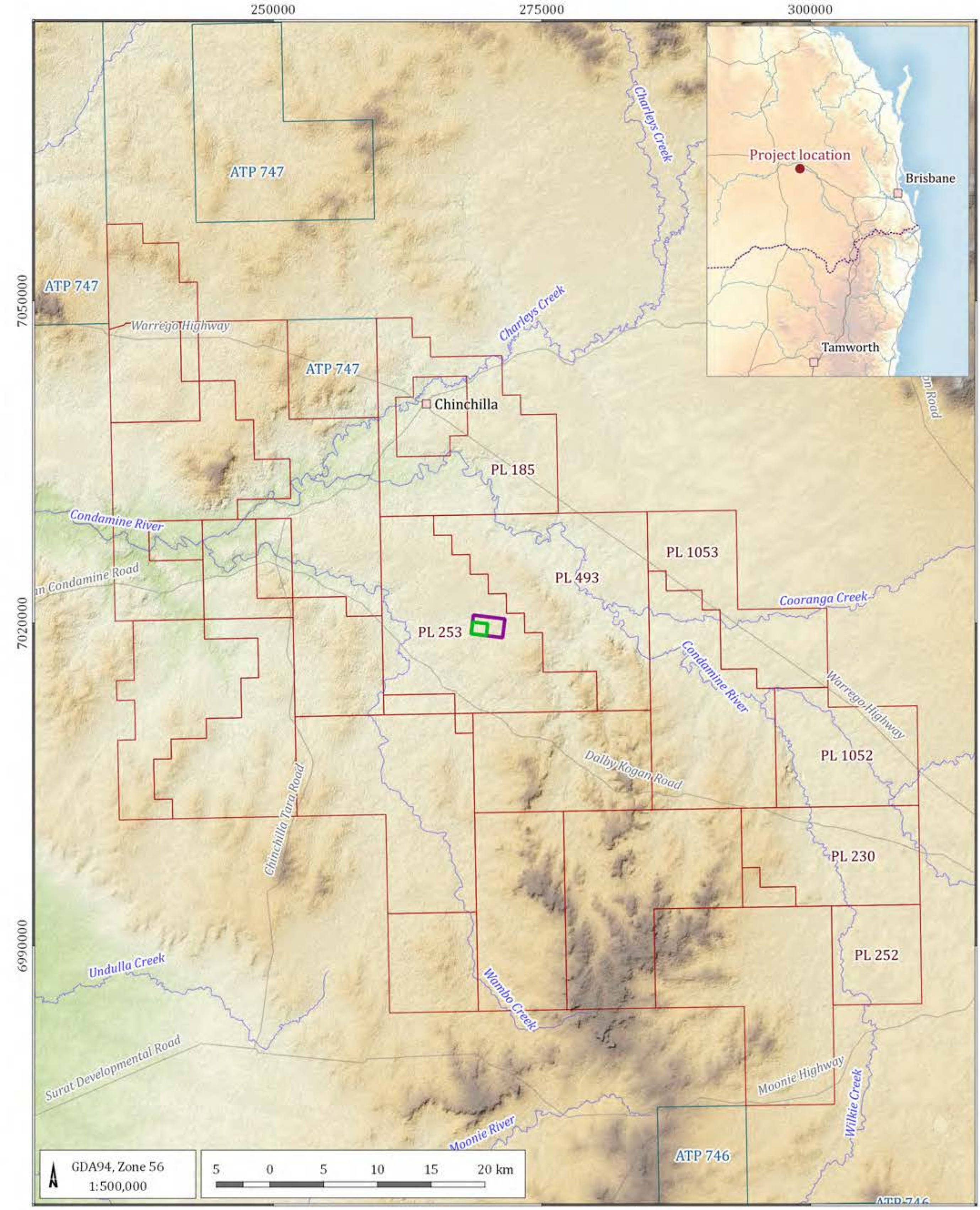
1.1 Scope of work

A phased work program was implemented including construction and calibration of a groundwater flow simulation in Phase 1 and development of contaminant fate and transport simulation in Phase 2. These models were then used to assess the impacts of current and proposed future Arrow Energy CSG extraction from the area surrounding Lot 40 DY85.

1.2 In this report

Consistent with the recommendations included in the current Australian Groundwater Modelling Guidelines (Barnett et al, 2012) this reporting is structured as follows:

- Section 2 outlines the objectives of the modelling work undertaken and presents a summary of the hydrogeological conceptualisation of the area.
- Key components of the Phase 1 groundwater flow model design are presented in Section 3.
- Groundwater flow model calibration results are presented in Section 4.
- The design of the Phase 2 contaminant fate and transport model is described in Section 5.
- Contaminant and fate and transport model calibration results are presented in Section 6.
- Groundwater flow and contamination transport predictions are presented in Section 7.
- The results of a predictive uncertainty analysis are presented in Section 8.
- Overall summary and conclusions are presented in Section 9.



LEGEND

- ☐ Populated place
- — Road
- — Rivers and other watercourses
- 🟩 MDL309 boundary
- 🟪 Lot 40 DY 85
- 🟥 Petroleum Lease (PL) area
- ☐ Authority to Prospect (ATP) area

Elevation (mAHD)

■	250
■	275
■	300
■	350
■	400

Hopelands Arrow (G2002)

Project Location

AGE

DATE
10/06/2020

FIGURE No:
1.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\01.01_G2002_Project location.qgs

2 Model objectives and conceptualisation

2.1 Model objectives

The objectives of the study and associated groundwater flow and contaminant transport models included to:

- review and where necessary revise the model previously developed by GHD; and
- use the resulting models to assess the impacts of existing and proposed Arrow Energy and other CSG wells on contaminant movement in and around the former Linc Energy Site.

2.2 Previous modelling and other studies

The numerical models reported herein represent the latest stage in the development of numerical models to assess potential impacts to contamination at the former Linc UCG site from proposed field development at the surrounding Arrow Energy Petroleum Lease (PL) areas PL253 and PL185/493 that included:

- Arrow Energy used the regional scale groundwater flow model developed by the Office of Groundwater Impact Assessment (OGIA, 2016a) for the purposes of assessing the cumulative impacts of approved CSG activities in the Surat Cumulative Management Area (CMA); and
- A local scale model of the PL253 and PL185/493 areas developed by GHD with a refined grid mesh and geological structure (GHD, 2019).

2.3 Conceptualisation

Detailed conceptualisation reports relating to the Surat Basin as a whole and PL253 have previously been prepared by OGIA (2016b) and Arrow Energy (2018) respectively and are not repeated here. Further information on the hydrogeological setting is also provided in Section 2 of the GHD modelling report (included as Appendix A). This report therefore assumes familiarity with these documents and of the strata present within this part of the Surat Basin.

3 Phase 1 groundwater flow model design

The Phase 1 groundwater flow model of PL253 and PL185/493 areas reported herein represents a further development of the GHD (2019) model with further refinements made to the model structure to included dedicated coal layers in each sub-unit of the Walloon Coal Measures at the site.

3.1 Data collation and review

Phase 1 data collation activities predominantly comprised collating the model files and calibration data used during development of the existing GHD Hopelands model. Model files related to the 2016 OGIA Surat CMA model (OGIA, 2016a), which provides boundary conditions to the GHD model, were also provided by Arrow (under licence) in addition to proposed well locations and estimated rates for each of the predictive scenarios described in Section 7.1.

Following a review of the GHD model a number of improvements to the existing model design and calibration were implemented, as described in Sections 3.2, 4.1 and 4.2, prior to undertaking the predictive simulations.

3.1.1 Additional data relating to the former Linc Energy site

Only very limited information relating to historic activities on the former Linc Energy site has been available to date. However, the following three additional groundwater level data sets were collated for use in the Phase 1 study which were not used previously used by GHD(2019):

- a series of bore completion reports relating to 11 HSM series monitoring bores installed within the site boundaries on the behalf of DES during 2018 (AECOM, 2018);
- data for three nested monitoring facilities comprising eight monitoring points (HL20 to HL27) recently installed by Arrow close to the boundary of Lot 40 DY 85 and
- a 2013 paper prepared for a Society of Petroleum Engineers conference (Perkins et al, 2013) which includes key information on the location and operating periods of five UCG gasifiers on the site.

3.1.2 Groundwater level data

Data used for calibration of the Phase 1 model are summarised in Table 3.1 below. Calibration data locations are shown in Figure 3.1. The majority of the data used was also previously used by GHD although calibration was undertaken using updated data sets for the Wyalla 16, Wyalla 18, and Dundee 20 monitoring points extracted from the Queensland Globe[1]. Preparation of the available groundwater level data for model calibration purposes is described in Section 4.1.

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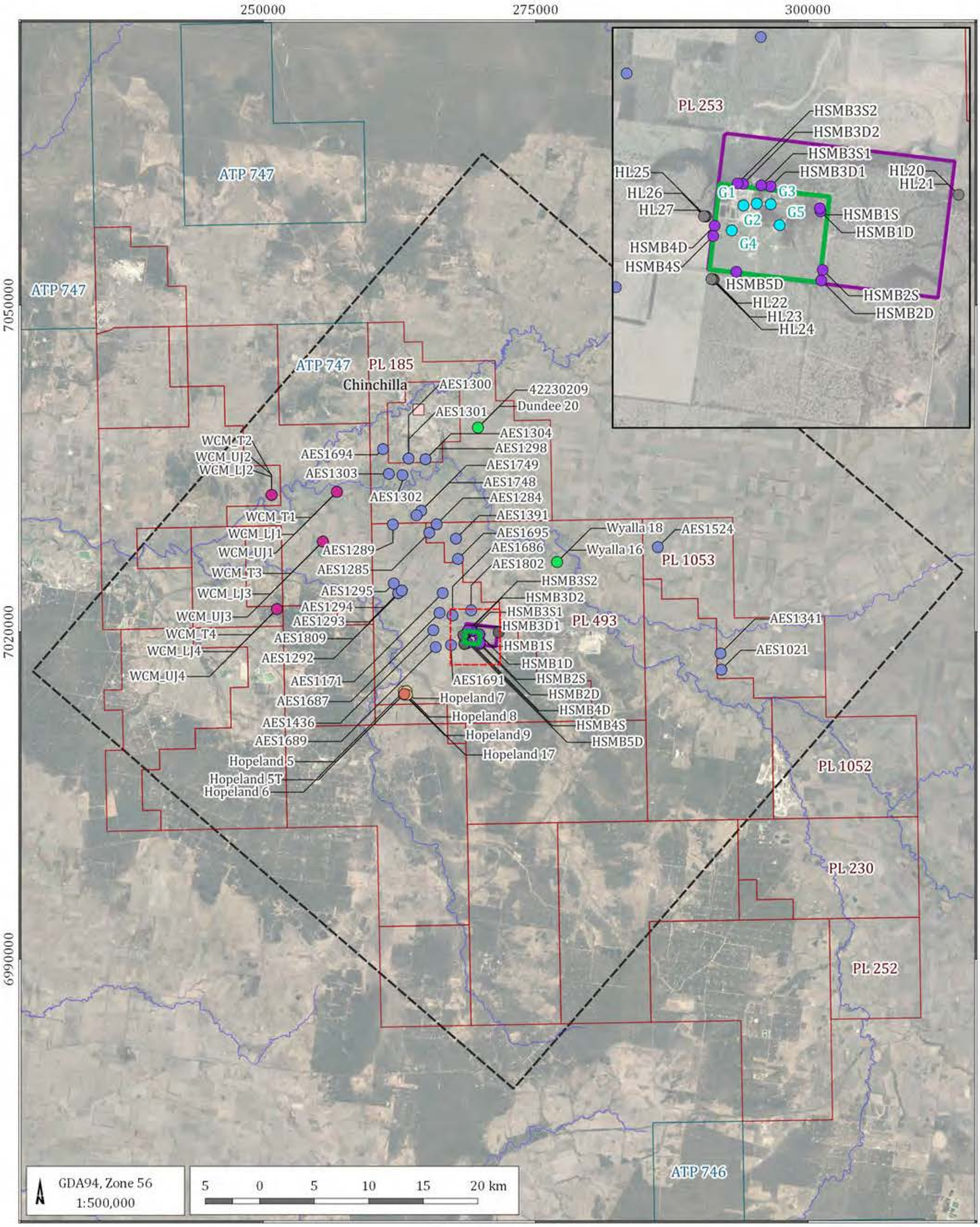
[1] https://qldglobe.information.qld.gov.au/



LEGEND

- 🟥 Populated place
- — Rivers and other watercourses
- 🟩 MDL309 boundary
- 🟪 Lot 40 DY 85
- ☐ Petroleum Lease (PL) area
- ☐ Authority to Prospect (ATP) area
- ⬚ Model extent

- ● Gasifier locations

Groundwater level data points

- ● Hoepland 17 nested
- ● Hopeland pilot CSG
- ● Landholder
- ● MDL 390
- ● Arrow HL 20 - 27
- ● Other Arrow
- ● Regional GW level
- ● State Monitoring

Hopelands Arrow (G2002)

Groundwater level data points, location map

AGE

DATE
10/06/2020

FIGURE No:
3.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\03.01_G2002_Groundwater level data points, location map.qgs

Table 3.1 Groundwater level data availability

Monitoring bore/data type	Number of locations	Number of data points	Data period	Notes
State monitoring bores	1	45	15/03/2013 to 15/04/2018	Single monitoring bore 42230209 completed into the Condamine Alluvium
Baseline monitoring in local landholder bores	29	58	15/07/2012 to 15/05/2018	Typically, 1 to 2 readings taken in landholder in Springbok Sandstone or Walloon Coal Measures bores as part of baseline surveys undertaken by Arrow Energy
Hopelands pilot CSG wells	6	176	15/02/2014 to 15/08/2018	Groundwater level data for CSG pilot wells. Corrected using Theim equation (Section 4.1.1)
Hopelands 17 nested monitoring facility	4	223	15/07/2014 to 15/05/2019	Nested VWP facility operated by Arrow with monitoring in the Springbok Sandstone and at three levels in the Walloon Coal Measures.
Arrow HL series bores (HL 20 to HL27)	3	7	13/03/2020 to 15/04/2020	Nested monitoring points recently installed by Arrow around the periphery of Lot 40 DY85 with monitoring the Springbok Sandstone, Macalister and Wambo coal seams.
Other Arrow monitoring bores	7	413	15/11/2013 to 15/08/2019	Arrow operated monitoring points at the Wyalla (Wyalla 16 and Wyalla 18) and Dundee (D20) sites.
DES monitoring bores within Lot 40 DY85	11	45	15/05/2018 to 15/05/2019	Monitoring at the former Linc Energy site. Typically comprises nested monitoring at the base of the Springbok Sandstone and underlying Macalister sub-unit.
Extracted from regional groundwater level contours	12	20	15/11/2016 to 15/11/2017	Estimated groundwater levels in the upper and lower Juandah and Taroom Coal Measures extracted from regional contours provided by Arrow at four locations to the east of PL-253.
Total	**70**	**980**		

Table 3.2 Former Linc Energy site additional site geology data (after AECOM, 2018)

Bore ID	Base of Springbok (mbgl)	Macalister A seam		Macalister B seam	
		Top (mbgl)	Thickness (m)	Top (mbgl)	Thickness (m)
HSMB1D	112	120	6	129	5
HSMB1S	112.5	120	5	- [a]	-
HSMB2D	114	118.5	6	133.5	3.5
HSMB2S	112.5	121	4	- [a]	-
HSMB3D1	112.5	125	6	131[b]	6
HSMB3S1	111	123	6	129 [b]	6
HSMB3D2	108	117.5	5	122.5[c]	5
HSMB3S2	109.5	116	5	121 [c]	5
HSMB4D	109.5	129	4.5	133.5[d]	4.5
HSMB4S	- [e]	-	-	-	-
HSMB5D	133.5	135	6	143	3

Notes: [a] *Bore terminated above Macalister B seam.*

[b] *12 m of continuous coal logged, boundary between A and B seams assumed to be at 6 m.*

[c] *10 m of continuous coal logged, boundary between A and B seams assumed to be at 5 m.*

[d] *9 m of continuous coal logged, boundary between A and B seams assumed to be at 4.5 m.*

[e] *Bore terminated above the base of the Springbok Sandstone.*

Table 3.3 Former Linc Energy site UCG gasifier operational periods

Gasifier	Start date	End date	Data source
Gasifier 1 (G1)	1999	2001	Perkins et al (2013)
Gasifier 2 (G2)	2007	2007	Perkins et al (2013)
Gasifier 3 (G3)	2008	2009	Perkins et al (2013)
Gasifier 4 (G4)	February 2010	March 2012	Perkins et al (2013)
Gasifier 5 (G5)	October 2011	October 2013	Perkins et al (2013)

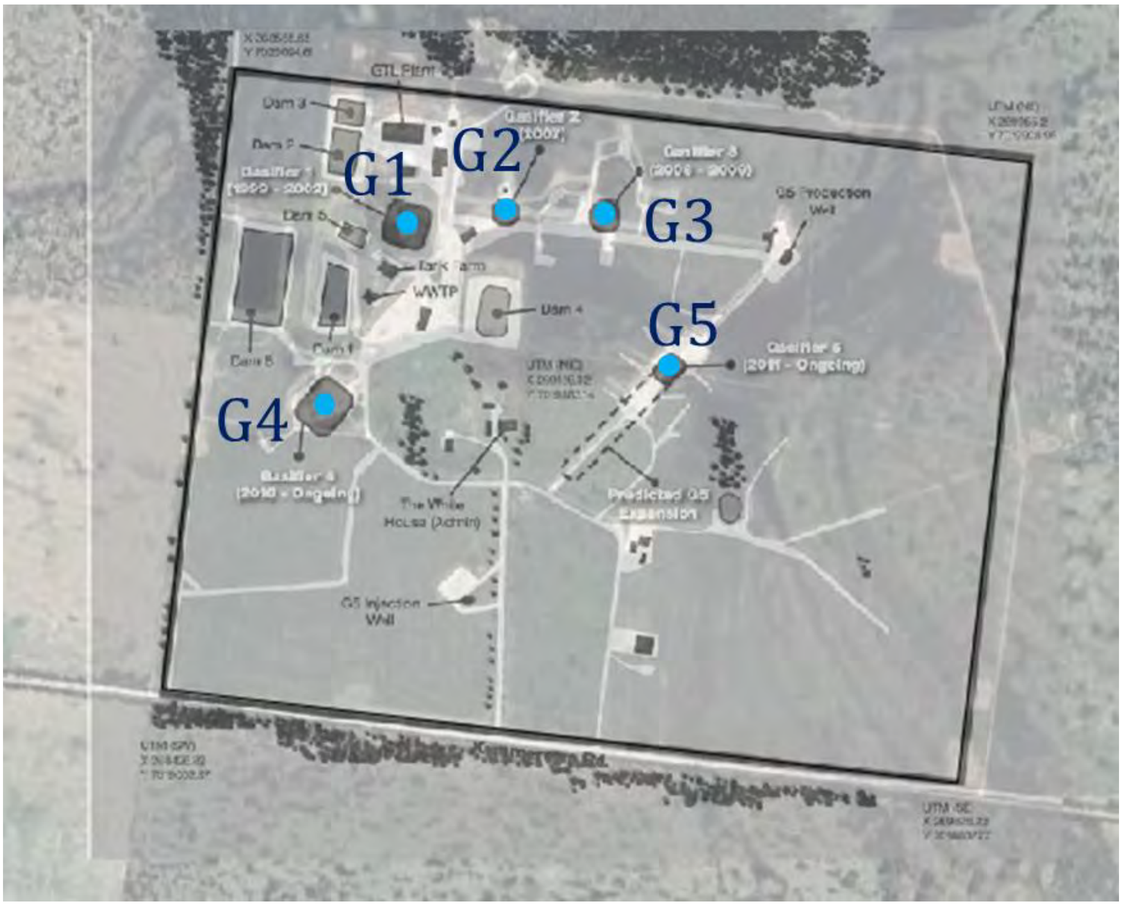


Figure 3.2 Linc Energy UCG gasifier locations

3.1.3 *Arrow Energy geological model outputs*

Additional data were also received from a geological model developed by Arrow Energy and which forms the basis for their model of the coal reservoir within the area. This model includes a detailed representation of the Walloon Coal Measures within PL253 and the surrounding area and models the distribution of coal and interburden facies within the geological model domain. Outputs from this model were used to derive isopachs of the total thickness of coal within each of the coal measures sub-units (i.e. the Kogan, Macalister, Wambo, Argyle, Tangalooma, Taroom and Condamine). Within the former Linc Energy site this data suggests total coal thicknesses within the Macalister sub-unit of around 7 m and is therefore broadly consistent with the results of drilling at the site summarised in Table 3.2 which suggest approximately 9 m to 12 m of coal.

3.2 Model design and initial parameterisation

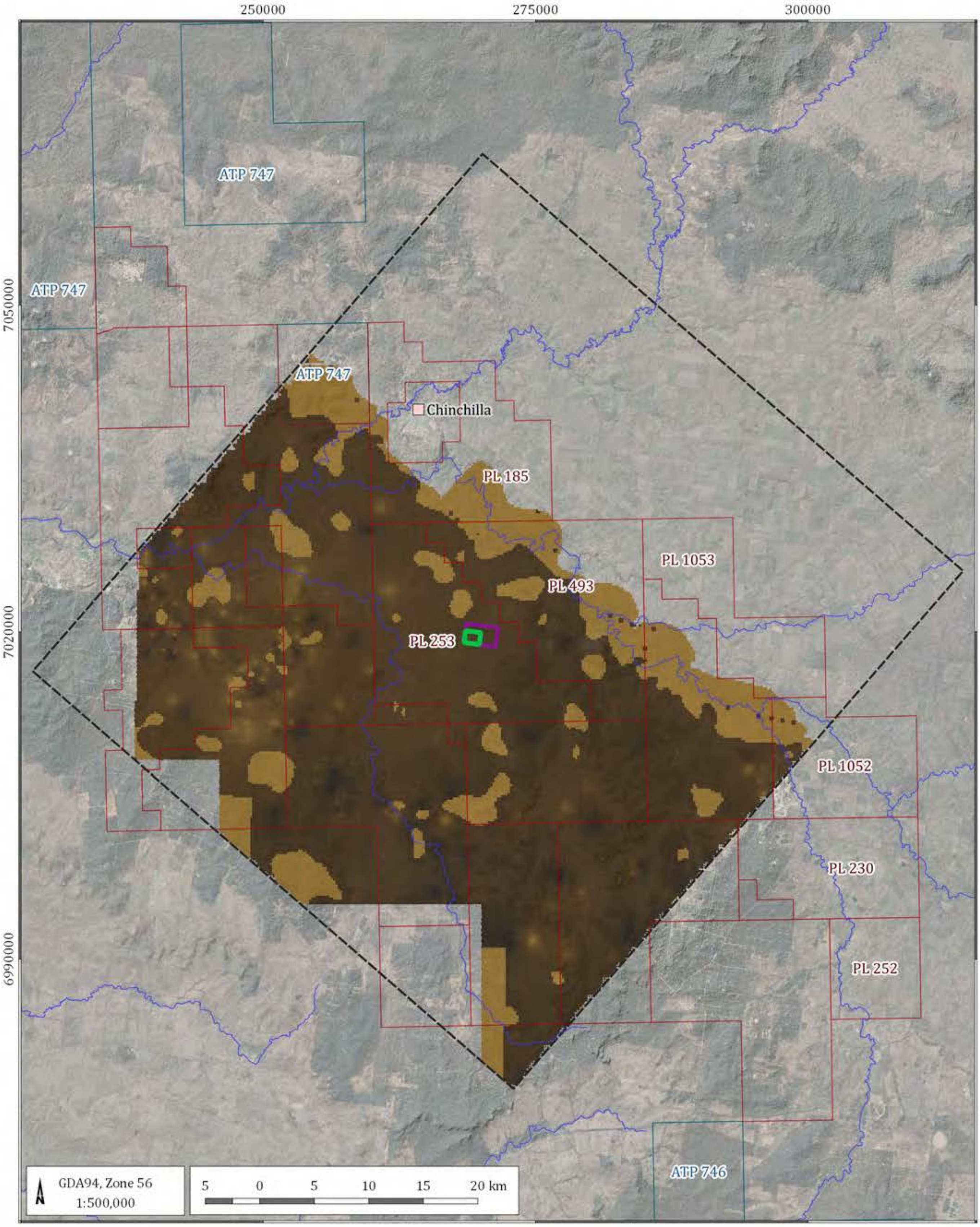
A number of refinements were made to the GHD model (GHD, 2019 see Appendix A) prior to its use for assessing impacts. These refinements are described below in Sections 3.2.1 to 3.2.4 below. In all other respects the model structure and boundary conditions are the same as those reported in Appendix A.

3.2.1 Revisions to model structure and parameterisation

The Walloon Coal Measures at the site is in excess of 300m thick and comprises a highly heterogenous sequence of siltstone, mudstone, sandstone and coal. Coal facies are distributed throughout the majority of the formation typically as relatively thin, discontinuous seams or plies separated by interburden. Coal typically comprises less than 10% of the total thickness of the Walloon Coal Measures and individual coal plies are typically less than 1 m thick and extend from 500 m to 3,000 m (OGIA, 2019a). The OGIA Surat CMA groundwater flow model (OGIA, 2019b) uses six layers of roughly equal thickness to represent the Walloon Coal Measures. Each layer therefore comprises a highly upscaled representation of an extremely heterogenous hydrogeological system. Accordingly whilst the horizontal hydraulic conductivity (Kh)of each of the modelled Walloon Coal Measures layers is several orders of magnitude higher than the vertical hydraulic conductivity (Kv), it is lower than the Kh of individual coal seams since as mentioned above individual coal seams are not present over long distances. Hence the median calibrated Kh for the Upper Walloon Coal Measures layer in the OGIA model, which includes the Macalister coal seams, is $1.2x10^{-4}$ m/d (OGIA, 2019b). However, drill stem tests (DSTs) of individual coal seams suggest a median value of around $4.5x10^{-2}$ m/d (OGIA, 2016a) i.e. around two orders of magnitude higher than the regional Kh calibrated in the OGIA model.

The GHD model (GHD, 2019) uses a similar number of layers to represent the Walloon Coal Measures and also uses initial parameters derived from the OGIA model. Accordingly, in terms of its representation of the Walloon Coal Measures this model is also highly upscaled and adopts initial Kh values which are less than those typical for individual coal seams. However, consistent with the earlier reporting (Perkins et al., 2013), drilling on the former Linc Energy site (Table 3.2) suggests the presence of two relatively thick (3 to 6 m) coal seams (Macalister A and B) close to the top of the Walloon Coal Measures at this location. These seams were the target for UCG operations within the site. The Arrow Energy geology model also shows relatively continuous coal rich units at the top of the Macalister sub-unit across the majority of the Hopelands model domain (Figure 3.3). Accordingly, an initial review of the OGIA and GHD models suggested that these models may underestimate lateral migration of particles from within the site due to the composite upscaled nature of the model layers. To address this the GHD model structure was altered adding a coal layer at the top of each Walloon Coal Measures sub-unit. The thickness of these coal layers were derived based on the total thickness of coal seams modelled within each sub-unit in the Arrow Energy geology model (Section 3.1.3). Similarly, initial Kh values for these layers were based on values extracted from the Arrow Energy geology model which were in turn based on DST tests undertaken targeting individual coal seams. These coal layers have conservatively been assumed to be continuous across all parts of the model domain where the each sub unit is modelled as being present. Modelled depths to the base of the Springbok Sandstone within the former Linc Energy site were also adjusted slightly to ensure consistency with additional geological data from the site (Table 3.2).

It should be stressed that the assumption of continuous coal seams extending throughout the model domain is considered to be highly conservative from a contaminant transport point of view. As mentioned above OGIA (2019a) report that coal plies within the Walloon Coal Measures are typically only laterally continuous over distances of between 500 and 3,000 m. Whilst it is recognised that the Macalister A and B seams in the area are relatively thick (compared to other seams and areas in the Surat Basin) it is considered extremely unlikely that these seams could actually be continuous to the south western boundary of the model around 28 km from the former Linc Energy site. OGIA (2019a) suggest that thicker coal plies may extend for up to 10 km. Furthermore, the lateral continuity of coal seams is also known to be affected by small faults which are particularly prevalent in this part of the Surat Basin. Such faults are also thought to limit hydrogeological continuity in the area by offsetting individual seams and due to the smearing of clay along fault surfaces. Faults affecting the Walloon Coal Measures are thought to be particular prone to clay smearing due to relatively clay content (OGIA, 2019c).



LEGEND

🟥	Populated place
—	Rivers and other watercourses
🟩	MDL309 boundary
🟪	Lot 40 DY 85
🟥	Petroleum Lease (PL) area
☐	Authority to Prospect (ATP) area
▭	Model extent

Proportion of coal

🟫	0
🟫	0.5
⬛	1.0

Hopelands Arrow (G2002)

Distribution of coal at the top of the Macalister sub-unit from Arrow geological model output

AGE

DATE 10/06/2020

FIGURE No: **3.3**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\03.03_G2002_Distribution of coal at the top of the Macalister sub-unit from Arrow Reservoir Model Output.qgs

The revised Phase 1 model structure and initial parameterisation adopted are summarised in Table 3.4 and Table 3.5 below.

As mentioned previously in Section 3.1.1 and discussed further in Section 4.1.3 a number of nested monitoring facilities have been installed within and around the periphery of the former Linc Energy site. These facilities typically comprise monitoring at the base Springbok Sandstone and in the underlying Macalister coal seam. In order to make full use of this data the model layers have been re-configured slightly within the site such that model layer 5 represents the lowermost part of the Springbok Sandstone, rather than the Kogan coal seams and interburden which are not present in this part of the area. Accordingly, the Springbok Sandstone is represented using two layers (model layers 3 and 5) in this part of the model.

Modelled recharge parameterisation was also revised compared to the GHD model to include three zones representing areas where the Condamine Alluvium, Gubberamunda Sandstone and Westbourne Formation are present at outcrop. Recharge rates for each of these three zones were taken from updated modelling completed by OGIA in 2019 (OGIA, 2019b) as follows:

- Condamine alluvium, 3.5 mm per year.
- Gubberamunda Sandstone, 1.0 mm per year.
- Westbourne Formation, 0.2 mm per year.

Table 3.4 Hydraulic conductivity calibration parameter constraints – Phase 1 groundwater flow model

Hydrostratigraphic Unit	Model Layer	K, Initial source	Kh, Range (m/d)	Kv, Initial (m/d)	Kv Range (m/d)	Initial Anisotropy (Kh:Kv)	Anisotropy Range (Kh:Kz)
Condamine Alluvium/ Gubberamunda Sandstone	1	OGIA	0.3 - 30	0.07	$3x10^{-4}$ – 3	100	10-1000
Westbourne Formation	2	OGIA	0.1 – 10	$1x10^{-2}$	$1x10^{-4}$ – 1	100	10-1000
Springbok Sandstone	3	OGIA	$1x10^{-3}$ – $1x10^{-1}$	$1x10^{-5}$	$1x10^{-7}$ – $1x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Kogan Coal)	4	Macalister DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Kogan Interburden)	5	OGIA	$5x10^{-3}$ – $5x10^{-1}$	$5x10^{-4}$	$5x10^{-6}$ – $5x10^{-2}$	100	10-1000
Walloon Coal Measures (Macalister Coal)	6	Macalister DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Macalister Interburden)	7	OGIA	$1x10^{-4}$ – $5x10^{-1}$	$1x10^{-5}$	$1x10^{-7}$ – $5x10^{-2}$	100	10–1000
Walloon Coal Measures (Wambo Coal)	8	Wambo DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Wambo Interburden)	9	OGIA	$5x10^{-4}$ – $5x10^{-2}$	$5x10^{-6}$	$5x10^{-8}$ – $5x10^{-4}$	1,000	100-10,000
Walloon Coal Measures (Argyle Coal)	10	Argyle DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Argyle Interburden)	11	OGIA	$1x\ 10^{-5}$ – $5x10^{-3}$	$1x10^{-6}$	$1x\ 10^{-8}$ – $5x10^{-4}$	100	10–1000
Walloon Coal Measures (Tangalooma Sandstone)	12	OGIA	$1x\ 10^{-7}$ – $1x10^{-1}$	Variable (Kh/100)	$1x\ 10^{-10}$ – $1x10^{-2}$	100	10-1000
Walloon Coal Measures (Upper Taroom Coal)	13	Argyle DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Upper Taroom Interburden)	14	OGIA	$1x10^{-3}$ – 1	$1x10^{-3}$	$1x10^{-6}$ – 0.1	100	10-1000
Walloon Coal Measures (Condamine Coal)	15	Argyle DST array	$1x10^{-3}$ – $5x10^{-1}$	$5x10^{-5}$	$1x10^{-7}$ – $5x10^{-3}$	1,000	100-10,000
Walloon Coal Measures (Condamine Interburden)	16	OGIA	$1x10^{-3}$ – $1x10^{-1}$	$1x10^{-5}$	$1x10^{-7}$ – $1x10^{-3}$	1,000	100-10,000
Eurombah Formation	17	OGIA	$1x\ 10^{-7}$ – $1x10^{-1}$	Variable (Kh/100)	$1x\ 10^{-10}$ – $1x10^{-2}$	100	10-1000
Hutton Sandstone	18	OGIA	$1x10^{-3}$ – $1x10^{-1}$	$1x10^{-5}$	$1x10^{-7}$ – $1x10^{-3}$	1,000	100-10,000

Table 3.5 Storage parameter calibration constraints – Phase 1 groundwater flow model

Hydrostratigraphic Unit	Model Layer	Sy, Initial	Sy, Range	Ss, Initial (m^{-1})	Ss Range (m^{-1})
Condamine Alluvium/Gubberamunda Sandstone	1	0.02	0.002 – 0.15	1 $x10^{-5}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Westbourne Formation	2	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Springbok Sandstone	3	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Kogan Coal)	4	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Kogan Interburden)	5	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Macalister Coal)	6	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Macalister Interburden)	7	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Wambo Coal)	8	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Wambo Interburden)	9	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Argyle Coal)	10	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Argyle Interburden)	11	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Tangalooma Sandstone)	12	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Upper Taroom Coal)	13	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Upper Taroom Interburden)	14	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Condamine Coal)	15	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Walloon Coal Measures (Condamine Interburden)	16	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Eurombah Formation	17	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$
Hutton Sandstone	18	0.01	0.001 – 0.1	1 $x10^{-6}$	2.3 $x10^{-7}$ – 2.0 $x10^{-5}$

3.2.2 *Linc Energy gasifier drain boundary conditions*

Neither the GHD Hopelands model (GHD, 2019) or the OGIA Surat CMA model (OGIA, 2016) include any specific representation of de-pressurisation associated with operation of gasifiers on the former Linc Energy site in part since information about historic activities at the site are limited. However, additional head data recently acquired for the site (Section 4.1.3) suggests that current pressures at the site remain well below likely pre-development levels. Accordingly representation of the five gasifiers was added to the GHD model for the current study based on mapping and other information presented in Perkins et al (2013, Section 3.1.1).

In terms of their hydrogeological impacts the development and operation of UCG gasifiers are considered to be analogous to longwall coal mining. Whilst the scale and mechanism of removal are somewhat different both operations result in removal of the target coal seam and any associated water leaving behind a void. In the case of longwall mining the coal (and water) is removed mechanically whilst the coal in the UCG case is effectively consumed in a combustion process. Accordingly, each gasifier at the site were simulated using a MODFLOW drain based approach developed for assessing the impacts of longwall mining activities and widely applied by AGE and other practitioners in this area. Key elements of this approach include the use of the MODFLOW:

- Drain (DRN) package to simulate dewatering of the coal seam to the base of each gasifier during operation; and
- Time varying materials (TVM) package to simulate changes in aquifer material properties and which affect the recovery of pressures post closure.

Drain cells used to simulate each gasifier were assigned a conductance of 100 m^2/day and set at the base of the Macalister coal seam (model layer 6). Upon closure, horizontal and vertical hydraulic conductivity rates and storage were increased to represent the resulting void, which was assumed to be limited to the modelled thickness of the Macalister coal seam (model layer 6). Hydraulic parameters assigned to the void and surrounding strata using the Time Varying Materials package in MODFLOW-USG are summarised below (Table 3.6). The vertical hydraulic conductivity (Kv) of layer 5 immediately overlying each gasifier was allowed to increase from background during the calibration, reflecting the fact that material immediately overlying the gasifier is likely to have been subject to fracturing during operation and/or post closure as material collapses into the gasifier. The Kv value for model layer 5 shown in Table 3.6 therefore represents a calibrated value which is substantially higher than the pre-development value. Conversely parameters for the void itself in layer 6 are assumed based on previous experience modelling longwall mining voids.

Table 3.6 Linc Energy gasifier void properties

Unit	Kh (m/day)	Kv (m/day)	Sy	Ss (m^{-1})
Layer 5 (calibrated)	-	0.02	-	-
LINC Gasifier void (layer 6)	100	100	1	5 x 10^{-6}

3.2.3 *Non-Arrow CSG well boundary conditions*

Boundary conditions relating to existing and proposed non-Arrow CSG wells within the model domain were re-extracted from the 2016 OGIA model (OGIA, 2016a) and distributed evenly across the Walloon Coal Measures model layers present at each location. To account for different cell sizes used by the OGIA and the Phase 1 model extraction volumes were also weighted according to the relative area of the cells in the two models.

3.2.4 Representation of Arrow CSG wells

Extraction from existing and proposed Arrow CSG wells were apportioned to multiple Walloon Coal Measures layers using a transmissivity weighting approach, such that the volume taken is proportional to the relative hydraulic conductivity and thickness of the model layers screened as shown in Figure 3.4. The flow rate in each layer along the well was calculated using the following equation:

$$Q_i = \frac{T_i Q}{\sum_{i=1}^{N} T_i} \qquad (1)$$

where Q is the well flow rate, T is the layer transmissivity, i index refers to layer number, and N is the number of layers.

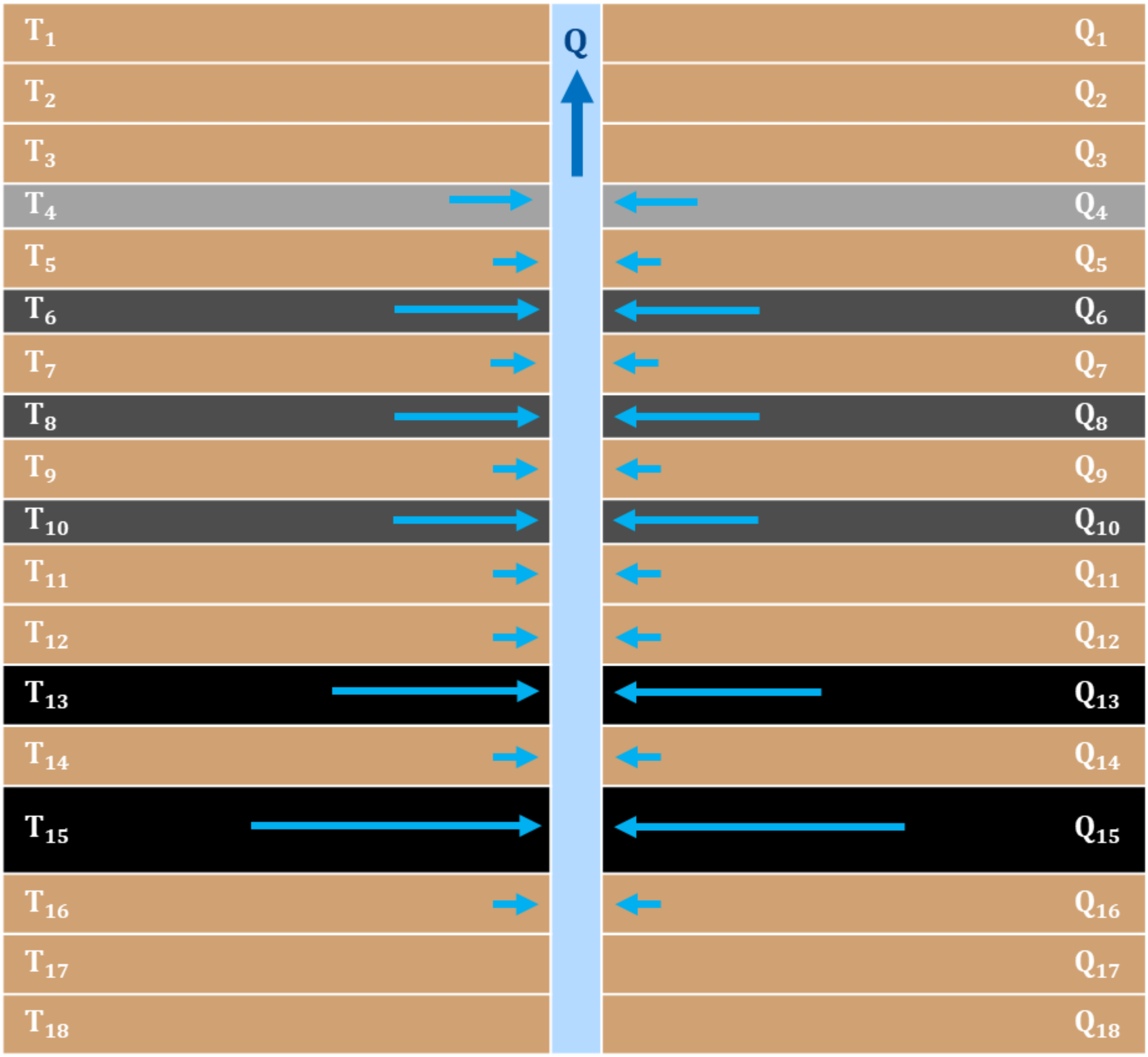
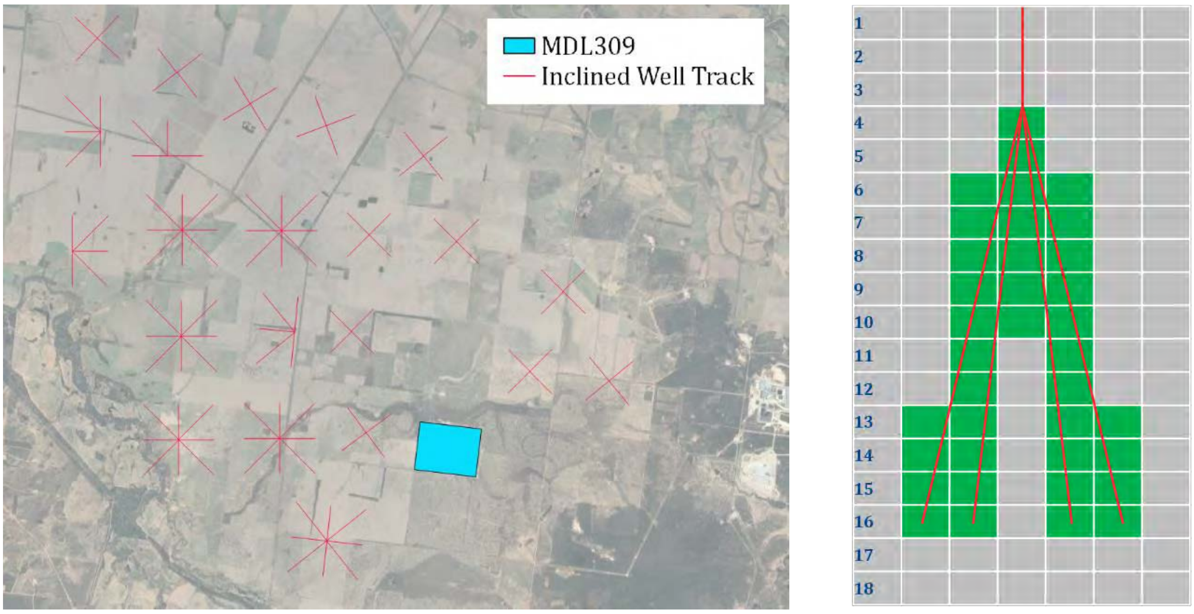


Figure 3.4 Transmissivity-based weighting of well flow rate per layer

Additional functionality was also developed to allow simulation of inclined wells (i.e. multiple non-vertical wells drilled from single drilling pads to minimise land disturbance). As shown in Figure 3.5 information on the proposed track of each well was intersected with the model structure to identify which model cells are screened in each well at different depths within the Walloon Coal Measures.



a) Inclined well tracks – plan view

b) Inclined well tracks and model layers – cross section

c) Inclined well model cells

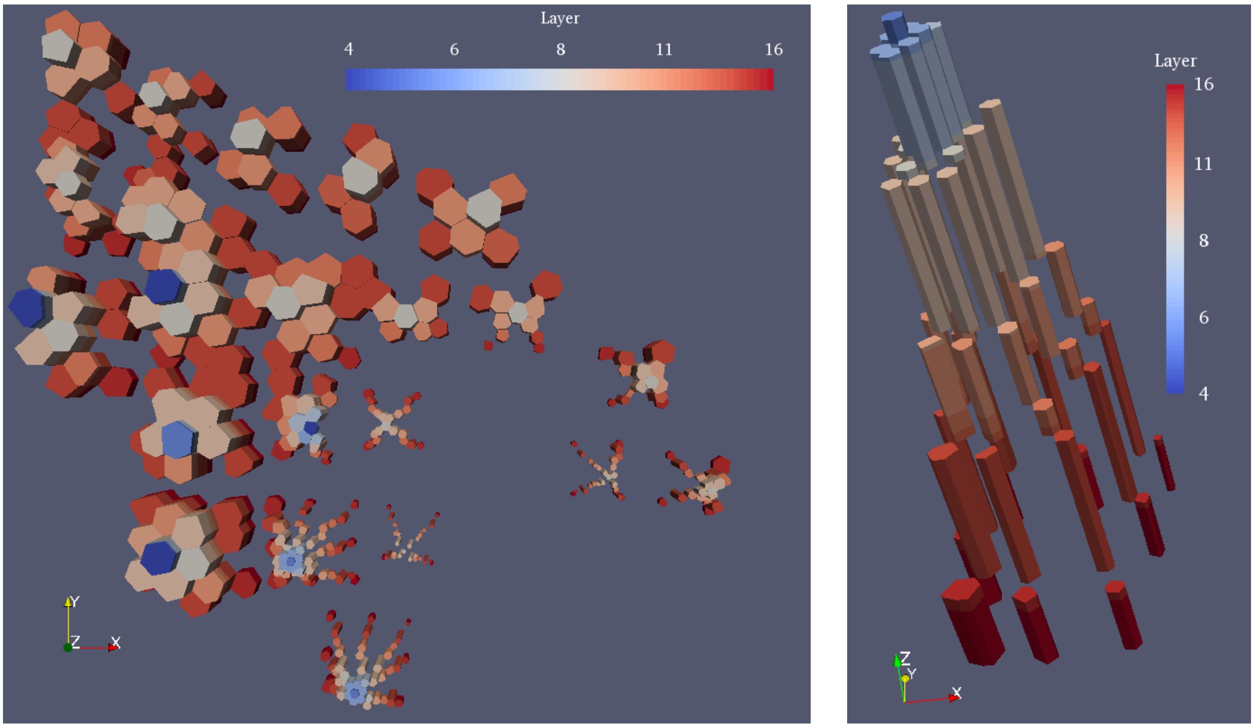


Figure 3.5 Simulation of inclined CSG Wells

4 Phase 1 groundwater flow model calibration

4.1 Calibration data preparation and review

Preparation of groundwater level data used for calibration of the Phase 1 groundwater flow model is described below.

4.1.1 Hopelands pilot wells

Calibration data within the model domain includes groundwater level data from six authorised pilot CSG wells (HL005, HL005T, HL006, HL007, HL008 and HL009), located on PL253 located around 8 km south west of the former Linc Energy site. Over four years of data are available for each well and were previously used without correction to calibrate the GHD model. For the model re-calibration, however, these data were corrected prior to use through application of the Theim equation. This correction was required since:

- intermittent extraction was occurring from each well during the monitoring period; and
- the model cells in which each well sits are substantially larger than the diameter of each well.

Accordingly, the observed head in each well during pumping will tend to be much lower than that calculated using a numerical model unless the diameter of the model cell and well are the same. Fortunately, as outlined in Anderson & Woessner (1991) the Theim equation provides a means by which observed heads in a pumping well can be corrected to account for the difference between the effective radius of the well and model cell. Uncorrected input heads and Theim corrected heads used for calibration for each pilot well are shown in Figure 4.1. As shown a correction is only applied during periods when each well is operating and there is likely to be a significant head gradient towards the well. During periods of heavy pumping adjusted heads are in some cases more than 200 m higher than observed, illustrating the significance of these corrections.

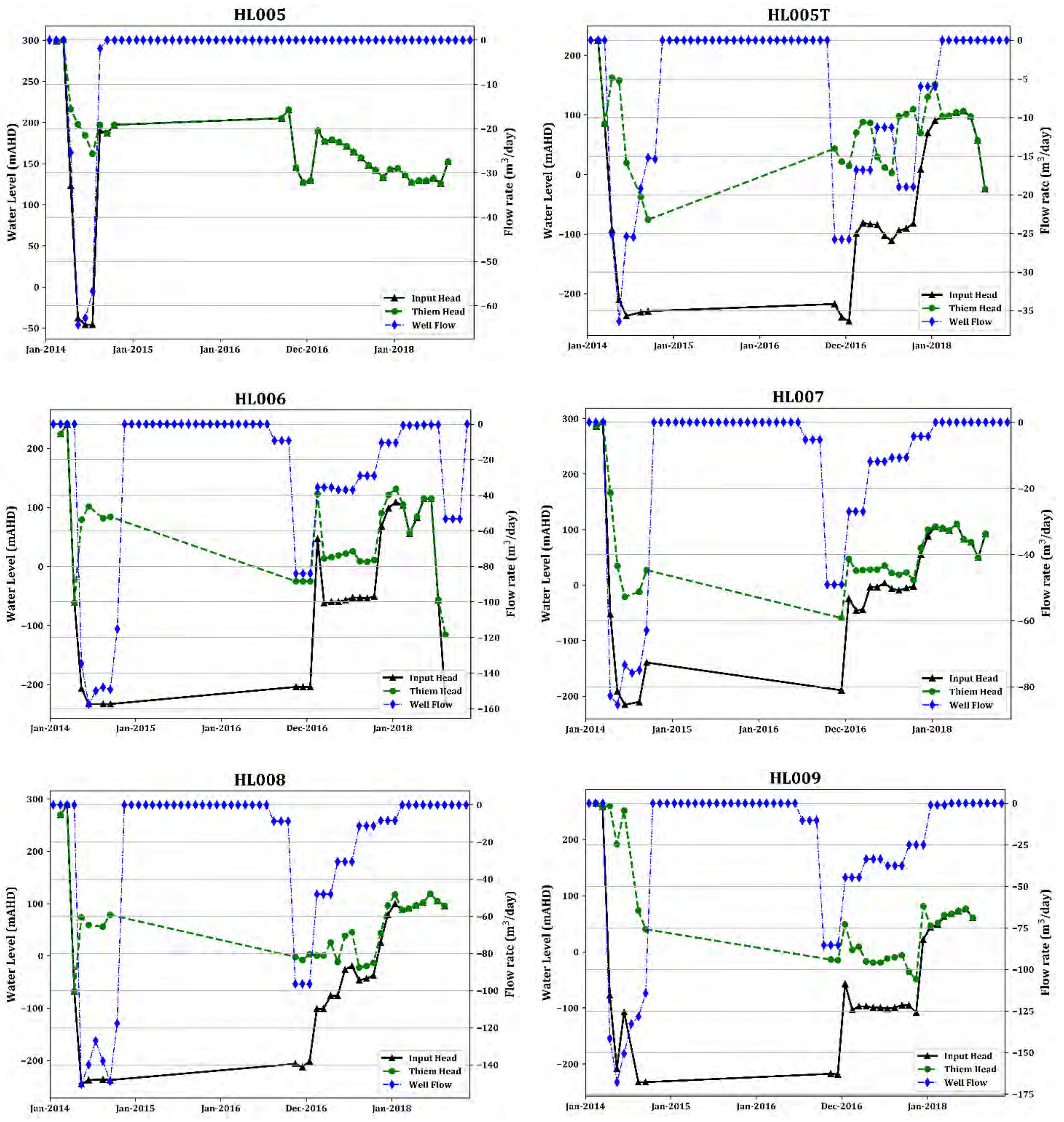


Figure 4.1 Hopelands pilot wells, head corrections

4.1.2 Hopelands 17 head data

Calibration data are also available for a multi-level vibrating wire piezometer nest installed in a re-purposed CSG exploration hole (Hopelands 17) around 50m north east of the HL008 pilot well discussed above. This facility includes monitoring of groundwater levels in the Springbok Sandstone (161 mbgl) and at three levels (269, 380 and 441 mbgl) in the underlying Walloon Coal Measures. Time series groundwater levels for this location (Figure 4.2) were previously used by GHD to calibrate the model and have also been used for the current re-calibration. However, a second head difference data set has also now been generated by calculating the difference in observed heads in each pair of monitoring points (Figure 4.3). Incorporation of this second calibration data set minimises the possibility that absolute heads could be matched in the model whilst at the same time modelling a head gradient which is at odds with the observations.

This problem is particularly acute in inland areas such as the Surat Basin where observed absolute heads are typically substantially larger than head differences between adjacent units. As shown in Figure 4.3 head difference data for the Hopelands 17 monitoring facility suggests gradually increasing downward gradients with depth within the Walloon Coal Measures.

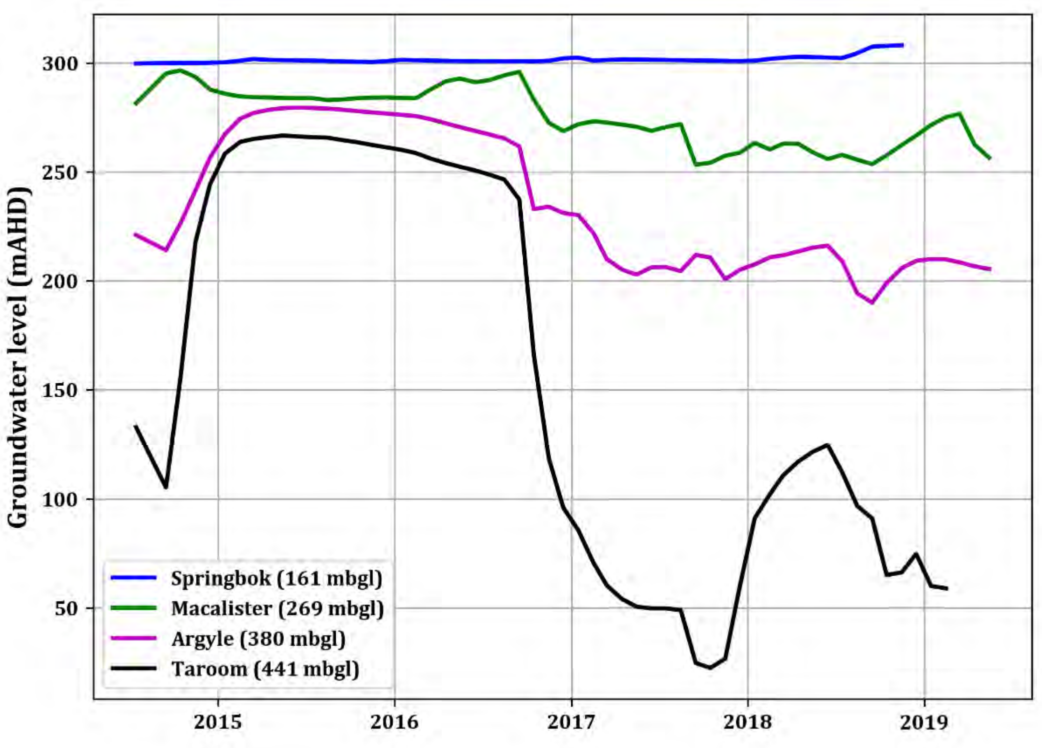


Figure 4.2 Observed groundwater levels Hopeland 17 nested monitoring facility, 50 m north east of pilot well HL008

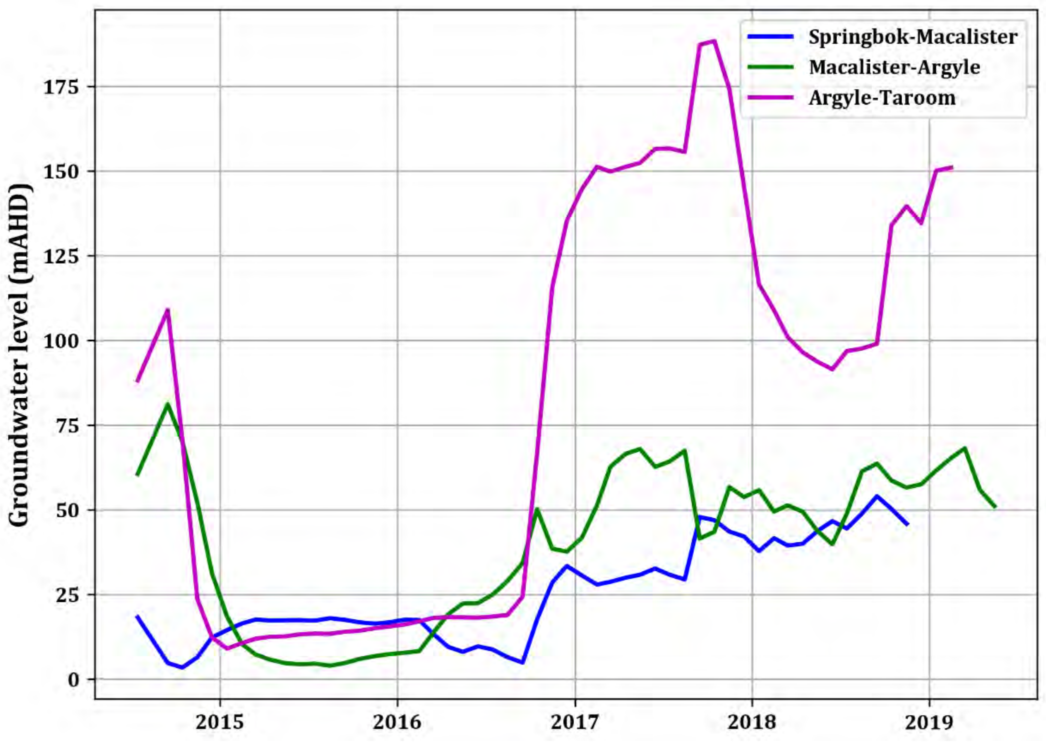


Figure 4.3 Observed head differences Hopelands 17 nested monitoring facility

Hopelands 17 (or HL17) is approximately 64m away from pilot well HL009 and accordingly provides good information on the hydraulic and storage properties of the coal seam it screens. Figure 4.4 provides a fence diagram showing the construction details and relative coal measure elevations at these two bores.

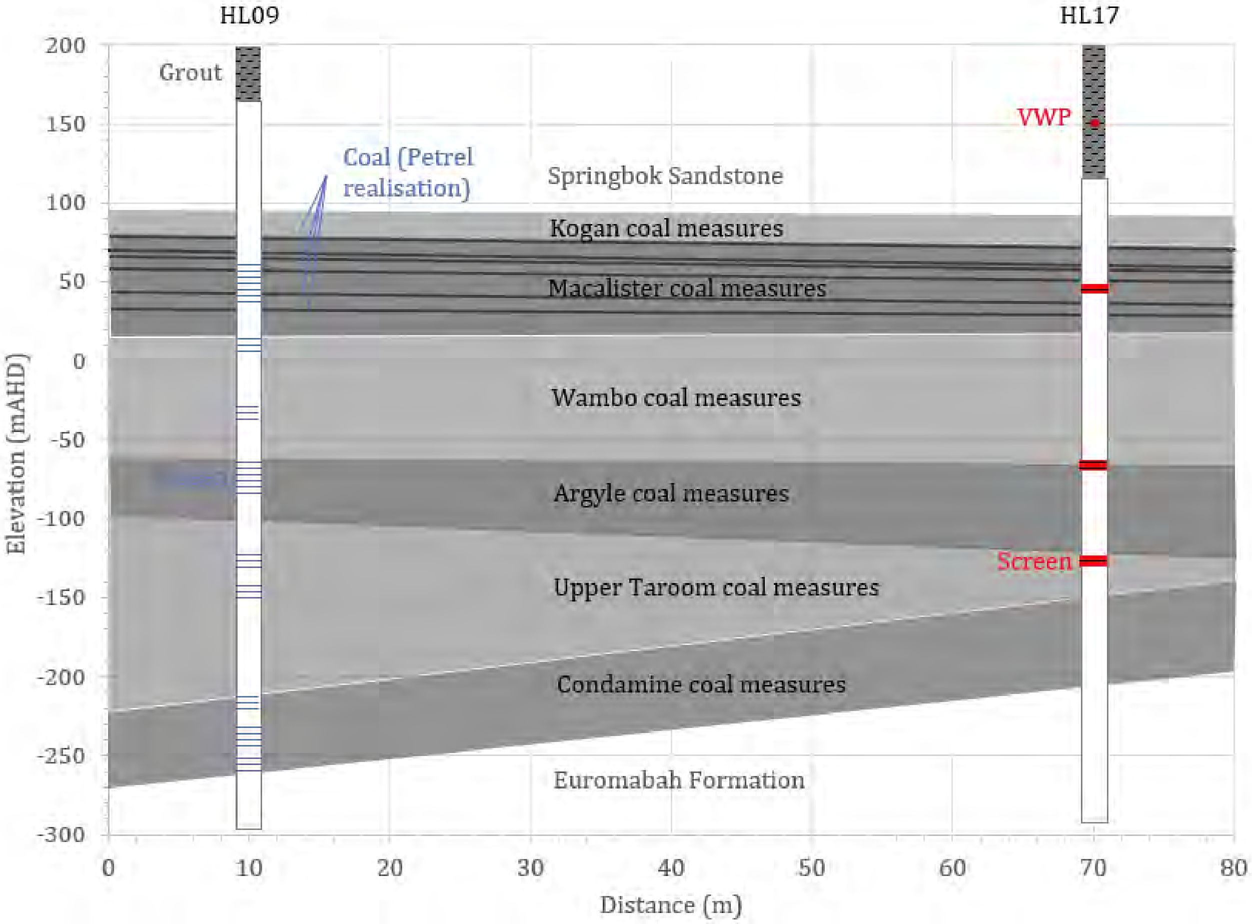


Figure 4.4 Fence diagram of HL09 to HL17 based on well log and Petrel realisation data

4.1.3 Head data for the former Linc Energy site (Lot 40 DY 85)

A small amount of head data for the former Linc Energy site have also has been recently provided to Arrow Energy by the Department of Environment and Science (DES) and were used by GHD for calibration of the Hopelands model. This data suggests current groundwater levels of as low as 199 mAHD towards the top of the Walloon Coal Measures and as low as 209 mAHD in the overlying Springbok Sandstone. However, monitoring of landholder bores in the area and of the Springbok Sandstone at the Hopelands 17 monitoring bore (Figure 4.2) suggests pre-development background pressures in the area of around 300 mAHD. Current pressures at the former Linc Energy site are therefore thought to be around 100 m below pre-development pressures. It is considered highly unlikely that the low observed pressures at the former Linc Energy site are related to CSG extraction since:

- the nearest currently operating CSG well is more than 7.3 km from the Linc site;
- as shown in Figure 4.2 drawdown in the Macalister sub-unit close to the top of the Walloon Coal Measures at around 50 m from a CSG pilot well is only around 50 m; and
- also as shown in Figure 4.2 groundwater levels in the Macalister sub-unit around 10 km south west of the Linc Site and much closer to CSG wells which are currently operating are currently around 250 mAHD, some 50 m higher than at the Linc Site suggesting a more local sink.

More likely the low observed pressures reflect slow recovery of pressures in the area following the cessation of UCG operations on the site in October 2013.

Initial groundwater level measurements obtained for the HL monitoring locations recently installed by Arrow Energy around the periphery of Lot 40 DY85 tend to confirm the above conclusions. Data for these bores indicate current groundwater levels for the Macalister Coal Seam in the range 231.8 mAHD at HL26 to the west of the site and 257.4 mAHD at HL23 to the south. This new data provides further confirmation that groundwater flow remains towards the site and that the low observed pressures at the site are not related to regional drawdown caused by ongoing CSG extraction to the west.

4.2 Calibration approach

A review of the calibrated parameter fields generated by GHD indicated substantial variations in hydraulic parameters over short distances suggesting the use of closely or irregularly spaced pilot points. Accordingly, re-calibration of the model was undertaken using PEST_HP (Watermark Numerical Computing, 2020), regularly spaced pilot points and a regularisation approach designed to generate relatively smooth output parameter fields.

Calibration was achieved by varying primarily modelled:

- Kh and Kv in each layer using pilot points, these parameters therefore vary spatially within each layer;
- Ss and Sy using single values for most layers and pilot points within layers and areas of primary interest (i.e. the former Linc Energy site and layers 5 and 6 which represent the Springbok Sandstone and Macalister coal seam in this part of the model); and
- Kv in layer 5 immediately over each gasifier using a multiplier to allow for potential fracturing of the overlying material (Section 3.2.2).

4.3 Calibration results

4.3.1 Head calibration

Comparisons of modelled and observed groundwater levels are shown in Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8. As shown in Figure 4.5 overall a scaled root mean square error of 9.5% has been achieved, only marginally within the 10% target typically adopted for transient calibrations (Barnett et al, 2012). However, a relatively large proportion of this misfit is attributed to relatively large differences between modelled and observed heads at the Hopelands pilot wells. As described in Section 4.1.1 observed heads in these bores have been estimated through application of the Theim equation and may therefore be subject to significant measurement type errors. Excluding this data from the calibration statistics and scatter plot (Figure 4.6) results in a reduced overall SRMS of 6.4% and confirms that the model is able to achieve a relatively good fit to the remainder of the calibration data set which is likely to be less prone to measurement error. As shown in , Figure 4.7 observed groundwater levels at each of the horizons monitored in the key Hopelands 17 nested monitoring facility are also well matched.

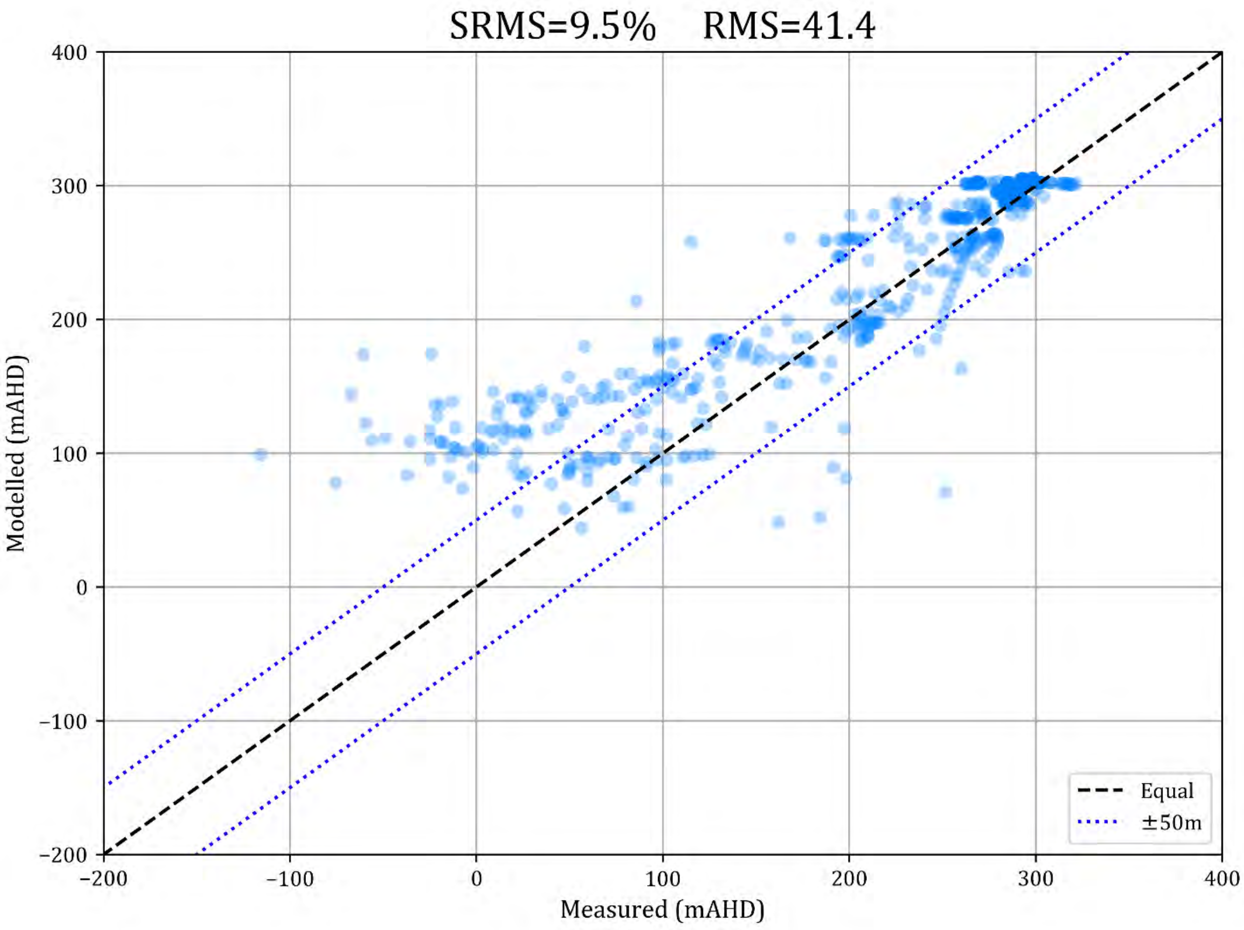


Figure 4.5 **Modelled versus observed head calibration scatter plot**

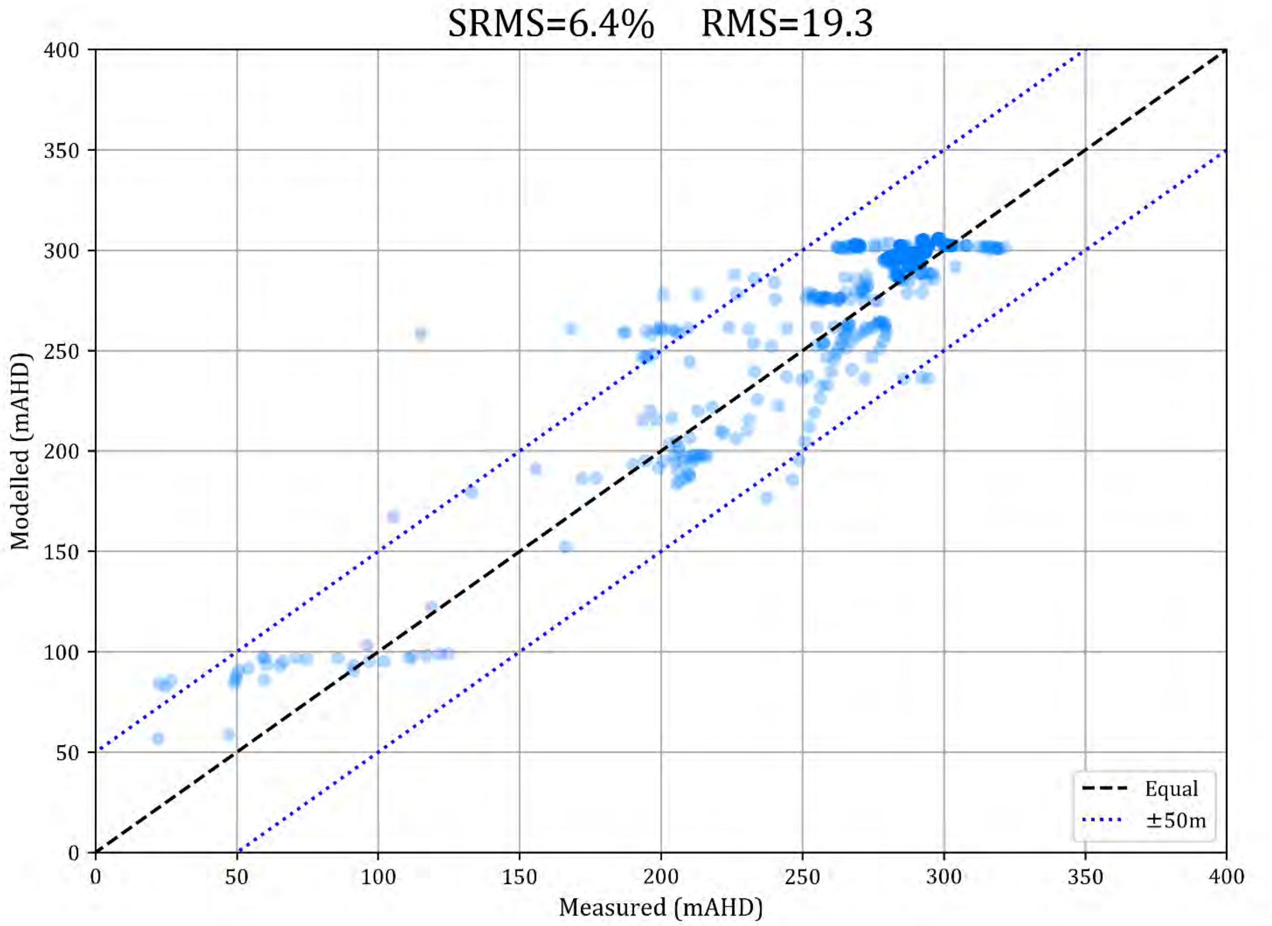


Figure 4.6 Modelled versus observed head calibration scatter plot, excluding estimated head data for pilot CSG production bores

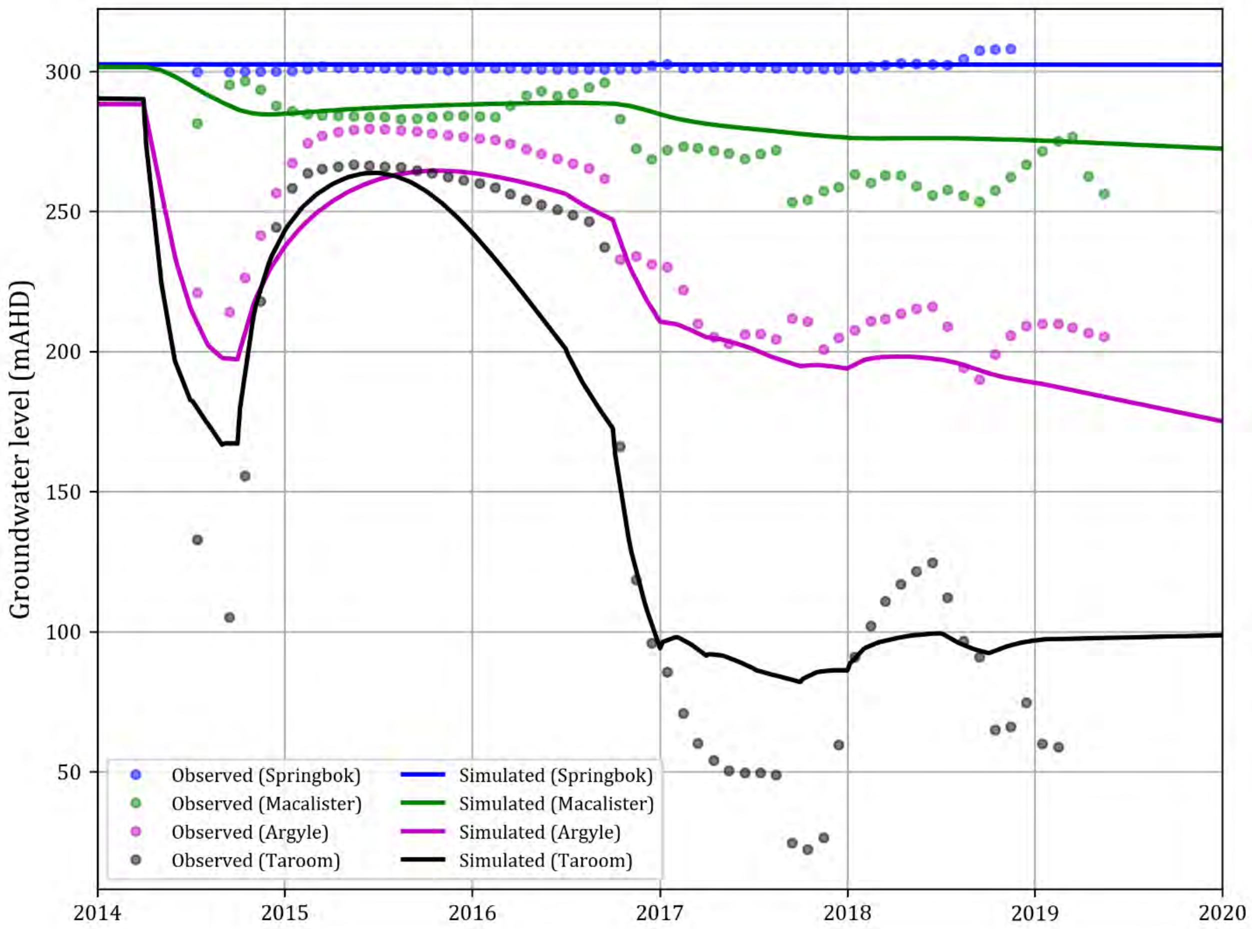


Figure 4.7 **Modelled versus observed groundwater level time series, Hopelands 17**

Comparisons of observed and modelled heads at the HSM series bores installed within the former Linc Energy site are shown in Figure 4.8. These plots show simulated groundwater levels in the Springbok Sandstone (model layers 3 and 5 in this part of the model) and the Macalister A and B seams (model layer 6). As outlined previously in Section 3.2.2 Linc gasifier drain cells are sequentially removed from layer 6 according to dates outlined in Table 3.3, meaning all stresses from the Linc area are removed by November 2013. The minimum elevation of the Linc gasifiers (Gasifier 5) is approximately 190 mAHD. Accordingly, the observed data for the site which indicate current levels of below 200 mAHD in HSMB1, HSMB2, HSMB3-2 and HSMB4 in the Macalister coal seam suggests very slow rates of groundwater level recovery at this location. However, as shown in Figure 4.8 data for the two other monitoring points within Lot 40 DY85 suggests groundwater levels of over 260 mAHD at HSMB3-1 and HSMB5 also within the Macalister coal seam. The model is unable to simulate this degree of spatial variability in part since other data for the site suggests the Macalister coal seam is likely to be continuous and highly permeable. Similar variability in groundwater levels within the site can also be seen in the observed data for the Springbok Sandstone. Accordingly, the modelled fit within the former Linc Energy site is considered to be close to the best that can be achieved without introducing say unmapped faults or other barriers to flow between the observation points.

Hydrographs showing observed and modelled data for all monitoring points used in the flow model calibration are provided in Appendix B.

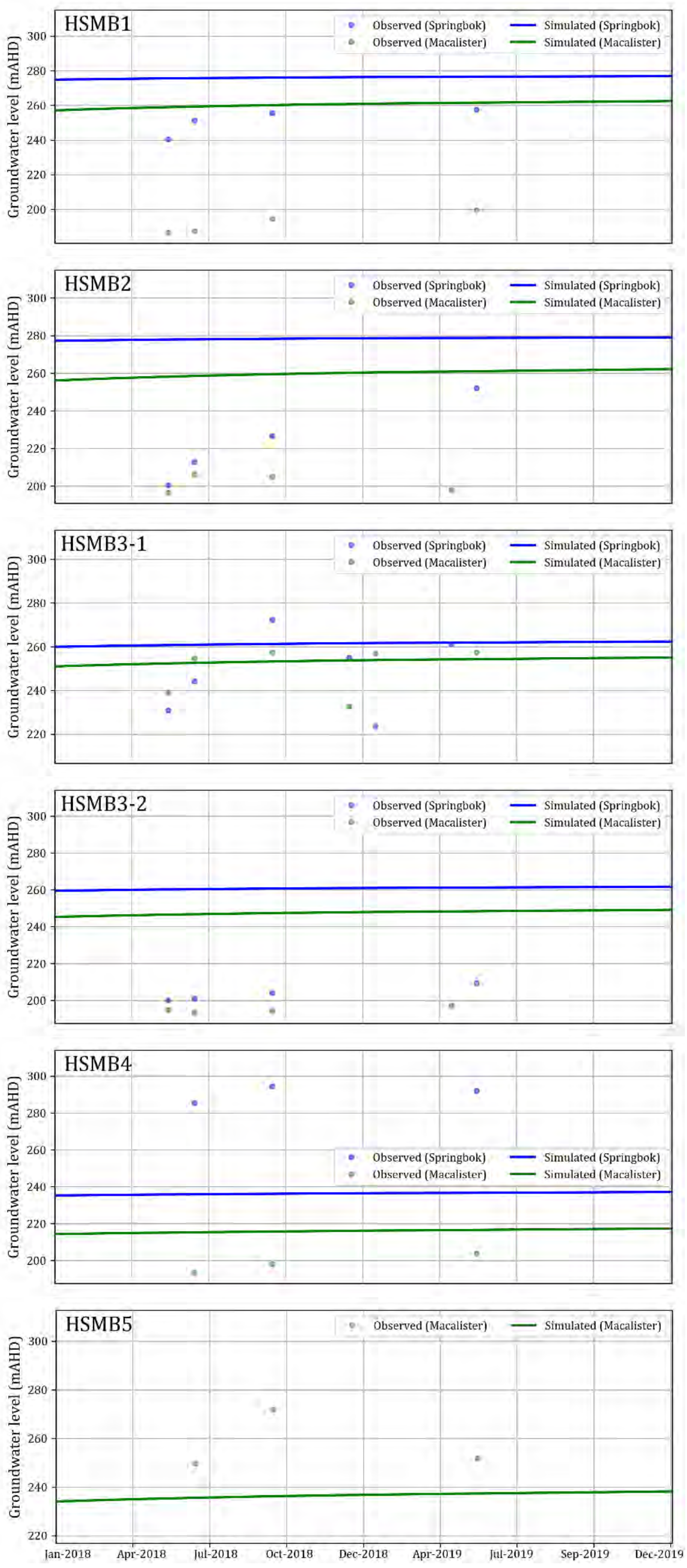
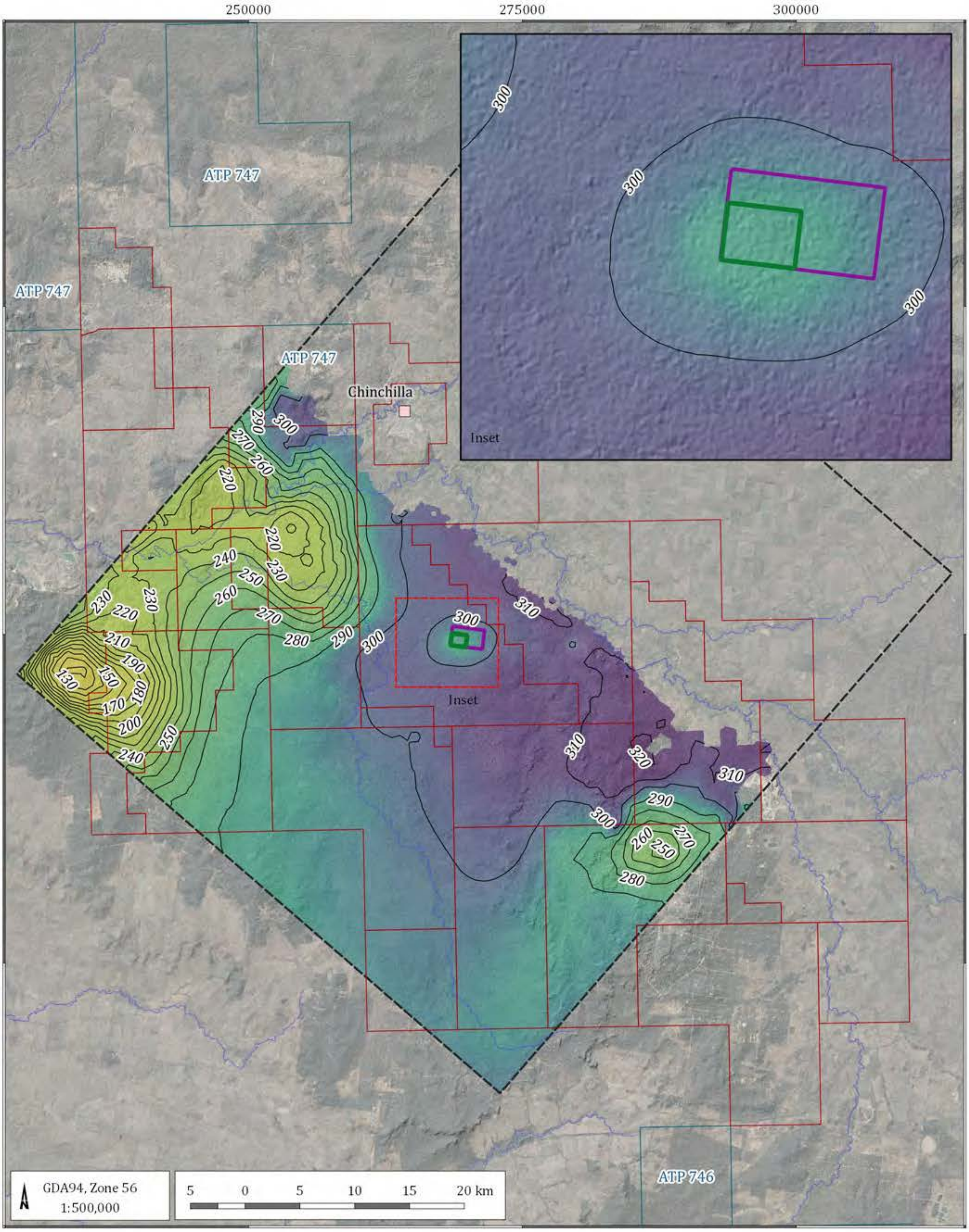


Figure 4.8 Modelled versus observed groundwater level time series, Lot 40 DY85

Modelled heads in the Springbok Sandstone at the end of the Phase 1 model calibration period in December 2019 are shown in Figure 4.9 and Figure 4.10. The inset maps on these diagrams show modelled heads in and around the former Linc Energy site confirming heads of below 250 mAHD in the Macalister coal seam (model layer 6) within the site.

A summary of calibrated model parameters are presented in Table 4.1 and Table 4.2.



LEGEND

- 🟥 Populated place
- Rivers and other watercourses
- Groundwater elevation contour (mAHD)
- 🟩 MDL309 boundary
- 🟪 Lot 40 DY 85
- 🟥 Petroleum Lease (PL) area
- 🟦 Authority to Prospect (ATP) area
- Model extent
- Inset

Groundwater elevation (mAHD)

- 🟨 100
- 🟩 200
- 🟩 250
- 🟦 300
- 🟪 350

Hopelands Arrow (G2002)

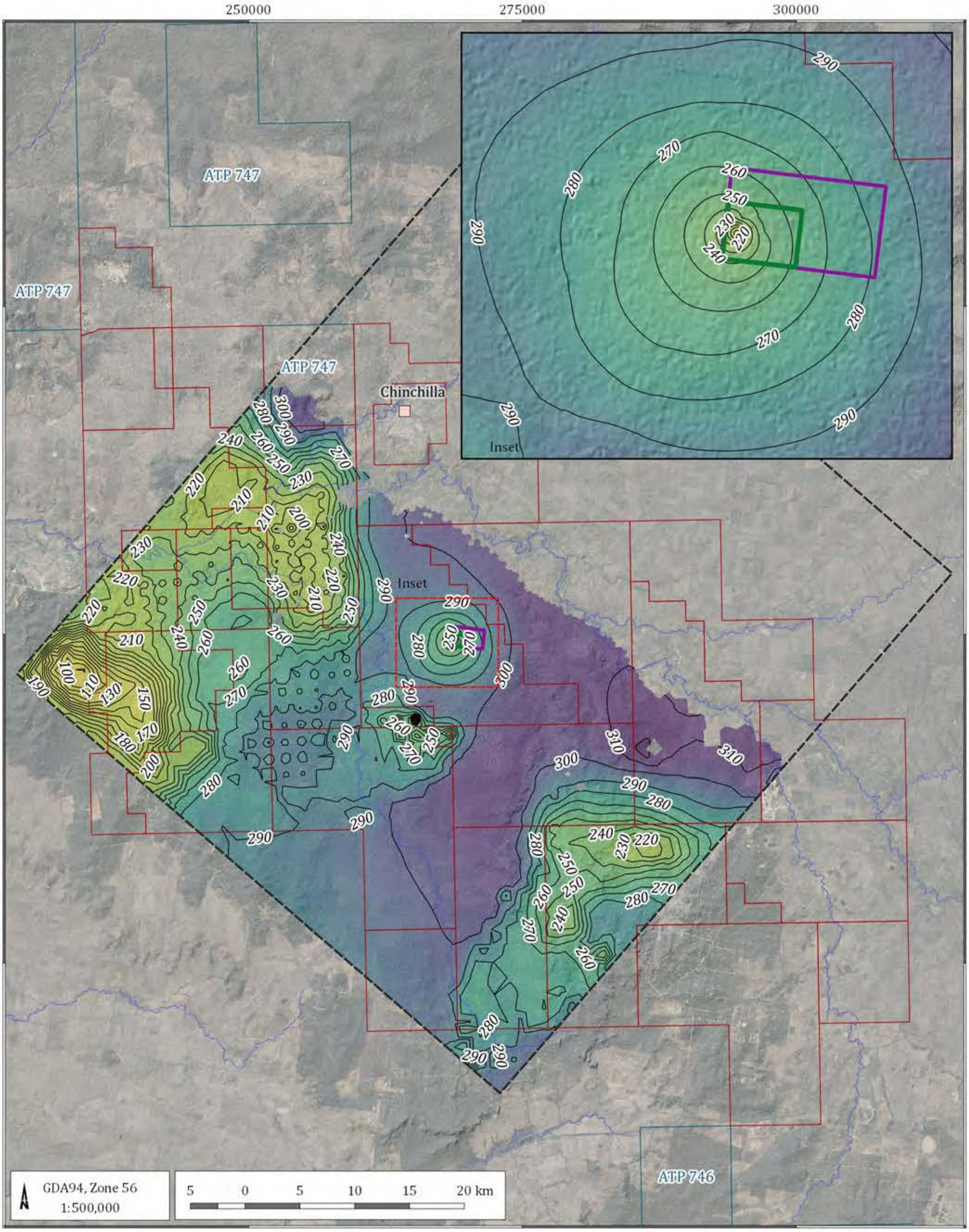
Modelled groundwater levels, December 2019, Springbok Sandstone (model layer 3)

AGE

DATE
10/06/2020

FIGURE No:
4.9

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\04.09_G2002_Modelled groundwater levels, December 2019 , Springbok Sandstone (model layer 3).qgs



LEGEND

- ▫ Populated place
- — Rivers and other watercourses
- — Groundwater elevation contour (mAHD)
- ▭ MDL309 boundary
- ▭ Lot 40 DY 85
- ▭ Petroleum Lease (PL) area
- ▭ Authority to Prospect (ATP) area
- ⌐¬ Model extent
- ⌐¬ Inset

Groundwater elevation (mAHD)

- 🟨 100
- 🟩 200
- 🟩 250
- 🟦 300
- 🟪 350

Hopelands Arrow (G2002)

Modelled groundwater levels, December 2019, Macalister coal seam (model layer 6)

AGE

DATE 10/06/2020

FIGURE No: **4.10**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\04.10_G2002_Modelled groundwater levels, December 2019, Macalister coal seam (model layer 6).qgs

Table 4.1 Calibrated hydraulic conductivity parameter summary

Hydrostratigraphic Unit	Model Layer	Median Kh, Calibrated (m/d)	Kh, Range (m/d)	Median Kv, Calibrated (m/d)	Kv Range (m/d)	Median Anisotropy (Kh:Kv)	Anisotropy Range (Kh:Kv)
Condamine Alluvium/Gubberamunda Sandstone	1	2.7	2x10^{-4} – 50	1	7x10^{-8} – 23	10	2-20,000
Westbourne Formation	2	1x10^{-4}	4x10^{-5} – 4x10^{-3}	2x10^{-7}	6x10^{-9} – 1x10^{-5}	1000	50-550,000
Springbok Sandstone	3	0.2	2x10^{-4} – 1.4	1x10^{-5}	2x10^{-8} – 6x10^{-4}	20,000	20-150,000
Walloon Coal Measures (Kogan Coal)	4	0.27	6x10^{-5} – 0.3	0.1	1x10^{-7} – 0.1	5	1-18,000
Walloon Coal Measures (Kogan Interburden)	5	0.11	1x10^{-4} – 0.1	2x10^{-8}	1x10^{-9} – 2x10^{-5}	450,000	1,000-2,000,000
Walloon Coal Measures (Macalister Coal)	6	0.02	1x10^{-5} – 0.09	0.02	1x10^{-5} – 0.09	1	1-1
Walloon Coal Measures (Macalister Interburden)	7	0.001	1x10^{-5} – 0.1	1x10^{-8}	4x10^{-9} – 2x10^{-5}	100,000	2,500–5,000
Walloon Coal Measures (Wambo Coal)	8	0.3	0.001 – 0.3	0.1	0.001 – 0.1	3	1-3
Walloon Coal Measures (Wambo Interburden)	9	0.002	1x10^{-4} – 0.05	5x10^{-9}	3x10^{-9} – 7x10^{-6}	500,000	7,000-33,000
Walloon Coal Measures (Argyle Coal)	10	0.3	1x10^{-4} – 0.3	0.1	1x10^{-4} – 0.1	3	1-3
Walloon Coal Measures (Argyle Interburden)	11	7x10^{-4}	1x10^{-4} – 0.08	8x10^{-9}	3x10^{-9} – 1x10^{-5}	80,000	8,000–33,000
Walloon Coal Measures (Tangalooma Sandstone)	12	0.002	1x10^{-4} – 0.1	5x10^{-9}	1x10^{-9} – 1x10^{-5}	300,000	10,000-100,000
Walloon Coal Measures (Upper Taroom Coal)	13	0.3	2x10^{-4} – 0.3	0.1	1x10^{-7} – 0.1	3	3-2,000
Walloon Coal Measures (Upper Taroom Interburden)	14	0.007	2x10^{-5} – 0.1	6x10^{-9}	1x10^{-9} – 2x10^{-4}	1,000,000	500-20,000
Walloon Coal Measures (Condamine Coal)	15	0.3	1x10^{-4} – 0.3	0.1	1x10^{-7} – 0.1	3	3-1,000
Walloon Coal Measures (Condamine Interburden)	16	0.007	3x10^{-4} – 0.1	4x10^{-7}	3x10^{-8} – 7x10^{-6}	15,000	10,000-14,000
Eurombah Formation	17	2x10^{-4}	3x10^{-5} – 5x10^{-4}	8x10^{-8}	1x10^{-8} – 2x10^{-6}	2,500	250-3,000
Hutton Sandstone	18	0.03	2x10^{-3} – 0.08	1x10^{-5}	6x10^{-7} – 6x10^{-5}	3,000	1,300-3,300

Table 4.2 Calibrated Storage parameter summary

Hydrostratigraphic Unit	Model Layer	Sy, Calibrated	Sy, Range	Ss, Calibrated (m^{-1})	Ss Range (m^{-1})
Condamine Alluvium/Gubberamunda Sandstone	1	0.015 -0.018	0.002 – 0.15	5.5 x10^{-5} 8.0 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Westbourne Formation	2	0.004	0.001 – 0.1	2.7 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Springbok Sandstone	3	0.009	0.001 – 0.1	2.3 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Kogan Coal)	4	0.02	0.001 – 0.1	2.0 x10^{-5}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Kogan Interburden)	5	0.008	0.001 – 0.1	2.0 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Macalister Coal)	6	0.02	0.001 – 0.1	2.3 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Macalister Interburden)	7	0.013	0.001 – 0.1	5.1 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Wambo Coal)	8	0.02	0.001 – 0.1	2.0 x10^{-5}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Wambo Interburden)	9	0.010	0.001 – 0.1	8.7 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Argyle Coal)	10	0.02	0.001 – 0.1	1.5 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Argyle Interburden)	11	0.006	0.001 – 0.1	4.8 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Tangalooma Sandstone)	12	0.018	0.001 – 0.1	2.3 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Upper Taroom Coal)	13	0.02	0.001 – 0.1	5.4 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Upper Taroom Interburden)	14	0.008	0.001 – 0.1	2.3 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Condamine Coal)	15	0.02	0.001 – 0.1	1.1 x10^{-5}	2.3 x10^{-7} – 2.0 x10^{-5}
Walloon Coal Measures (Condamine Interburden)	16	0.008	0.001 – 0.1	3.3 x10^{-7}	2.3 x10^{-7} – 2.0 x10^{-5}
Eurombah Formation	17	0.01	0.001 – 0.1	5.0 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}
Hutton Sandstone	18	0.01	0.001 – 0.1	1.0 x10^{-6}	2.3 x10^{-7} – 2.0 x10^{-5}

4.3.2 Head validation

Data for the HL series monitoring bores were received following completion of the model calibration and were therefore used for model validation purposes. Results are summarised below in Table 4.3 and suggest that the model tends to under-estimate observed heads at five out of six of these monitoring points which are located around the periphery of the former Linc Energy Site. Conversely as discussed above (Section 4.3.1) modelled heads at four of six sites within the site are higher than observed. Hence whilst the model appears to replicate observed flow directions towards the site it tends to under-estimate the lateral gradient, suggesting that the Macalister coal seam may be somewhat less continuous and/or less permeable than currently modelled. This is not unexpected given the deliberately conservative assumptions on coal continuity inherent within the model (Section 3.2.1).

Table 4.3 Modelled head validation HL21 to HL27

Bore ID	Strata monitored	Measured (mAHD)[a]	Modelled (mAHD)	Error (m, modelled – measured)
HL20	Macalister coal seam	No head data		
HL21	Wambo coal seam	273.0	293.6	20.6
HL22	Springbok Sandstone	296.9	266.1	-30.8
HL23	Macalister coal seam	257.4	244.2	-13.2
HL24	Wambo coal seam	293.3	281.0	-12.3
HL25	Springbok Sandstone	291.3	255.9	-35.4
HL26	Macalister coal seam	249.2	231.8	-17.4
HL27	Wambo coal seam	291.7	279.7	-12

Note: *[a] measured head March to April 2020*

4.4 Parameter identifiability

Identifiability is a term used to describe the capability of a model calibration to constrain parameters used by a model and ultimately reduce the uncertainty in predictions made by the model. An identifiability value of one means that the range in the model parameter can be constrained during the calibration process and hence the parameter is highly estimable. In contrast, an identifiability value of zero indicates that the parameter is not being constrained by the calibration and hence its uncertainty is not reduced through the calibration process.

To further investigate this issue the PEST utility GENLINPRED was used to provide an estimate of identifiability of each model parameter. Results are presented in Table 4.4 which shows the identifiability of groundwater model parameter zones for Kx, Kz, Sy and Ss in respect to the groundwater level observation dataset used for calibration.

Table 4.4 Average parameter identifiability

Model layer	Lithology	Horizontal hydraulic conductivity (Kx)	Vertical hydraulic conductivity (Kz)	Specific storage - Ss	Specific yield - Sy
1	Condamine Alluvium/ Gubberamunda Sandstone	0.11	0.03	0.01	<0.005
2	Westbourne Formation	0.03	0.04	<0.005	<0.005
3	Springbok Sandstone	0.16	0.09	0.08	0.02
4	Walloon Coal Measures (Kogan Coal)	0.18	0.02	0.04	0.01
5	Walloon Coal Measures (Kogan Interburden)	0.32	0.11	0.02	<0.005
6	Walloon Coal Measures (Macalister Coal)	0.32	0.02	0.28	0.04
7	Walloon Coal Measures (Macalister Interburden)	0.31	0.23	0.01	<0.005
8	Walloon Coal Measures (Wambo Coal)	0.16	<0.005	0.94	<0.005
9	Walloon Coal Measures (Wambo Interburden)	0.03	0.08	0.86	<0.005
10	Walloon Coal Measures (Argyle Coal)	0.09	<0.005	0.91	<0.005
11	Walloon Coal Measures (Argyle Interburden)	0.22	0.35	0.02	0.01
12	Walloon Coal Measures (Tangalooma Sandstone)	0.12	0.13	0.89	<0.005
13	Walloon Coal Measures (Upper Taroom Coal)	0.14	0.01	0.99	0.01
14	Walloon Coal Measures (Upper Taroom Interburden)	0.69	0.44	0.61	0.02
15	Walloon Coal Measures (Condamine Coal)	0.27	<0.005	0.98	<0.005
16	Walloon Coal Measures (Condamine Interburden)	0.24	0.07	0.87	0.01
17	Eurombah Formation	0.09	<0.005	0.98	<0.005
18	Hutton Sandstone	0.21	<0.005	0.98	0.01

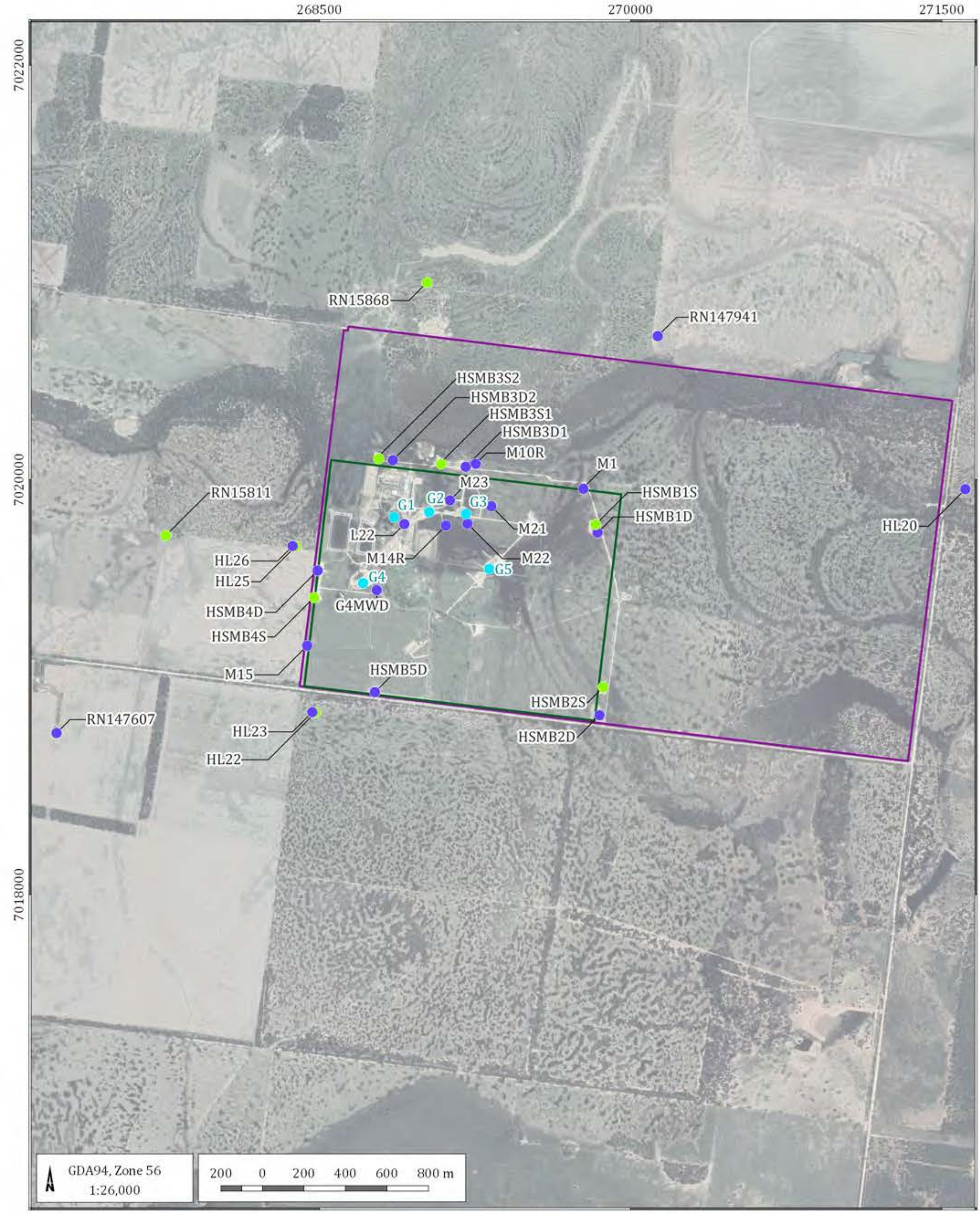
5 Phase 2 contaminant fate and transport model design

5.1 Contaminant transport data collation and review

Contaminant concentration data used for calibration of the Phase 2 contaminant transport model are summarised in Table 5.1 below. Calibration data locations are shown in Figure 5.1. Two contaminants (Benzene and Naptahlene) known to be present at the site were selected for simulation in the model. Benzene was selected since it is a known carcinogen and Napthalene since it is the most soluble polyaromatic hydrocarbon (PAH) of those present at the site. The discussion below and the numerical modelling work is therefore limited to these two contaminants. Other water chemistry data is available for the site and surrounding area and consideration was given to simulating transport of a potassium, a non-reactive chemical species which is also thought to be associated with contamination at the site for the purposes of calibrating some of the non-reactive transport parameters. However, high potassium concentrations have also been observed in recently completed monitoring bores at the site, due to the presence of residual drilling muds, and hence the available potassium data was not considered to be reliable enough to be used for model calibration.

As shown in Figure 5.1 the majority of the available data relates to the Macalister coal seam and the Springbok Sandstone within or close to the former Linc Energy site, since existing contamination is thought largely to be limited to the site itself and these two units. Accordingly, calibration of the fate and contaminant transport model has been carried out through reference to Benzene and Napthalene data for these two units. All available Benzene and Naphthalene data for the Springbok Sandstone and Macalister coal seam used for model calibration are presented Figure 5.2 and Figure 5.3. As shown concentrations of Benzene and Napthalene have gradually reduced at almost all monitoring points since the commencement of monitoring in June 2018. This suggests that there is no substantial ongoing source of contamination or contaminant movement at the site. If either an ongoing source was present or if significant contaminant movement was occurring, then one would expect to see some observed increases particularly in observations points towards the south west of the site. Given the south westerly dip of the strata in the area then monitoring bores in this area would be expected to be downgradient of the site, at least under natural conditions. However, reference to data for observation points HSMB4S and HSMB5D (Springbok Sandstone, Figure 5.2) and HSMB5D (Macalister coal seam Figure 5.3) towards the south west of the Lot 40 DY 85 also suggests long term decline in Benzene and Napthalene concentrations in these bores. Insufficient data are available for HSMB4D to determine a trend.

The above observations relating to the absence of an ongoing source or substantial movement are considered to be consistent with other information available for the site. In particular groundwater level monitoring data suggests that current pressures within the former Linc Energy site are around 100 m below pre-development pressures and observed pressures in other nearby monitoring points. Accordingly the available groundwater level data (Section 4.1.3) suggests ongoing flow towards rather than away from the site which would tend to promote gradual adsorption and dispersion of the contaminant plume in situ rather than advective transport of contaminants outside of the lease area.



LEGEND

🟩 MDL309 boundary

🟪 Lot 40 DY 85

● Gasifier locations

Contamination concentration locations

● Macalister

● Springbok

Hopelands Arrow (G2002)

Observed contaminant concentration data points, location map

AGE

DATE
09/06/2020

FIGURE No:
5.1

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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Table 5.1 Observed contaminant concentration data

Monitoring bore/data type	Springbok Sandstone		Macalister coal seam		Notes
	Number of monitoring locations	Number of data points[1]	Number of monitoring locations	Number of data points[1]	
Local landholder bores	2	4	2	4	Sampling results for local landholder bores close to Lot 40 DY85
Lot 40 DY85 monitoring bores	5	68	16	176	Monitoring at the former Linc Energy site. Comprises nested monitoring at the base of the Springbok Sandstone and underlying Macalister sub-unit from five HSM series bores. Some data also available for the Macalister coal seam for other bores
Arrow HL series monitoring bores (HL20 to HL27)	2	4	3	6	HL series bores installed close to the boundary of Lot 40 DY85. Contaminant data also available for three locations in the Wambo Coal Seam (HL21, HL24 and HL 27) but have not been used for model calibration
Total	**9**	**76**	**20**	**184**	

Note: *[1] Total number of readings available, Benzene and Naphthalene only.*

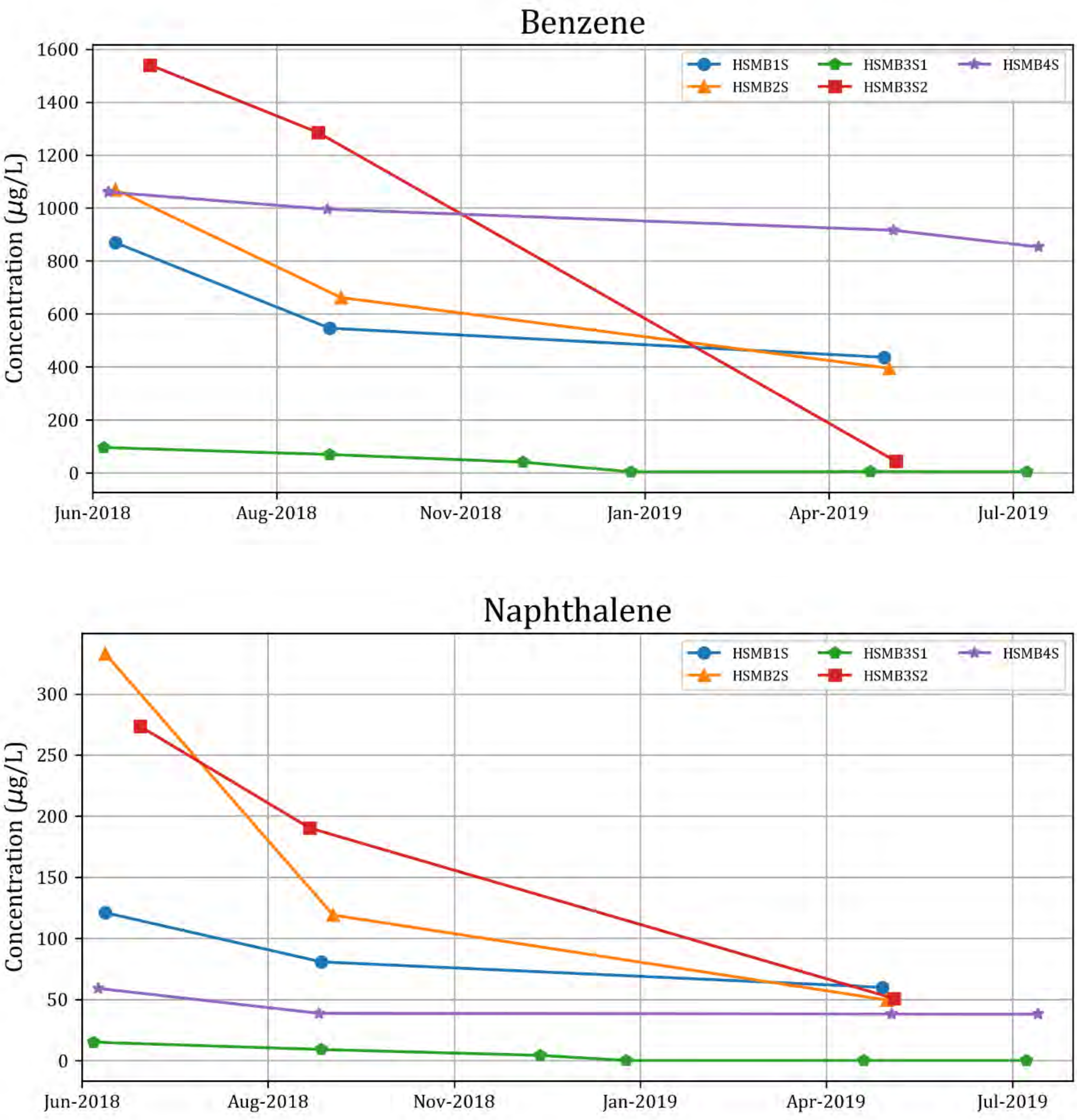


Figure 5.2 Observed contaminant concentration data, Springbok Sandstone

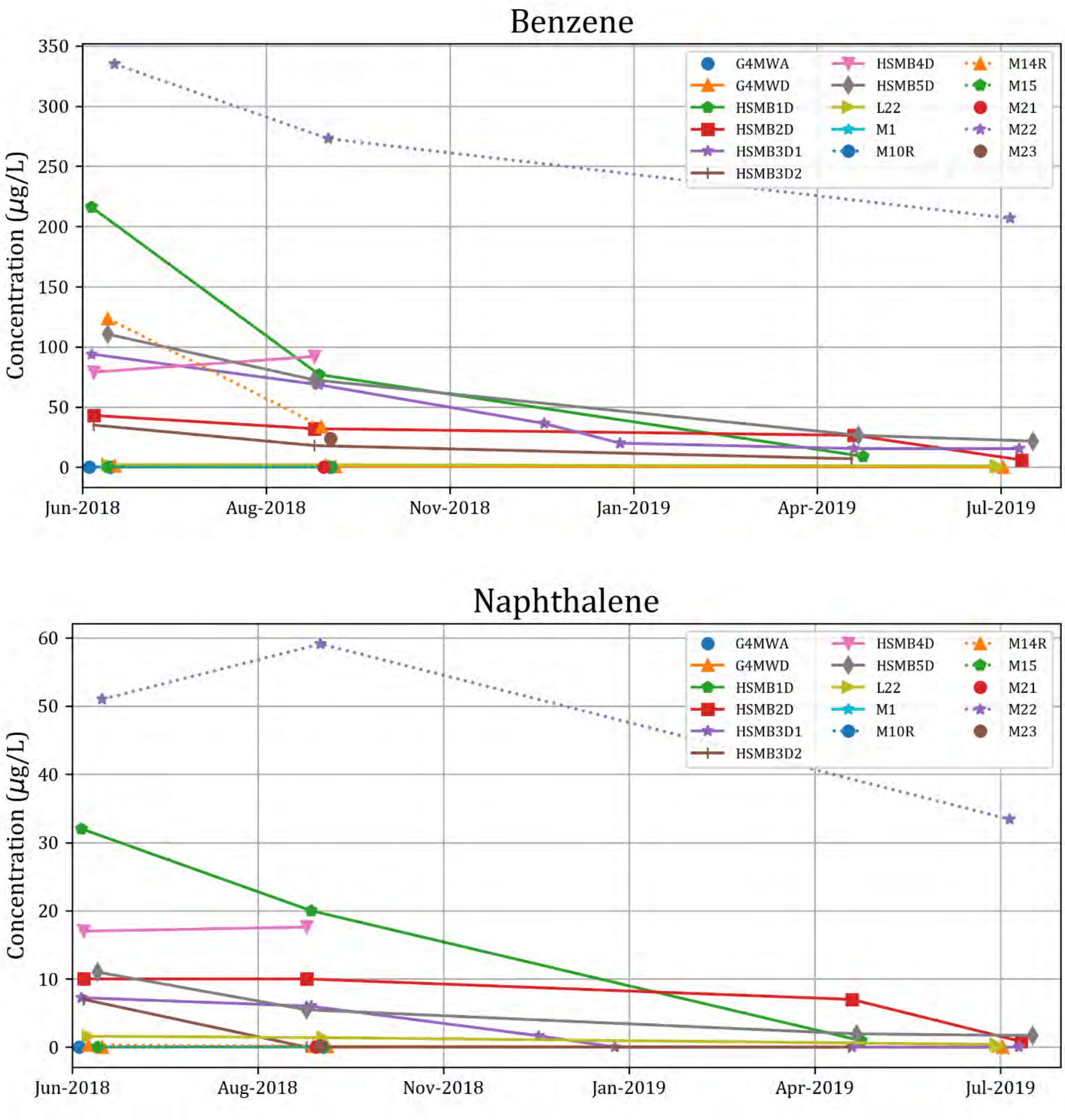


Figure 5.3 Observed contaminant concentration data, Macalister coal seam

5.2 Model design and initial parameterisation

Numerical modelling work completed in Phase 2 predominantly comprised the development of a contaminant fate and transport simulation from the Phase 1 groundwater flow model. Phase 2 contaminant transport modelling was undertaken using the MODFLOW Block Centred Transport (BCT) package (GSI, 2019) and included simulation of the following transport processes:

- Advective transport.
- Dispersion (lateral and transverse).
- Linear/non-linear adsorption.
- First order decay.

Hydraulic parameters estimated during calibration of the groundwater flow model (Section 4) were adopted unchanged for the Phase 2 model. Initial porosity and transport parameters and likely possible ranges were taken from analyses of geophysical logs previously undertaken by OGIA (Section 5.2.1) and commonly references literature guides (Section 5.2.2) respectively and were then calibrated using the observed data as described in Section 6.

5.2.1 Porosity values

Effective porosity ranges for the various formations present at the site have been previously reported by OGIA (2016b, see Table 5.2). These statistics are based on the analysis of geophysical logs for 82 representative CSG wells within the Surat CMA area. Initial effective porosity values and likely ranges adopted for modelled purposes based on the OGIA data are summarised in Table 5.3.

Table 5.2 Effective porosity ranges by formation (after OGIA, 2016b)

Hydrostratigraphic Unit	Model Layer	10th percentile	Median	90th percentile
Condamine Alluvium/Gubberamunda Sandstone	1	2%	15%	24%
Westbourne Formation	2	2%	6%	16%
Springbok Sandstone	3	6%	14%	22%
Walloon Coal Measures (Kogan)	4	1%	7%	14%
Walloon Coal Measures (Macalister)	5	1%	7%	14%
Walloon Coal Measures (Wambo)	6	1%	7%	14%
Walloon Coal Measures (Wambo)	7	1%	7%	14%
Walloon Coal Measures (Argyle)	8	1%	7%	14%
Walloon Coal Measures (Tangalooma Sandstone)	9	1%	7%	14%
Walloon Coal Measures (Upper Taroom)	10	1%	7%	14%
Walloon Coal Measures (Condamine)	11	1%	7%	14%
Eurombah Formation	12	1%	4%	10%
Hutton Sandstone	13	2%	12%	21%

Table 5.3 Effective porosity parameter range – Effective porosity

Unit	Porosity range	Initial porosity	Source
Alluvium (Layer 1)	0.15 – 0.2	0.15	OGIA 2016b
Westbourne Formation (Layer 2)	0.06 – 0.2	0.06	OGIA 2016b
Springbok Sandstone (Layer 3)	0.125 – 0.2	0.125	OGIA 2016b
Interburden (Layers 5,7,9,11,12,14,16,17)	0.07 – 0.2	0.07	OGIA 2016b
Coal (Layers 4,6,8,10,13,15)	0.07 – 0.2	0.07	OGIA 2016b
Hutton Sandstone (Layer 18)	0.105 – 0.2	0.105	OGIA 2016b

5.2.2 Transport parameters

Initial transport parameters and likely possible ranges based on commonly referenced literature guides including Pubchem/Semspub (2020) are summarised in Table 5.4. It is recognised that the upper bound of the range of values adopted for the first order decay coefficient (Foc) for Benzene is somewhat higher than typical ranges identified in the literature. However, the typical values quoted the literature relate to anaerobic conditions whilst aerobic conditions would have been prevailed in the vicinity of the gasifiers during operation and potentially for some considerable time afterwards. Initial runs of the transport simulation tended to confirm that a higher upper bound FoC value for Benzene was likely to be required to achieve calibration leading to the same upper bound of 735 $t_{1/2s}$ being adopted for both Benzene and Napthalene for the final calibration.

Table 5.4 Initial transport parameterisation and calibration ranges

Parameter	Unit	Definitions/ Comment	Initial value	Adopted calibration range
Initial concentration of component species in water	M_w/L^3	M_w = mass of a component species in water	*See Appendix C*	*NA*
Longitudinal dispersivity	m	Mixing that occurs in the direction of flow	Coal layers 30 Other layers 30	Coal layers 30 - 70 Other layers 30 - 70
Transverse dispersivity	m	Spreading normal to flow direction	Coal layers 1 Other layers 1	Coal layers 1 - 7 Other layers 1 - 7
Bulk density	M_s/L^3	Density of the porous matrix	Coal layers 1,400 Other layers 2,600	Coal layers 1,400 – 1,900 Other layers 1,900 –2,600
Adsorbed concentration	M_a/M_s	M_a = mass of component species	*Not simulated*	*NA*
Adsorption coefficient	k_d		Benzene coal layers 25 Benzene other layers 0.1 Naphthalene coal layers 845 Naphthalene other layers 0.8	Benzene coal layers 25 – 80 Benzene other layers 0.03 – 0.1 Naphthalene coal layers 700 – 985 Naphthalene other layers 0.8 – 1.2
Freundlich adsorption isotherm exponent	e	Exponent of contaminant species from $c_s = k_d c^e$	Benzene coal layers 2 Benzene other layers 1.2 Naphthalene coal layers 1.2 Naphthalene other layers 1.7	Benzene coal layers1 – 10 Benzene other layers 1 – 10 Naphthalene coal layers 1 – 10 Naphthalene other layers 1 – 10
First order decay coefficient in water and soil	$1/t_{1/2s}$	*25 – 35 days Benzene (anerobic conditions)* *100 – 735 days Naphthalene (anerobic conditions)*	Benzene coal layers 100 Benzene other layers 100 Naphthalene coal layers 250 Naphthalene other layers 300	Benzene coal layers25 – 735 Benzene other layers 25 – 735 Naphthalene coal layers 100 – 735 Naphthalene other layers 100 – 735

5.2.3 Initial conditions

No data are currently available during the operational period of the gasifiers and hence it was not possible to simulate the source of the contamination and/or the period from cessation of operations in October 2013 to the commencement of monitoring in June 2018. The contaminant transport simulation therefore commences in June 2018 with initial concentrations of Benzene and Napthalene in the Springbok Sandstone (model layer 5 in the vicinity of Lot 40 DY85) and the Macalister coal seam (model layer 6) derived from the concentration data available at this time (see Appendix C). Simple kriging was then applied at the start of the modelling process to generate a continuous distribution of initial Benzene and Napthalene concentrations. For kriging purposes values of half of the detection limit (DL) were assumed in any cases where reported concentrations were less than the DL. Of the 29 monitoring points used in the Phase 2 calibration actual data for June 2018 are available for 25 monitoring points and hence initial conditions are well defined. However, in the remaining four cases (the recently completed Arrow monitoring points HL22, HL23, HL25 and HL26) monitoring only recently commenced and initial concentrations have been estimated based on the minimum observed rate of contaminant decline in the nearest HSM series monitoring point.

It should be noted that the simple kriging approach used to generate initial conditions is considered likely to over-estimate the extent of the historic contaminant 'plume' especially in the Springbok Sandstone. As shown in Appendix C Benzene and Napthalene data for June 2018 predominantly comprise relatively high concentrations of contaminants in HSM series bores around the periphery of the site. Offsite monitoring is limited to data for the Arrow monitoring bores HL22 and HL25 and a landholder bore to the south and west of Lot 40 DY85. Data for all of these off site bores shows Benzene and Napthalene concentrations at or below detection limits. However, as shown in Appendix C no off site data is available to the east or north of the former Linc Energy site and hence initial concentrations in the Springbok Sandstone are poorly constrained in these areas. The available observations to the south and west suggest that Benzene and Napthalene are likely to be less than detection limits in these areas but there are currently no observations to confirm this and hence interpolation of the data that this available results in initial concentrations exceeding 1 ug/l outside of the site boundary.

6 Phase 2 contaminant fate and transport model calibration

6.1 Calibration approach

Calibration of the transport model was undertaken using PEST_HP (Watermark Numerical Computing, 2020), by adjusting all layer wide parameters simulated by the Block-centred transport package as listed in Table 5.3 and Table 5.4. All other parameters associated with the LPF, GHB and RCH packages remained unchanged from the calibrated Phase 1 groundwater flow model.

6.2 Calibration results

Plots of observed versus modelled Benzene and Naphthalene concentrations resulting from the model calibration are presented in Figure 6.1 and Figure 6.2 respectively and show similar SRMS values and level of fit to the observed concentration data to that achieved for the head calibration (Section 4.3.1). In the authors experience the degree of fit which can be achieved to contaminant concentration data is typically lower than that achieved to heads since simulation of contaminant concentrations as well as flows adds another level of complexity to the calculations required. The relatively good fit achieved despite the adoption of a simple calibration approach, using layer wide rather than spatially variable transport parameters, therefore suggests that contaminants at the site are behaving in a relatively predictable manner.

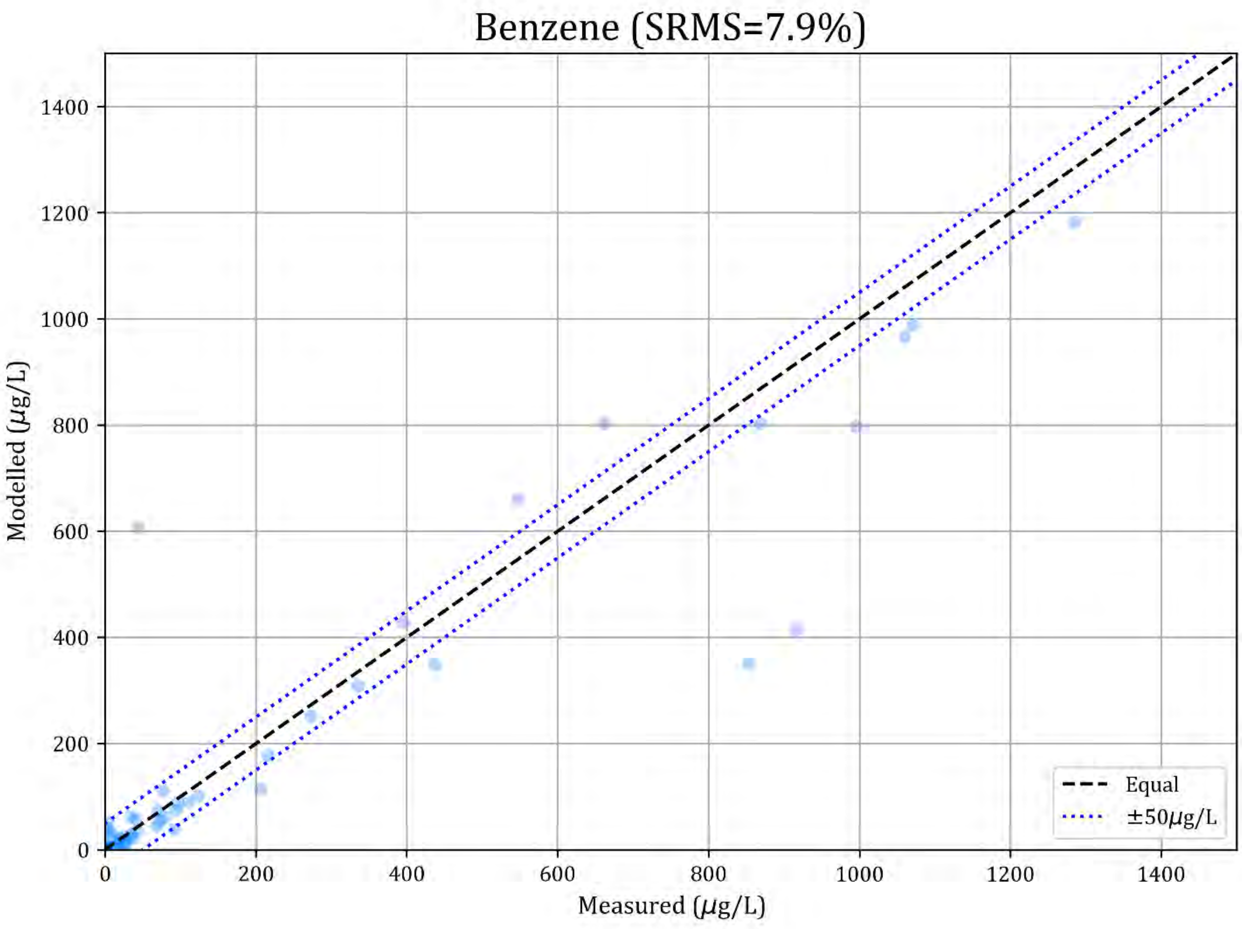


Figure 6.1 Modelled versus observed contamination calibration scatter plot – Benzene

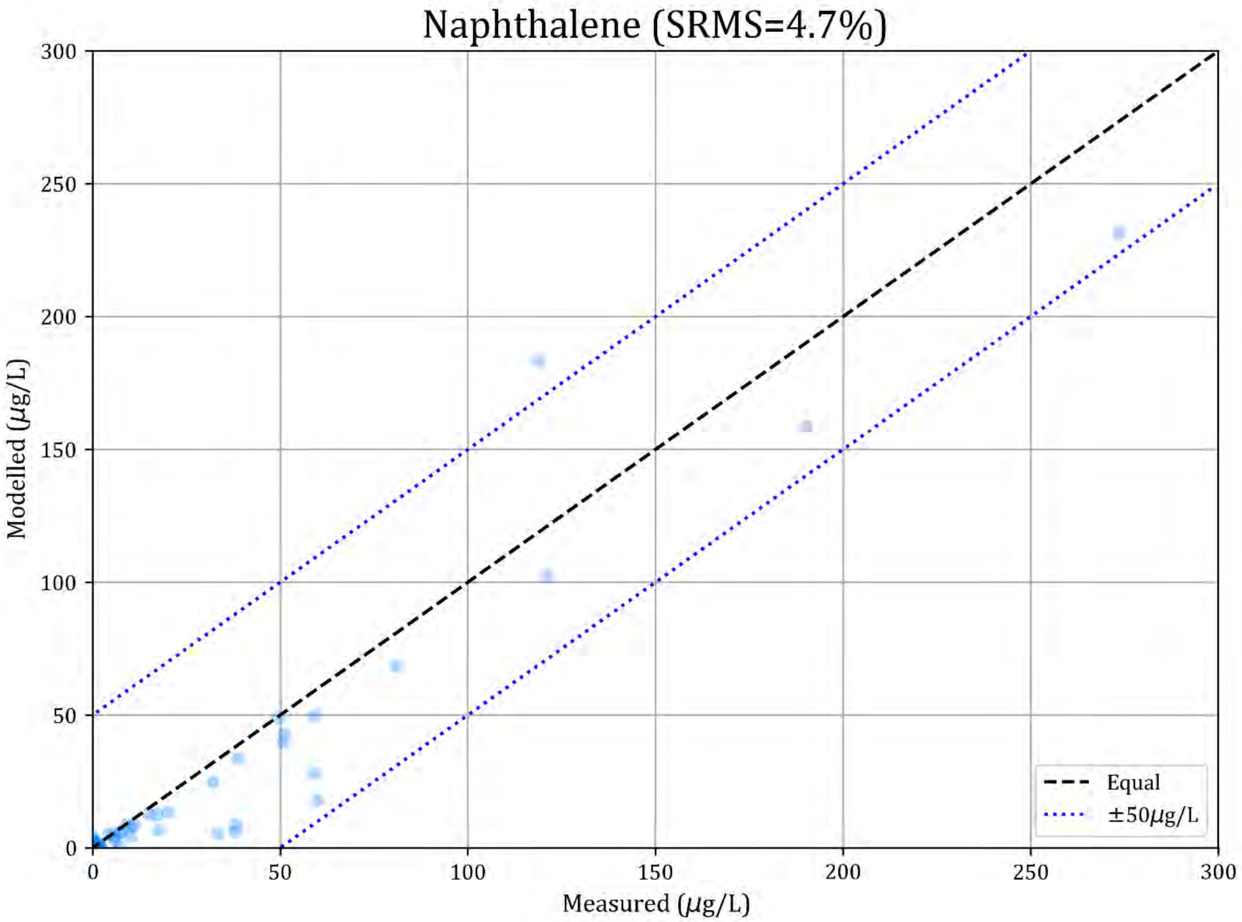


Figure 6.2 Modelled versus observed contamination calibration scatter plot – Naphthalene

Table 6.1 Calibrated transport parameter summary

Parameter	Unit	Calibrated value
Initial concentration of component species in water	M_w/L^3	*See Appendix C*
Longitudinal dispersivity	m	Coal layers 30 Other layers 30
Transverse dispersivity	m	Coal layers 1 Other layers 1
Bulk density	M_s/L^3	Coal layers 2,600 Other layers 1,400
Adsorption coefficient	k_d	*Benzene coal layers 80* *Benzene other layers 0.1* *Napthalene coal layers 985* *Napthalene other layers 1.2*
Freundlich adsorption isotherm exponent	e	*Benzene coal layers 4.3* *Benzene other layers 1* *Napthalene coal layers 5.5* *Napthalene other layers 1*
First order decay coefficient in water and soil	$1/t_{1/2s}$	Benzene coal layers 144 Benzene other layers 374 Naphthalene coal layers 108 Naphthalene other layers 175

6.3 Parameter identifiability

Table 6.2 shows the identifiability of groundwater model parameter zones for transport parameters in respect to the Benzene and Naphthalene concentration observation dataset used for calibration.

Table 6.2 Parameter identifiability - Transport

Pest parameter name	Description	Identifiability
dli	Longitudinal dispersivity (non coal)	0.003
dlc	Longitudinal dispersivity (coal)	0.004
dti	Transverse dispersivity (non coal)	1.00
dtc	Transverse dispersivity (coal)	1.00
dni	Density (non coal)	<0.001
dnc	Density (coal)	<0.001
adi_b	Adsorption (kd - non coal - Benzene)	0.71
adc_b	Adsorption (kd - coal - Benzene)	<0.001
adi_n	Adsorption (kd - non coal - Naphthalene)	<0.001
adc_n	Adsorption (kd - coal - Naphthalene)	<0.001
deci_b	1st order decay (non coal - Benzene)	1.00

Pest parameter name	Description	Identifiability
decc_b	1st order decay (coal - Benzene)	1.00
deci_n	1st order decay (non coal - Naphthalene)	1.00
decc_n	1st order decay (coal - Naphthalene)	1.00
flii_b	Freundlich adsorption isotherm exponent (non coal - Benzene)	1.00
flic_b	Freundlich adsorption isotherm exponent (coal - Benzene)	<0.001
flii_n	Freundlich adsorption isotherm exponent (non coal - Naphthalene)	1.00
flic_n	Freundlich adsorption isotherm exponent (coal - Naphthalene)	<0.001
por3	Porosity zon3 (Springbok)	0.29
por4	Porosity zon4 (Mac A-B)	1.00

7 Model predictions

7.1 Predictive scenarios

Two predictive scenarios were run using the model as described below.

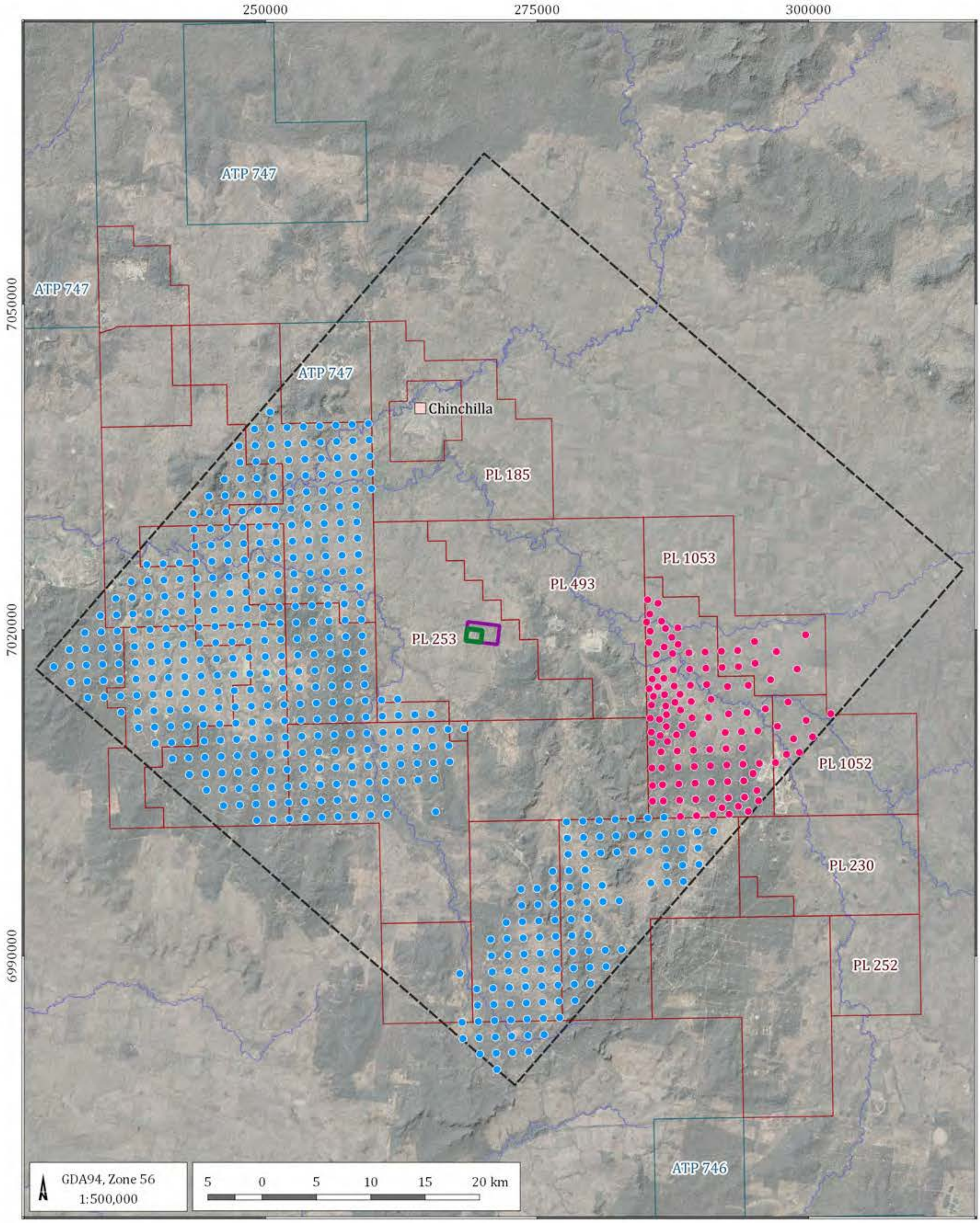
The distribution of existing and proposed CSG wells included in the '**baseline scenario'** is shown in Figure 7.1. This scenario only includes currently authorised CSG wells to be operated by Arrow on PLs 253, 185, 493 and those operated by other companies within the model domain.

Figure 7.2 shows the '**Arrow FDP scenario**', the proposed full field development plan (FDP) for PL253, which includes CSG wells within around 1.5 km of the former Linc Energy site.

A summary of the number of Arrow Energy CSG wells included in the Arrow FDP scenario is provided below in Table 7.1. As shown in Table 7.1 around half of the proposed CSG wells to be installed PLs 253 and 393, including the majority of the wells installed close to the former Linc Energy Site will not be completed into the Macalister coal seam and will therefore only extract other underlying coal seams. Accordingly, extraction from these wells will not directly affected groundwater level gradients at the site. CSG wells are gradually added to PLs 253 and 393 as per the current Arrow Energy FDP for this area which includes CSG wells being completed between 2022 and 2037.

Table 7.1 Arrow FDP scenario modelled CSG well counts

CSG well type	Number of CSG wells
Currently authorised	290
Proposed - completed into the Macalister coal seam	129
Proposed - not completed into the Macalister coal seam	124
Total	**543**



LEGEND

□ Populated place

— Rivers and other watercourses

▢ MDL309 boundary

▢ Lot 40 DY 85

▢ Petroleum Lease (PL) area

▢ Authority to Prospect (ATP) area

⬚ Model extent

CSG well

● Arrow authorised

● Non - Arrow

Hopelands Arrow (G2002)

Baseline scenario

DATE 10/06/2020

FIGURE No: **7.1**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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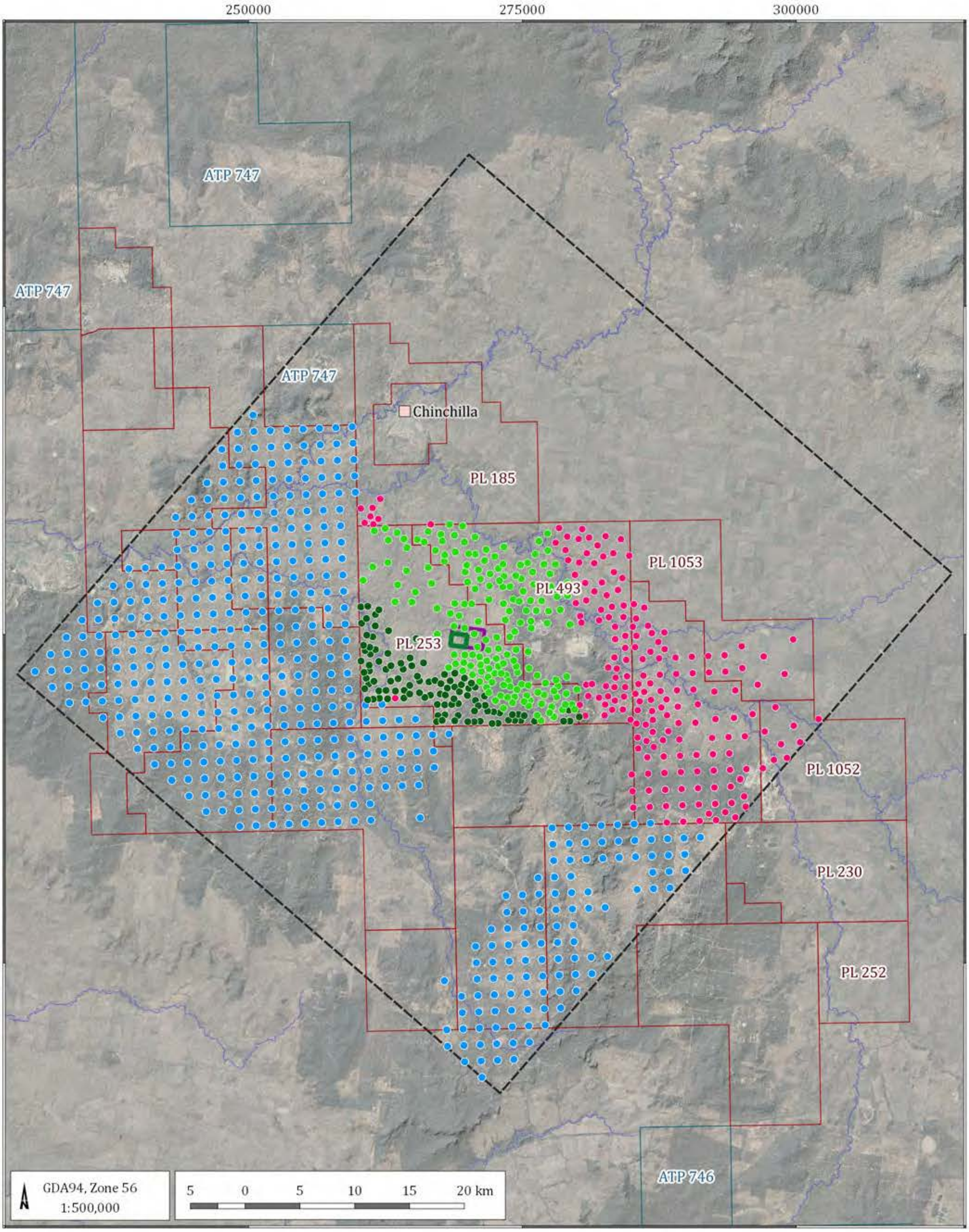

LEGEND

- ▢ Populated place
- — Rivers and other watercourses
- ▢ MDL309 boundary
- ▢ Lot 40 DY 85
- ▢ Petroleum Lease (PL) area
- ▢ Authority to Prospect (ATP) area
- ⬚ Model extent

CSG well

- ● Arrow proposed - screened into the Macalister coal seam
- ● Arrow proposed - not screened into the Macalister coal seam
- ● Arrow authorised
- ● Non - Arrow

Hopelands Arrow (G2002)

Arrow FDP scenario

AGE

DATE	FIGURE No:
10/06/2020	**7.2**

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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7.2 Impact prediction

Both the baseline and Arrow FDP scenarios were initially assessed using the Phase 1 groundwater flow model through reference to the predicted movement of a series of hypothetical particles added into the Springbok Sandstone and Macalister coal seam at each modelled gasifier cell at the end of the operational period. The impacts of the proposed Arrow FDP was then estimated by comparing the total distance travelled by particles over a 20-year period from 2019 to 2040 under the Arrow FDP scenario with results for the baseline. Results are summarised below in Section 7.2.1 and suggest very limited contaminant movement over the period modelled in either scenario.

Following development and calibration of the Phase 2 contaminant transport model a further series of predictions were generated to predict contaminant concentrations, as well as the rate of movement. This model and related predictions were developed since, based on the available observations (Section 5.1), the current contaminant plume appears to be contracting and may be fully dissipated prior to the commencement of the Arrow FDP. Predicted contaminant concentrations are presented in Section 7.2.2.

7.2.1 Particle tracking

Summary particle tracking results for both scenarios are summarised in Table 7.2 and shown in Figure 7.3 and Figure 7.4. As shown the average total distance travelled under the baseline scenario from the point of application within each of the gasifiers ranges from 13 m in the Springbok Sandstone to 16 m in the Macalister sub-unit over the 20 year forecast period (January 2020 to December 2040). Under the Arrow FDP scenario average distances travelled during the forecast period increase only slightly by around six to eight metres to 19 m and 24 m in the Springbok Sandstone and Macalister coal seam respectively.

As shown in Figure 7.3 and Figure 7.4 whilst particle movement is predicted to be limited during the forecast period from January 2020 to December 2040 model results suggest more substantial movement during the simulated historic period. This is a reflection of modelled groundwater levels which show relatively steep gradients and hence particle movement southwards towards gasifier G4 during the modelled period to January 2020 but little very limited movement thereafter (Figure 7.4) since consistent with groundwater level observations (Section 4.1.3) overall modelled groundwater flow directions remain towards the site.

As shown in Figure 7.4 in particular model predictions suggest particle movement during the historic period to January 2020 from gasifiers G1, G2, G3 and G5 south and south westward generally towards gasifier G4. Due to the dip of the strata in the area this would have been the deepest of the five gasifiers and was also closed relatively during the operational period in March 2012. However, all particles all particles are predicted to remain well within the boundaries of the former Linc Energy site throughout the modelled period and under both scenarios considered and would not therefore reach any existing or proposed CSG wells within the period modelled. The nearest proposed CSG well to the west of the site is located around 1.3 km from the boundary of Lot 40 DY85.

Table 7.2 Predicted particle tracking impacts, 1 January 2020 to 31 December 2040

Scenario	Total distance travelled (m)			Predicted impact (m)		
	Min	Average	Max	Min	Average	Max
Springbok Sandstone (model layer 3)						
Baseline	<1	13	29	NA	NA	NA
Arrow FDP scenario	<1	19	45	<1	6	16
Macalister sub-unit (model layer 6)						
Baseline	<1	16	29	NA	NA	NA
Arrow FDP scenario	<1	24	45	<1	8	16

LEGEND

🟩 MDL309 boundary
🟪 Lot 40 DY 85
🟦 Modelled gasifier areas

Predicted particle position

- ● Prior to January 2020
- ● December 2020
- ● December 2025
- ● December 2030
- ● December 2035
- ● December 2040

Hopelands Arrow (G2002)

Predicted particle movement, Springbok Sandstone (model layer 3)

DATE
26/05/2020

FIGURE No:
7.3

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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LEGEND

🟩 MDL309 boundary
🟪 Lot 40 DY 85
🟦 Modelled gasifier areas

Predicted particle position

● Prior to January 2020
● December 2020
● December 2025
● December 2030
● December 2035
● December 2040

Hopelands Arrow (G2002)

Predicted particle movement, Macalister coal seam (model layer 6)

DATE
26/05/2020

FIGURE No:
7.4

Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G2002.Hopelands_Arrow\3_GIS\Workspaces\001_Deliverable1\07.04_G2002_Predicted particle movement, Macalister coal seam (model layer 6).qgs

7.2.2 Contaminant concentrations

Predicted contaminant concentrations under the baseline and Arrow FDP scenarios for the Springbok are summarised in Table 7.3 and Table 7.4. Predicted contaminated concentrations at selected dates during the June 2018 to December 2040 modelling period are also presented in Appendix D. As shown in Appendix D and summarised in Table 7.3 predictions suggest that the observed historic dissipation of the plume will continue into the future resulting in Napthalene concentrations of less than 1ug/l in the Springbok Sandstone throughout the former Linc Energy site by the end of 2021 and Benzene concentrations of less than 1 ug/l by the end of 2026. Predictions for the Macalister coal seam (Table 7.4) suggest concentrations of Napthalene falling to below 1 ug/l by the end of 2020 and Benzene by 2024.

As would be expected given that the model has been calibrated using the available observed data these predictions are broadly consistent with the observed data. For instance as shown in Figure 5.3 data for the most recent comprehensive round of sampling in July 2019 suggest Napthalene concentrations in the Macalister coal seam of less than 2 ug/l in all monitoring points bar M22 which shows much higher concentrations of both Benzene and Napthalene than observed at other monitoring points.

Consistent with particle tracking results predictions in both hydrostratigraphic units also suggest that the time taken for the plume to fully degrade will not be affected by CSG development in the surrounding area. In part this due to the timing of construction, extraction from many of the CSG wells proposed nearby will not commence until after 2026, but also many of the nearby wells will not intersect the Macalister coal seam and so will not substantially affect groundwater gradients at the site.

Table 7.3 Predicted contaminant transport impacts, Springbok Sandstone

Impact metric	Base line scenario	Arrow FDP scenario	Project Impact
Average particle movement over 20 year period (m)	13	19	6 m
Time for degradation to <1 ug/l Benzene (years from June 2018)	2026 (7.5 years)	2026 (7.5 years)	<1 year
Time for degradation to <1 ug/l Napthalene (years from June 2018)	2021 (3.5 years)	2021 (3.5 years)	<1 year

Table 7.4 Predicted contaminant transport impacts, Macalister coal seam

Impact metric	Base line scenario	Arrow FDP scenario	Project Impact
Average particle movement over 20 year period (m)	16	24	8 m
Time for degradation to <1 ug/l Benzene (years from June 2018)	2024 (5.5 years)	2024 (5.5 years)	<1 year
Time for degradation to <1 ug/l Napthalene (years from June 2018)	2020 (2.5 years)	2020 (2.5 years	<1 year

8 Uncertainty Analysis

8.1 Methodology

Middlemis and Peeters (2018) outline three general approaches to analysing parameter uncertainty in increasing order of complexity and of the level of resources required, they are:

1. deterministic scenario analysis with subjective probability assessment;
2. deterministic modelling with linear probability quantification; and
3. stochastic modelling with Bayesian probability quantification.

A Null-space Monte Carlo (NSMC) uncertainty analysis was undertaken (option 3), implemented using the PEST suite of software, to quantify the magnitude of uncertainty in the future impacts predicted by the model. This type of analysis produces probability distributions for predictive impacts by assessing a composite likelihood of an impact occurring through assessing and ranking the predictions from hundreds of alternative model 'realisations'. Each model realisation is informed by the observation dataset by using the relationship between the observation's statistics to perturbations of each parameter in the groundwater model.

This uncertainty analysis was essentially a three-part process. Firstly, a valid range for each flow and transport parameters (i.e. pre-calibration range) was determined, and then 200 alternative model realisations were created, each having differing values of model parameters. Outputs from each realisation were then tested and any models that failed to converge or produced outputs that were inconsistent with the available calibration data set were rejected. In this case, however, all models converged and whilst none of the realisations achieved quite the same level of calibration as the fully calibrated models (Sections 4.3and 6.2) analysis of the root mean square error (RMS) for each realisation suggested that none of the 200 realisations was demonstrably inconsistent with the observations. The maximum RMS error reported for the uncertainty analysis realisations was 26.0-233.8 $\mu g/L$, compared to the 15.7-122.2 $\mu g/L$ achieved for Naphthalene and Benzene in the fully calibrated contaminant transport model. Accordingly, revised predictions based on all 200 alternative parameter realisations were generated and analysed statistically to investigate uncertainty.

8.2 Uncertainty analysis results

Predictive uncertainty has been assessed through reference to the time taken for Benzene and Napthalene concentrations in each model cell to fall below a detection limit of 1 $\mu g/L$. Results are presented in Appendix E as a series of maps (Figures E1 to E8). As shown in Figures E1 and E3 uncertainty analysis results suggest that the time taken for Benzene concentrations throughout the former Linc Energy site to fall below 1 $\mu g/L$ could increase by between 5 and 10 years (based on the 95th percentile of the available predictions) from the best estimate (or fully calibrated) predictions of 5.5 to 7.5 years reported above (Table 7.3 and Table 7.4). Similarly 95th percentile results for Napthalene shown in Figures E2 and E4 suggest that the time taken for concentrations to reduce to below 1 $\mu g/L$ could increase by between less than up to 4 years from the best estimate predictions presented in Table 7.3 and Table 7.4.

However, comparison of uncertainty analysis predictions for the Arrow FDP (Figures E1 to E4) and baseline scenarios (Figure E5 to E8) indicates no material differences re-inforcing the previous conclusion based on the fully calibrated predictions that development of PL 253 is unlikely to significantly affect contaminant movement on the former Linc Energy site.

9 Summary and conclusions

Phase 1 groundwater flow and Phase 2 contaminant fate and transport models have been developed and calibrated through further refinement of a model previously developed by GHD (2019). Initial parameterisation of the groundwater flow parameters drew primarily on the regional model of the entire Surat Cumulative Management Area previously developed by OGIA (2016a). Initial contaminant transport parameters and ranges were derived from commonly referenced literature guides including Pubchem/Semspub (2020).

Calibration of the Phase 1 and Phase 2 models was undertaken to head and concentration data available within the model domain but with particular emphasis on observations in and around the former Linc Energy site (Lot 40 DY85). Once calibrated the models were used to predict the rate of contaminant movement and contaminant concentrations within Lot 40 DY85 under a **baseline scenario,** and an **Arrow FDP scenario**.

Predictive results suggest minimal ongoing contaminant movement within the former Linc Energy site under either scenario and continued dissipation of the existing contamination. Results suggest that concentrations will reduce to less than 1 ug/l throughout the site by 2021 for Napthalene and for Benzene by 2026. Predictions also suggest that these timings will be unaffected by development of the surrounding PL253 since many of the proposed CSG wells close to Lot 40 DY85 do not target the Macalister coal seam and/or are programmed for construction after 2026. Accordingly flow directions in the Springbok Sandstone and Macalister coal seam remain predominantly towards Lot 40 DY85 with and without development of the surrounding PL, allowing the existing contamination to dissipate in-situ.

Uncertainty analysis results based on a further 200 sets of predictions suggest that the time taken for Benzene and Napthalene concentrations to reduce to less than 1 ug/l could increase by up to 10 years but tend to confirm that the time taken for recovery would not be affected by the field development plan proposed by Arrow.

10 References

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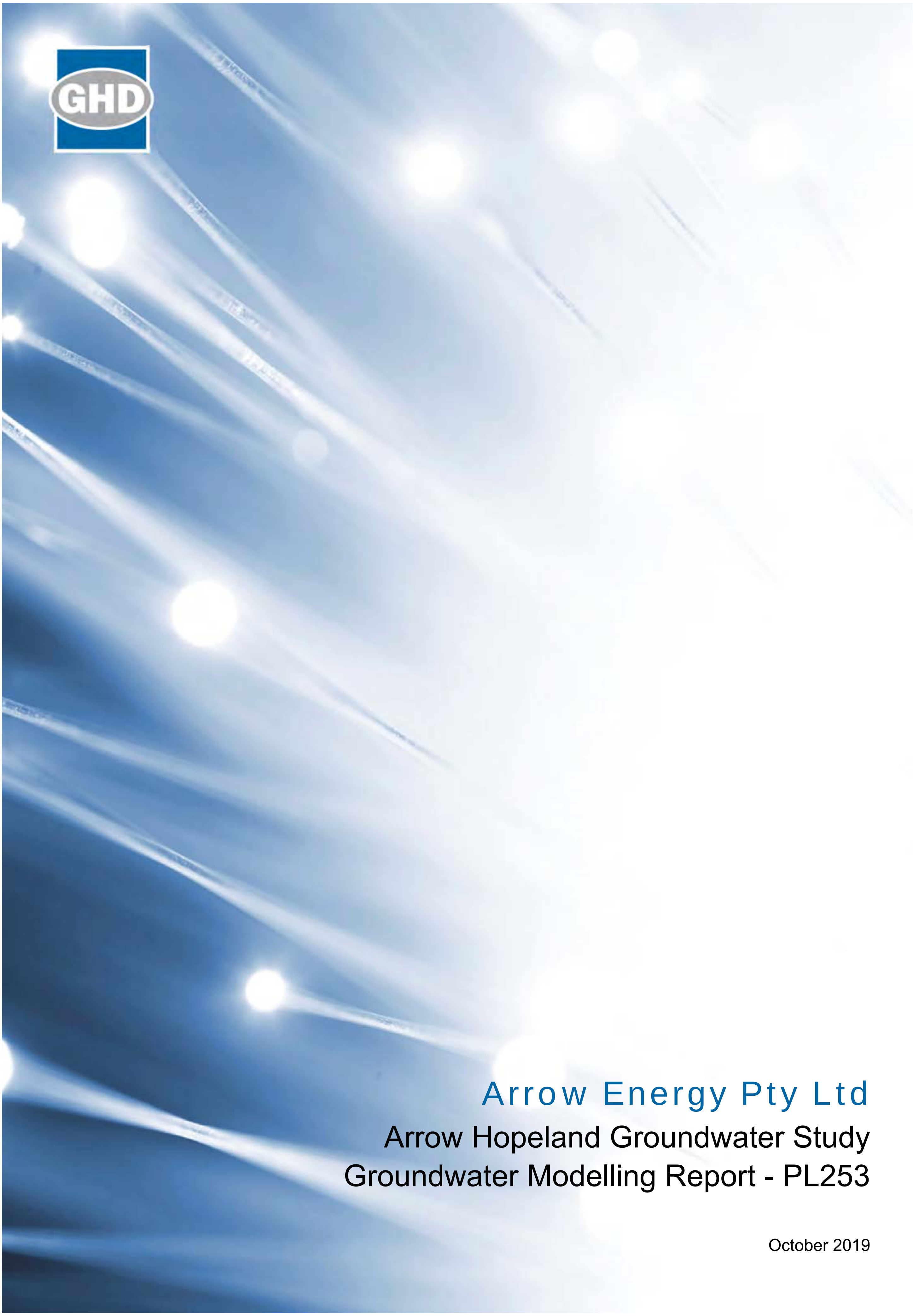
Appendix A Arrow Hopeland Groundwater Study, Groundwater Modelling Report – PL253



Arrow Energy Pty Ltd

Arrow Hopeland Groundwater Study
Groundwater Modelling Report - PL253

October 2019

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

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Appendices

1. Introduction

1.1 Background

Arrow Energy Pty Ltd (Arrow Energy) currently operates a coal seam gas (CSG) pilot facility at their Hopeland site, located approximately 24 km south of Chinchilla in Queensland (refer to Figure 1-1). CSG activities at the Hopeland site are situated on the petroleum lease PL253, and completed under the provisions of an environmental authority (EA000140).

Linc Energy Ltd (Linc Energy) formerly operated a pilot underground coal gasification (UCG) facility within MDL309 on Lot 40 DY85, and residual contamination is understood to be present within the groundwater of this site due to the conduct of historical UCG activities. The former Linc Energy site is located within the tenure of PL253, and petroleum leases held by Arrow Energy and other CSG operators adjoin PL253 on all sides.

CSG activities extract groundwater and have the potential to influence regional groundwater gradients. This groundwater modelling study has been completed to provide predictions of changes to the groundwater hydraulic gradient in the vicinity of Lot 40 DY85 with respect to approved Arrow CSG development on PL253 and the adjacent petroleum leases PL493 and PL185.

The Office of Groundwater Impact Assessment (OGIA) has developed a groundwater model for the Surat Cumulative Management Area (SCMA), which has previously been utilised to complete modelling associated with PL253. In order to effectively incorporate new monitoring data and improve the confidence in predictions, a new model has been developed.

1.2 Purpose of this report

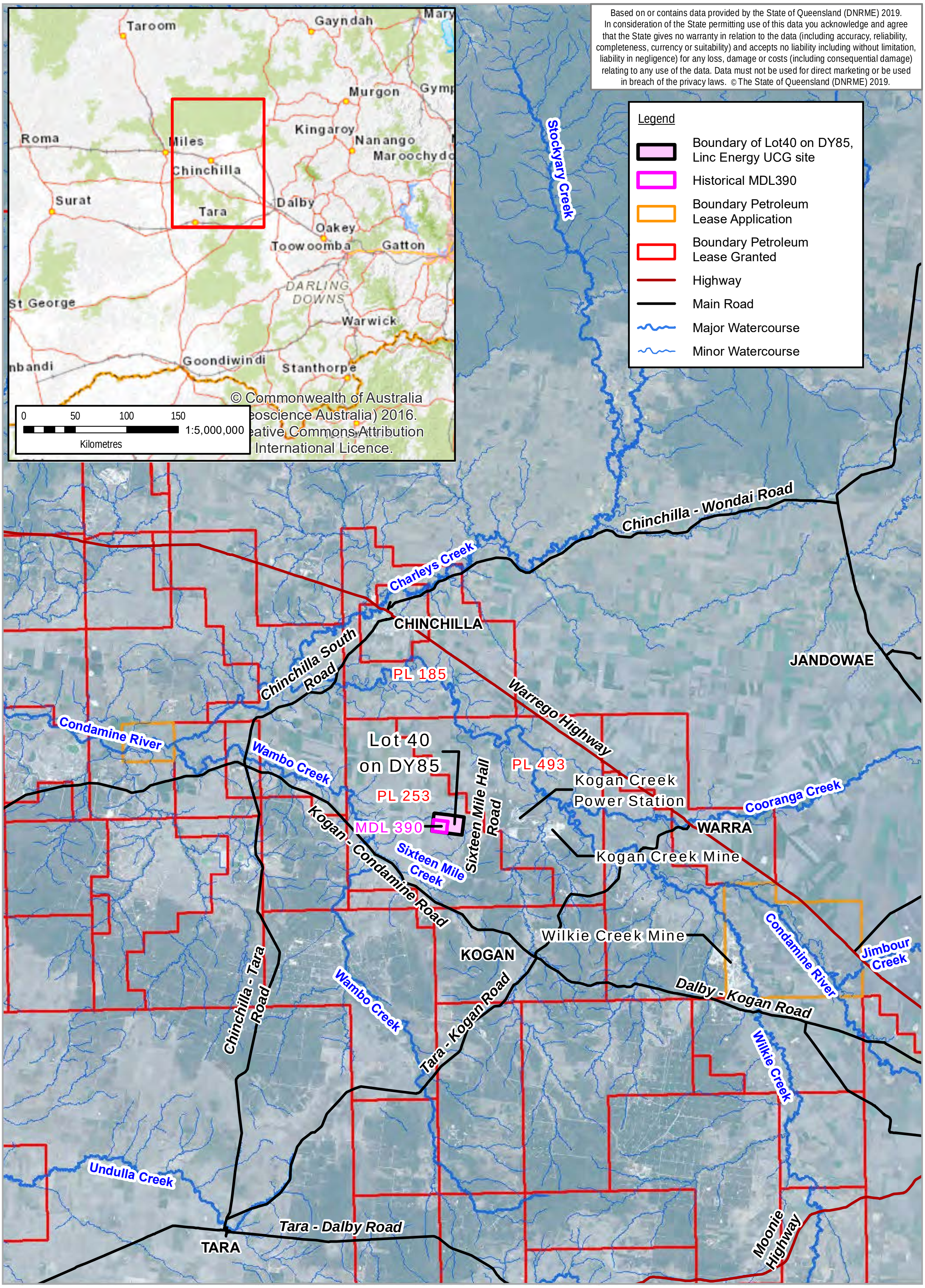
This report has been prepared to satisfy condition Water 1C of EA000140:

> *The environmental authority holder must annually calibrate the relevant groundwater model with the data collected as part of the Groundwater Characteristics Monitoring Program required under condition Water 1A*.

1.3 Scope of work

The following scope of work has been completed:

- Construction of a new groundwater flow model to represent groundwater conditions in and around PL253
- Calibration of the groundwater flow model utilising head data collected as part of the Groundwater Characteristics Monitoring Program (GHD, 2019a) as well as other supporting head and flow data
- Development of predictive scenarios to represent changes in groundwater flow conditions in the vicinity of Lot 40 DY85 associated with approved Arrow CSG development onPL253, PL185 and PL493
- Preparation of this report



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0 5 10 15 20

Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No. 41-32187
Revision No. B
Date 23 Oct 2019

Locality Map

FIGURE 1-1

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-01_locality_revA.mxd
Print date: 23 Oct 2019

Data source: DNRME: roads, watercourses, Petroleum Leases, Planning Cadastre (2019), imagery QldBase (2019), topo base map (2019). Created by: jvancooten

1.4 Scope and limitations

This report: has been prepared by GHD for Arrow Energy Pty Ltd and *may only be used and relied on by Arrow Energy Pty Ltd for the purpose agreed between GHD and Arrow Energy Pty Ltd as set out in section 1.2 of this report.*

GHD otherwise disclaims responsibility to any person other than Arrow Energy Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Arrow Energy Pty Ltd and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Assumptions

This report has been prepared to document the development and output of a numerical groundwater model. The groundwater model has been developed based upon information provided by others, including the Arrow geological model, data from the OGIA 2016 Surat CMA groundwater model, groundwater monitoring data supplied by Arrow and other data supplied by Arrow or sourced from government agencies. It is assumed that this information is correct and suitable to inform the model development.

2. Hydrogeological setting

2.1 Overview

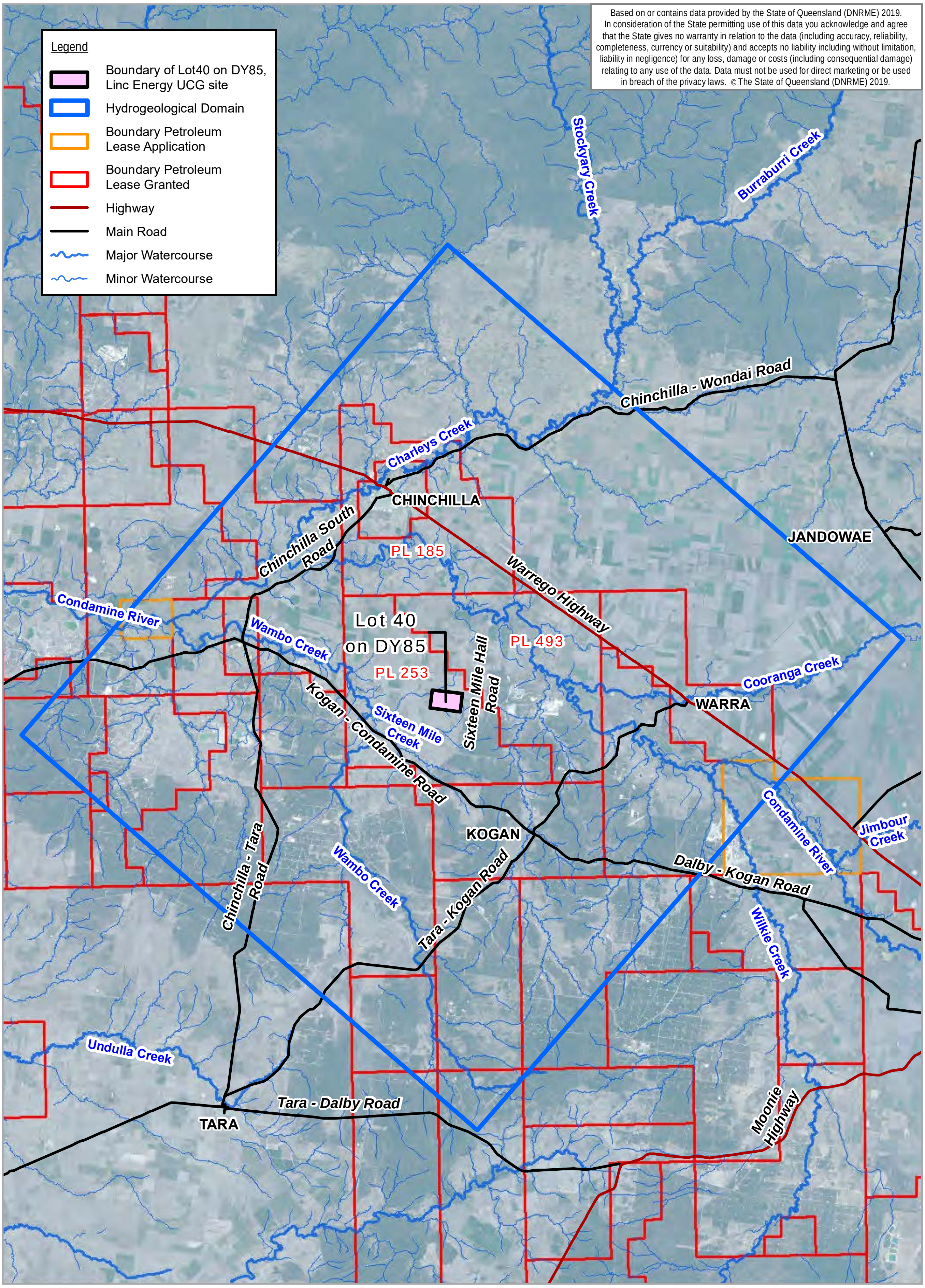
As outlined in Section 1, the purpose of this report is to describe the construction, calibration and predictions of the new groundwater model developed for an area encompassing PL253 utilising the data collected as part of the Groundwater Characteristics Monitoring Program. Hydrogeological information used to support the development of the model such as the distribution of piezometric heads, temporal trends and a range of aquifer properties are described in relevant sections of the report pertaining to the construction and calibration of the model. As such, the description of the hydrogeological setting and conceptual model presented in this section is limited to the delineation of hydrogeological domain, climate, topography and regional geology/hydrogeology.

For further details supporting the conceptualisation of the groundwater system refer to the Conceptual Model Report (Arrow Energy, 2018) and the Preliminary Site Investigation report (GHD, 2019b). For further details relating to the Groundwater Characteristics Monitoring Program, refer to GHD (2019a).

2.2 Hydrogeological domain

The hydrogeological domain defines the extent of the study area and ultimately the boundary of the numerical groundwater model. It should be large enough to capture key stresses on the groundwater system and their area of influence, both in the context of past and future activities.

Figure 2-1 presents the hydrogeological domain, with Lot 40 DY85 located in the centre. The hydrogeological domain has been developed to incorporate PL253, PL493 and PL185. The rectangular shape of the model boundary has been rotated so that the north-eastern boundary approximates the extent of the Walloon Coal Measures, while the north-west and south-eastern boundaries have are parallel to the strata dip and regional groundwater equipotential lines. The hydrogeological domain measures approximately 58 by 63 km with an area if 3,674 km^2.



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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

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Hydrogeological Domain

FIGURE 2-1

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Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

2.1 Climate

The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) hosts an enhanced climate databased called SILO. SILO contains Australian climate data from 1889 in two formats: Patch Point and Data Drill. Patch Point data is station data with gaps infilled using the closest nearby record. Data Drill is a synthetic dataset, compiled based on interpolation between nearest weather stations across Australia for any given point. Patch Point data was downloaded for the Chinchilla Water Treatment Plant (BoM station 41017).

Key monthly statistics for the site are summarised in Figure 2-2, and indicates that the area experiences hot, wet summers and cool, dry winters. Average evaporation exceeds rainfall in all months. Average climate data over the preceding thirty years (1989 to 2018) indicates annual average rainfall of 591 mm and evaporation of 1,929 mm/y.

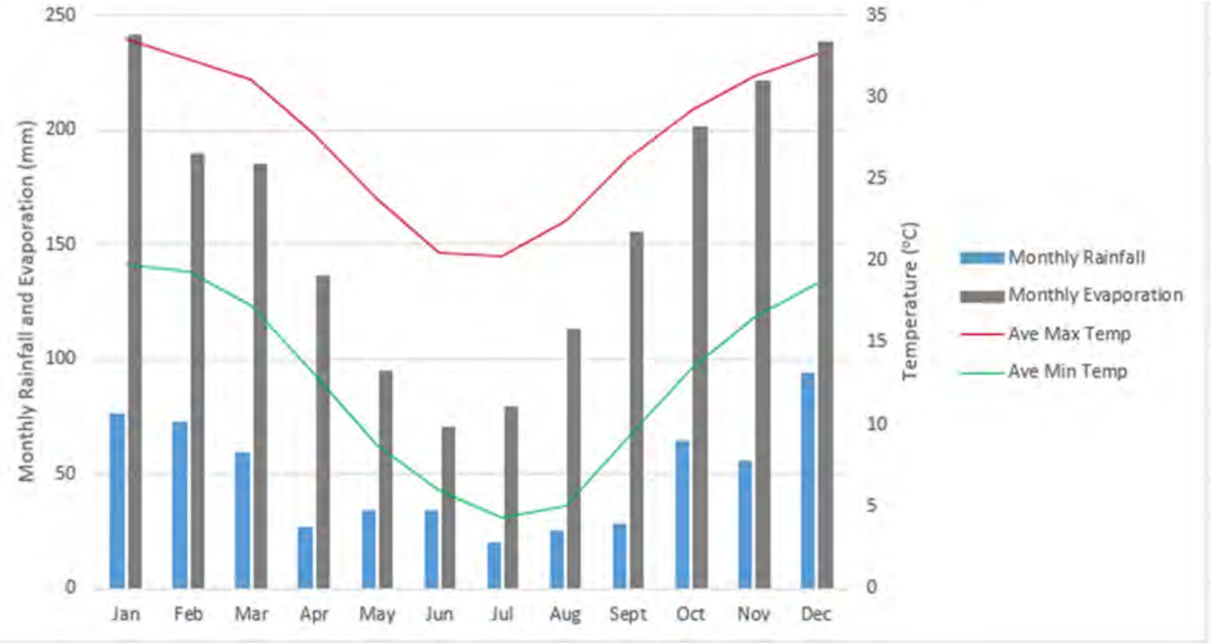
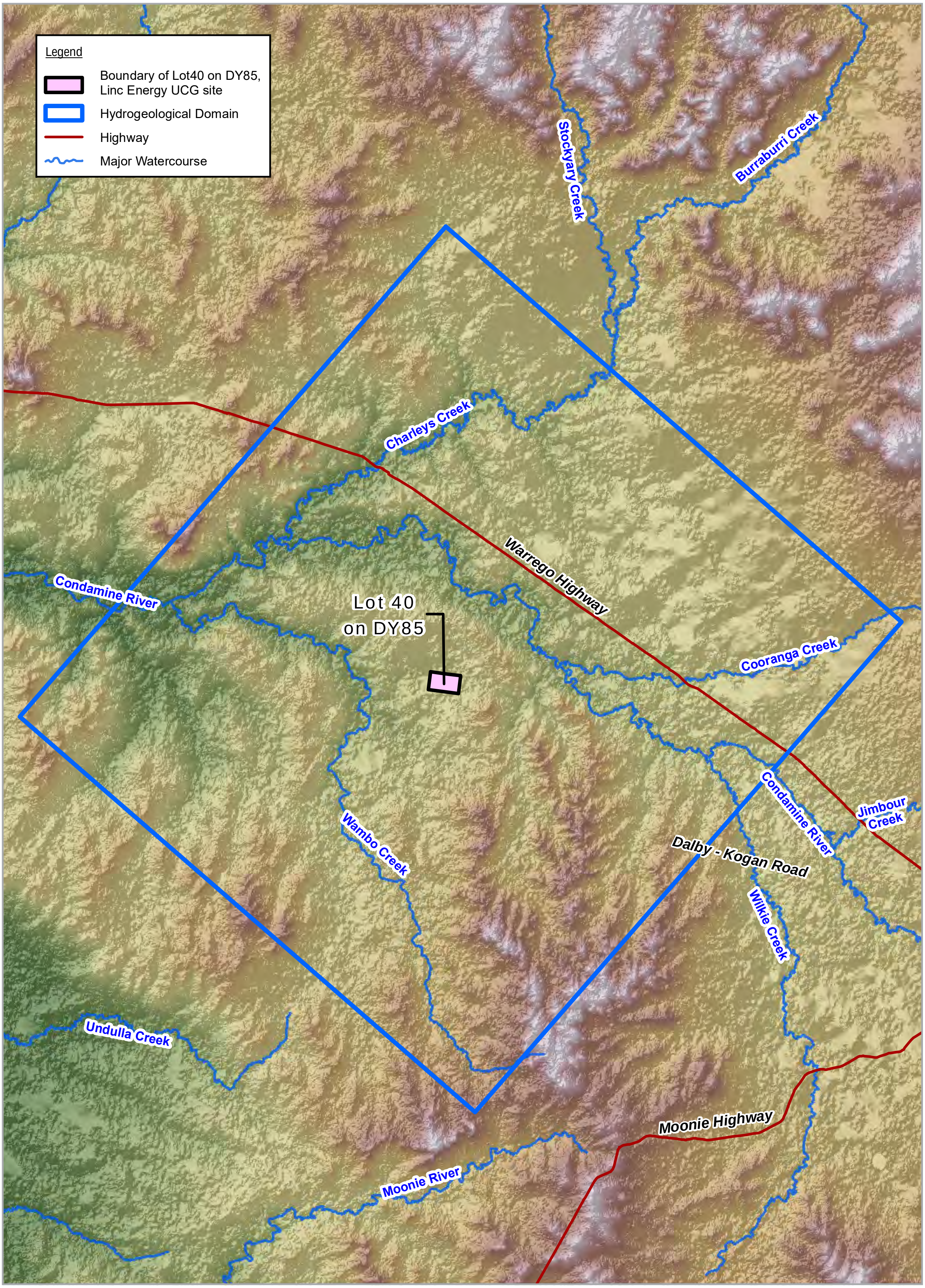


Figure 2-2 Average Climate Data

2.2 Topography and drainage

The topography and drainage of the hydrogeological domain and surrounding area is presented in Figure 2-3. The hydrogeological domain comprises of a westerly draining basin, with ground elevations ranging from approximately 209 mAHD in the west to 420 mAHD in the south. Across Lot 40 DY85 the land surface is relatively flat, ranging from approximately 315 to 320 mAHD. The hydrogeological domain is drained by the westerly flowing Condamine River that passes through the central portion of the domain, as well as the south-westerly flowing Charleys Creek and the north-westerly flowing Wambo Creek



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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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Topography and Drainage

FIGURE 2-3

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Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

2.3 Geology

The CSG targets within the Surat Basin are located within the Walloon Coal Measures (WCM). In the Surat Basin the WCM are divided into two main coal-bearing intervals; Juandah Coal Measures and the Taroom Coal Measures, with each interval further divided into lithostratigraphic coal seam packages (groupings of cycles/seams), in descending order: Kogan, Macalister, Wambo, Argyle, Upper Taroom and Condamine Members (Arrow 2014). The Juandah and Taroom Coal Measures are separated by the Tangalooma Sandstone, the Taroom Coal Measures are underlain by the Eurombah Formation. The stratigraphic sequence of the Surat Basin and Walloon Coal Measures is shown in Figure 2-4, while geological mapping is presented in Figure 2-5 (surface geology) and Figure 2-6 (solid geology)Figure 2-5

The top of the Walloon Coal Measures is marked by an erosional unconformity (base of the Springbok Sandstone), and is identifiable by a change in lithology from clean pale grey quartz sandstone to interbedded silts, clays, coals and dark grey clay chocked sandstones (Arrow 2014).

In general the lithology of the stratigraphic units are described as follows (Perkins *et.al.* 2013, Jell, 2012):

- Tertiary – Quaternary cover – uppermost unit – comprises clay, clayey silt and clayey sand deposited on the Condamine river floodplain during regular flooding events. The alluvium is unconformably underlain by Westbourne Formation and Springbok Sandstone.
- Jurassic-aged Westbourne Formation – sequence of medium grey interbedded carbonate cemented lithicfeldspathic siltstones
- Jurassic-aged Springbok Sandstone – fine sandstones with minor carbonaceous mudstone, mudstone and coal stringers. Medium to coarse grained, weakly cemented quartzofeldspathic sandstone lenses less than 1 m in thickness are noted in many drillholes, and form localised but discontinuous water-bearing zones. Near the contact with the coal, the fine sandstone and siltstone becomes increasingly interbanded/interlaminated with carbonaceous mudstone and rare coal stringers.
- Jurassic-aged Walloon Coal Measures – labile sandstones, siltstone, mudstone and coal in the upper half to two-thirds of the formation, with lesser calcareous sandstone, impure limestone and ironstone. The lower part of the unit represents stacked overbank deposits within highly sinuous fluviatile systems and the upper part of the unit was deposited as coal swamps.
- Jurassic-aged Hutton Sandstone – sublabile to quartzose sandstones with interbedded siltstone and shale, with minor coal and mudstone.

The Jurassic-aged strata dips to the south-west, and sub-crops in a series of broadly parallel north-west to south-east trending alignments as displayed on Figure 2-6.

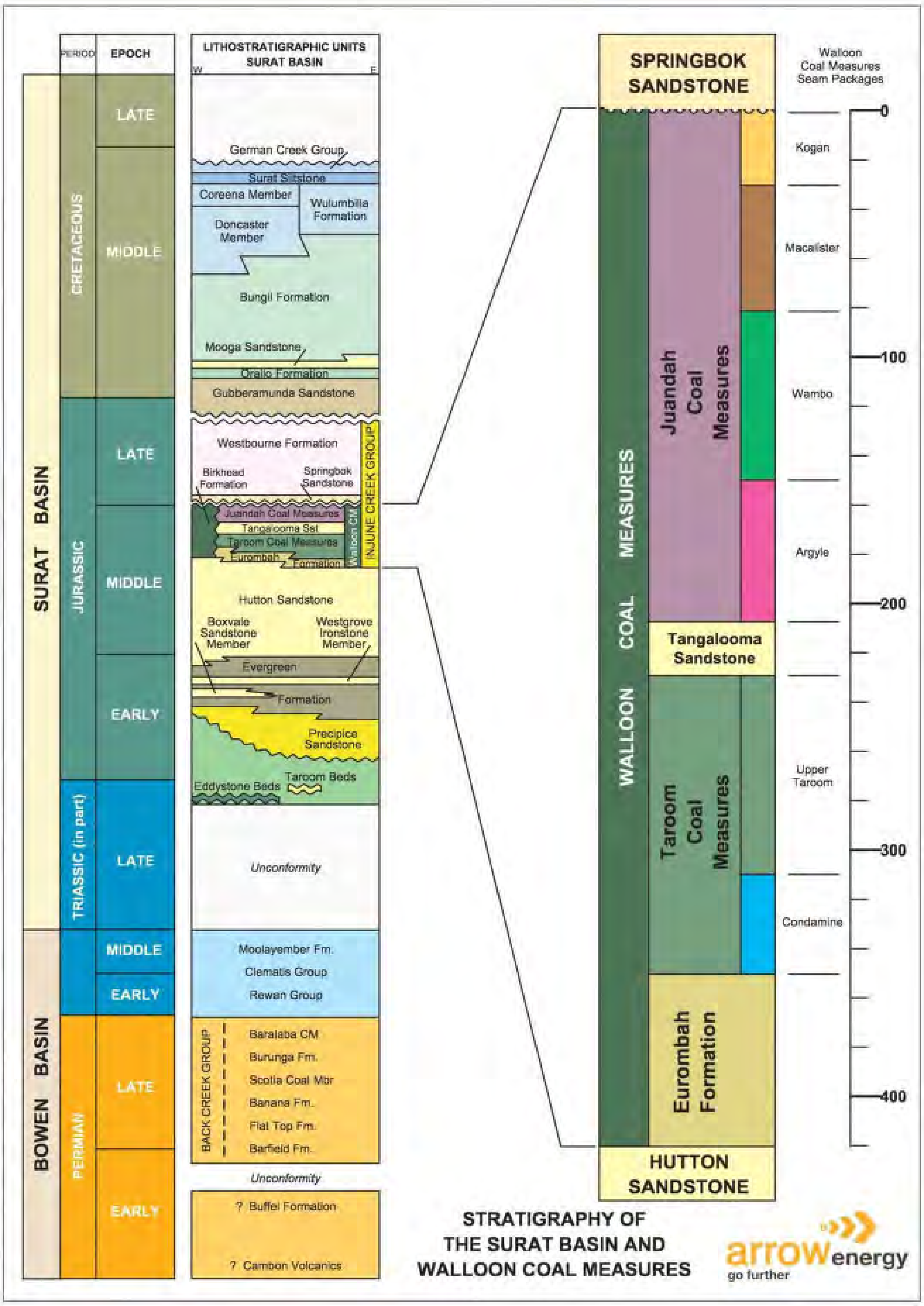
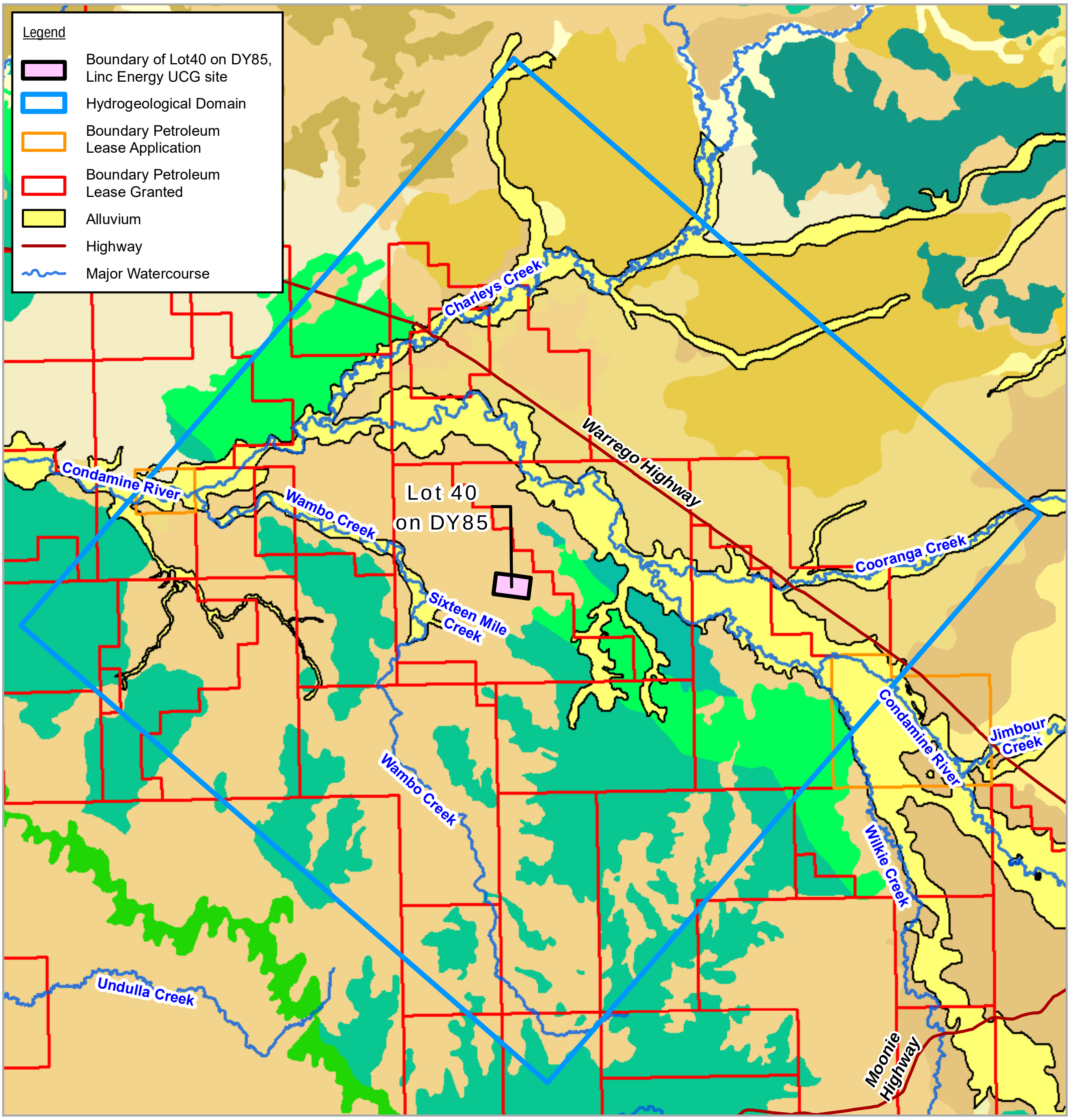


Figure 2-4 Stratigraphic sequence of the Surat Basin and the Walloon Coal Measures (Arrow 2014)



Surface Geological Details

- 🟩 Bungil Formation
- 🟨 Chinchilla Sand
- 🟨 Chinchilla Sand>Main Range Volcanics
- 🟩 Hutton Sandstone
- 🟩 Kumbarilla beds
- 🟩 Kumbarilla beds(w)
- 🟧 Main Range Volcanics
- 🟧 Main Range Volcanics?
- 🟩 Marburg Subgroup
- 🟩 Marburg Subgroup>Tib-QLD
- 🟨 Qa-QLD
- 🟨 Qa-QLD>Main Range Volcanics
- 🟨 Qa\b-QLD
- 🟨 Qa\b-QLD>Main Range Volcanics
- 🟨 Qpf-SEQ
- 🟨 Qrs-SEQ
- 🟨 Qrs-SEQ>Main Range Volcanics
- 🟨 Qs-SQ
- 🟨 Qs-SQ>Bungil Formation
- 🟨 Qs-SQ>Kumbarilla beds
- 🟨 Qs-SQ>Main Range Volcanics
- 🟨 Qs-SQ>Springbok Sandstone
- 🟩 Springbok Sandstone
- 🟩 Springbok Sandstone (w)
- 🟨 TQf-SEQ
- 🟨 TQf-SEQ>Main Range Volcanics
- 🟨 TQr\b-SEQ
- 🟫 TQs-QLD
- 🟫 TQs-QLD>Main Range Volcanics
- 🟫 Ts(w)-QLD
- 🟩 Walloon Coal Measures(w)
- Waterhole

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Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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Surface Geology

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FIGURE 2-5

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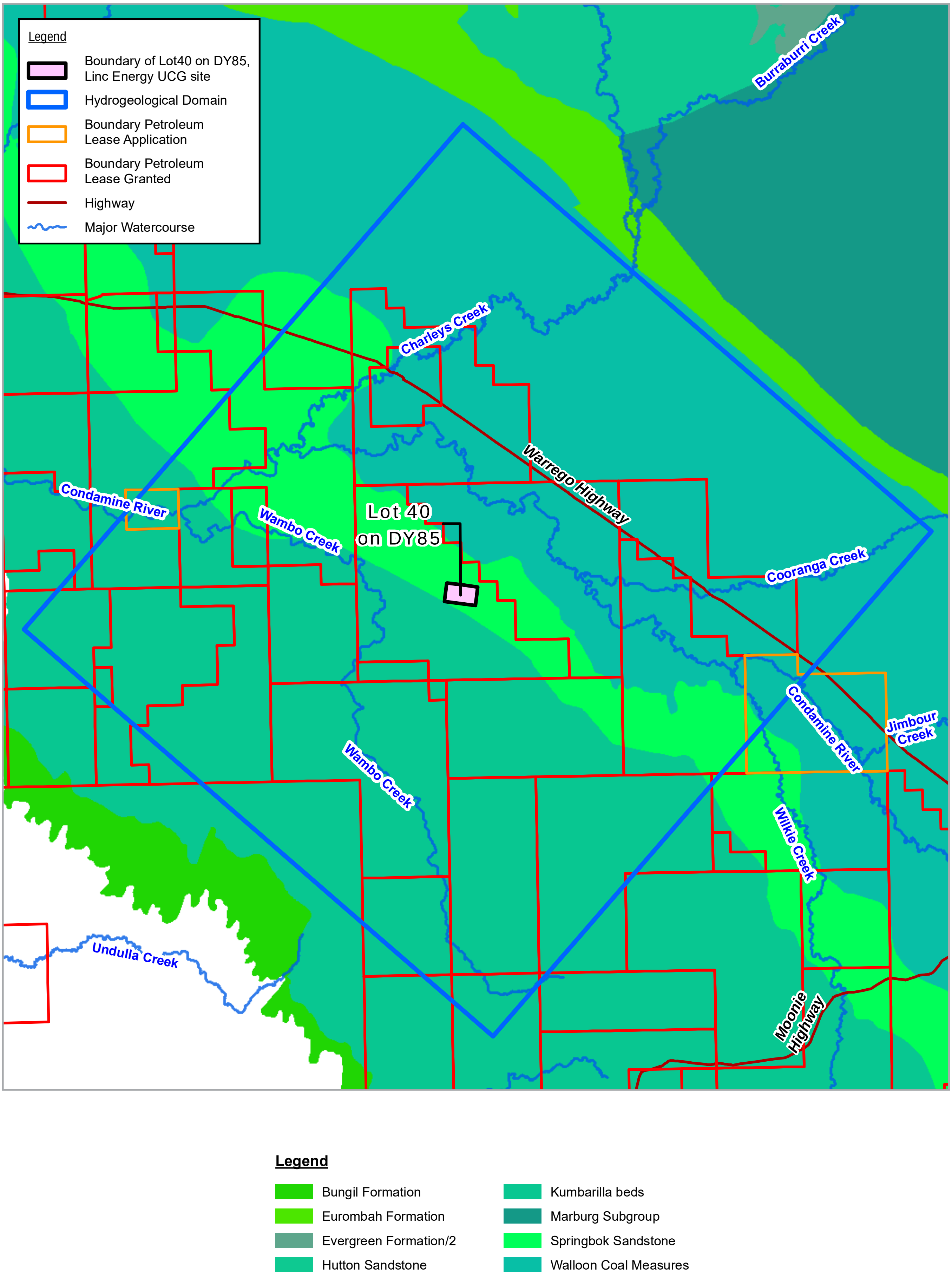
Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten



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Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

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Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

Solid Geology

FIGURE 2-6

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Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

2.1 Hydrogeology

Regionally there are significant aquifers within the Surat Basin and these are identified in Figure 2-7 (after OGIA UWIR 2016).

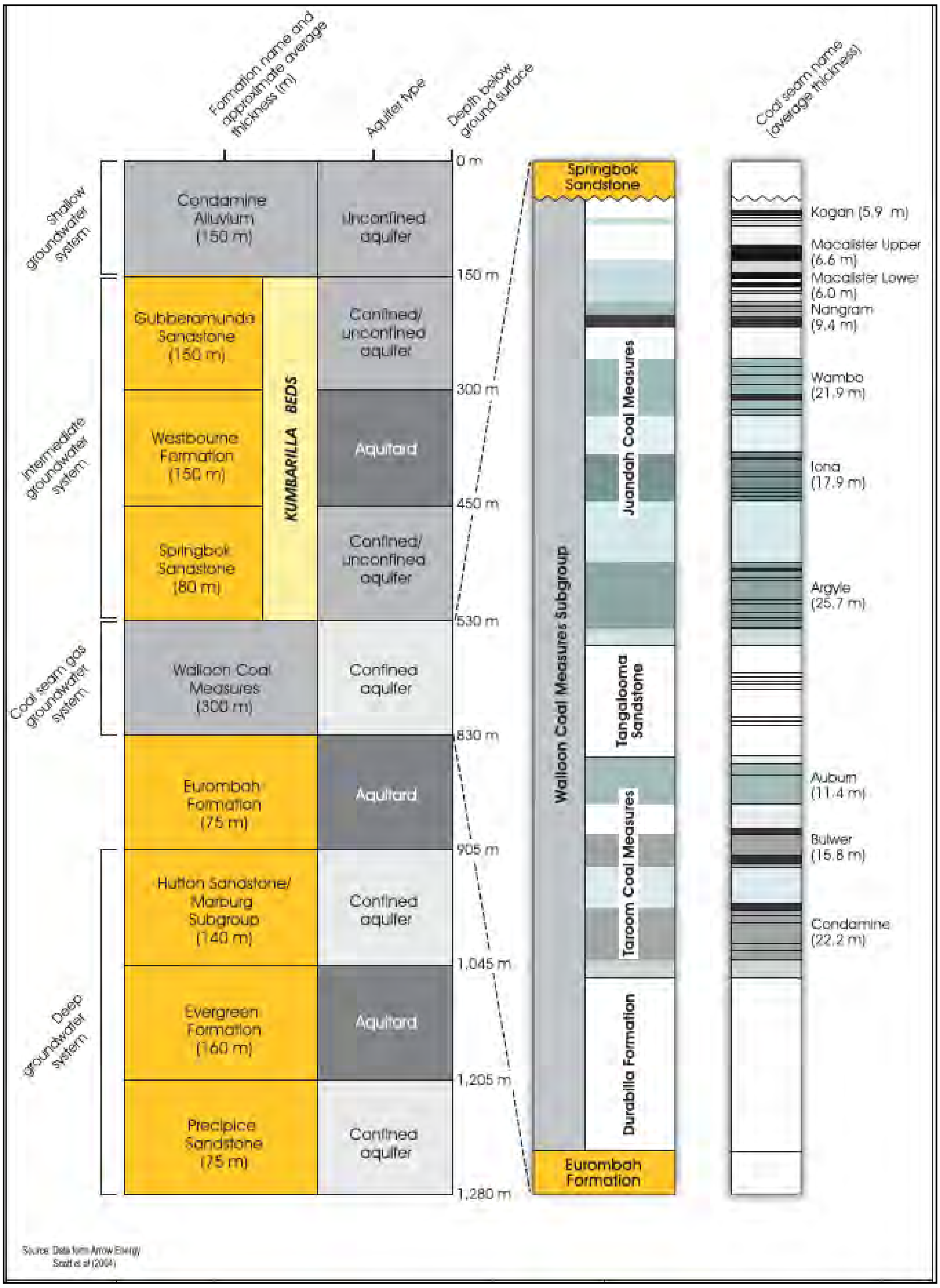
The regional groundwater flow direction is locally to the north along the eastern margin of the Surat Basin, where the confined aquifers sub-crop, becoming westerly towards the centre of the basin, following the overall dip direction of the strata. Over time, the CSG extraction activities in the west and south of the hydrogeological domain have induced regionally significant cones of depression in the piezometric surface of the confined coal seam aquifers, resulting in more westerly flow. The effect of CSG activities within the hydrogeological domain is evidenced by the gradual lowering of piezometric heads over time as well as low piezometric heads observed in a number of bores screened in the Springbok Sandstone and Walloon Coal Measures

The coal seams are interbedded between aquitards (interburden) that limit vertical movement of groundwater between each aquifer unit. Groundwater pressure (hydraulic) gradients between the aquifers are generally downward from the Springbok Sandstone to the Walloon Coal Measures and upward from the Hutton Sandstone to the Walloon Coal Measures. These vertical gradients have been recorded in a number of nested monitoring sites within the hydrogeological domain, which are used as key observation targets to calibrate the groundwater model (see Section 4.2.2).

Regional horizontal hydraulic conductivity data, as compiled by OGIA (DNRM 2016) from core tests, drill stem tests and pumping tests, indicates that there are a wide range of hydraulic conductivity values for the Springbok Sandstone and Walloon Coal Measures (refer to the Surat CMA UWIR 2016, Appendix C, Figure C-1). These values provide the basis for setting the realistic range of values used to calibrate the model parameters (see Section 4.2.4).

Groundwater bores within the hydrogeological domain are typically used for water supply for the purposes of stock watering, crop spraying and general domestic use (e.g. on gardens).

Recharge to the intake beds of the confined aquifers of the Surat Basin is low, with a typical range of value of 0 – 3 mm/year (Kellet et al, 2003). A recharge rate of 1 mm/year has been used previously in the numerical modelling of the Surat Basin (SWS, 2011).



Source: Data form Arrow Energy
Scott et al (2004)

Figure 2-7 Hydrostratigraphic units of the Surat Basin (after OGIA 2016)

3. Model design and construction

3.1 Overview

CSG activities in the Surat Basin result in the removal of groundwater and depressurisation of coal seams to facilitate the extraction of gas. The location and scale of CSG activities across the basin have resulted in regional changes to groundwater gradients and flow directions, and these impacts are predicted to continue into the future associated with ongoing CSG development in the region.

Groundwater contamination is understood to exist within the former Linc Energy site (Lot 40 DY85), and changes in regional groundwater gradients have the potential to contribute to the migration of contamination away from Lot 40 DY85. The groundwater modelling described in this section has been conducted at a sub-regional scale commensurate with the scale of CSG activities and associated influence on groundwater gradients, while providing localised refinement at and around Lot 40 DY85.

3.2 Model design and construction

3.2.1 Software selection

MODFLOW-USG (hereafter referred to as MF-USG) has been selected as the most appropriate groundwater modelling software for this study. MF-USG is an unstructured grid version of the industry standard MODFLOW code developed and maintained by the United States Geological Survey (Panday et al, 2013). Advantages of MF-USG include flexible meshing for efficient refinement of model cells in the area of interest and robust handling of saturation and desaturation of model cells for tracking the location of the water table. The model layers can also ‘pinch out’ where hydrostratigraphic units (HSUs) are not present and cells are not required throughout the model domain. This has flow-on benefits to the modern requirements of modelling projects such as run-intensive calibration and uncertainty analysis.

The unstructured mesh of the MF-USG model has been generated using AlgoMesh 1.2 (HydroAlgorithmics, 2016) and model input files have been prepared using a combination of AlgoMesh, Geographic Information Systems (GIS) and a range of in-house and third-party utilities. The model runs have been undertaken using a version of MF-USG called USG-Transport version 1.1.0, distributed by GSI Environmental, which supports advanced capabilities such as adaptive time stepping.

3.2.2 Model domain and unstructured mesh

Figure 3-1 presents the MF-USG model mesh. The extent of the model is the same as the hydrogeological domain defined in Section 2.1, where the model boundaries follow hydrogeologically sensible boundaries, encompassing the margin of the Surat Basin where the coal seams of the Walloon Coal Measures sub-crop. The domain is centred on Lot 40 DY85 and is large enough incorporate the cumulative effect of CSG activities associated with Arrow’s future development to the north and east as well as those associated with other CSG producers to the west and south.

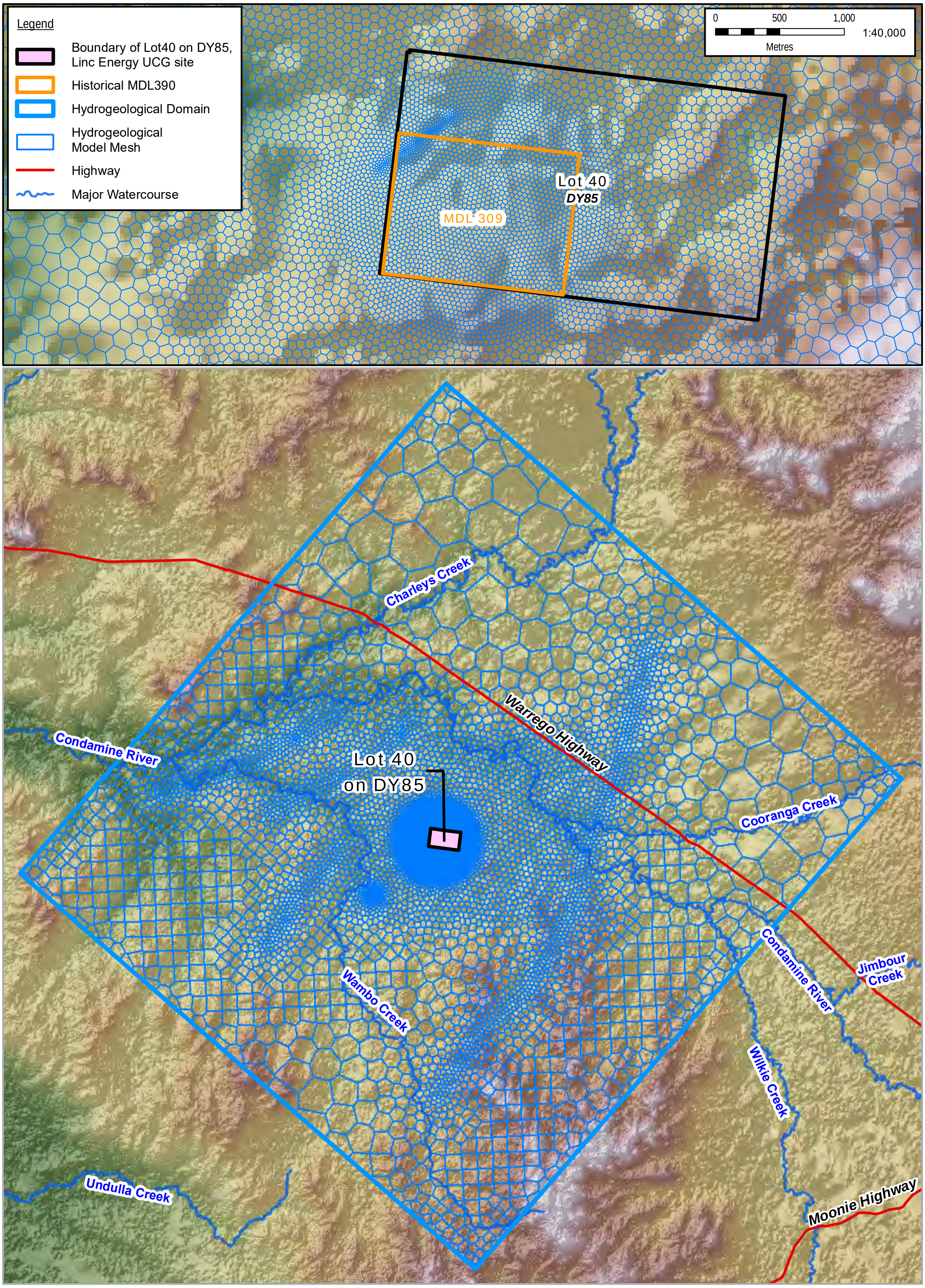
The model mesh uses voronoi-shaped (tessellated) cells (a shape considered numerically ideal for MF-USG’s control volume finite difference method). The mesh generation process has been iterative, based on careful consideration of the following:

- Target total cell number of less than 300,000 for the whole model, based on the requirement for run-intensive calibration and uncertainty analysis where sensible model run times are critical. For a multi-layered aquifer system with >10 layers, a cell count of less than 20,000 per layer was targeted.

- Fine mesh refinement in the area of Lot 40 DY85, with a cell edge length of 50 m over a 2 km wide area encompassing the former Linc Energy site, extending to a cell edge length of 100 m over a 5 km wide area and then 200 m over an 8 km wide area. The mesh was refined radially around Lot 40 DY85, as the flow conditions at and around this area could be influenced by the surrounding CSG activities from all directions.
- Fine mesh refinement in the area of Hopeland pilot testing site, where measurements of piezometric heads and groundwater extraction rates are available from the pilot testing program to enable rigorous transient calibration. The mesh was refined radially over an area encompassing the 6 CSG wells, consistent with the radial area of influence of pumping, with a minimum cell edge length of 30 m to simulate the local flow conditions.
- Mesh refinement over the area of PL253 and adjacent PL493, with a target edge length of 800 m, increasing gradually towards the boundary of the model. The mesh was optimized using AlgoMesh's highest pre-set quality to achieve ideal cell shapes with minimal offsets from adjacent cell centres.
- CSG gas wells and key observation bores (within PL253) were used as constrained points to align cell centres with the location of these features.
- Mesh refinement and constrained points along regionally significant faults, where displacement of stratigraphic layers is present in Arrow's geological model. Additionally, constrained points were introduced along a local northeast to southwest trending fault in the northwest corner of the former Linc Energy site based on the extent of fault delineated by Blinderman and Fidler (2003). Mesh refinement along these features enable the effects of faults to be simulated as flow barriers or pathways at their mapped locations, if required.

The model mesh has 14,766 cells per complete layer, covering an area of 3,674 km^2. The model has 13 layers with pinch outs (discontinuity), giving a total of 167,706 cells (well below the target 300,000 threshold).

The groundwater model documented in this report has been developed to support future contaminant transport modelling. Specifically, the grid has been designed to maintain the Peclet and Coutant numbers below 1.



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0 5 10 15 20

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No.	41-32187
Revision No.	B
Date	23 Oct 2019

Model Mesh

FIGURE 3-1

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Print date: 23 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

3.2.3 Model layers

Table 3-1 summarises the relationship between the model layers and hydrostratigraphy. The model layers have been derived from the surfaces of key stratigraphic units in Arrow's geological model. The ground surface, corresponding to the top of model layer 1, is set using the 30 m by 30 m resolution digital elevation model (DEM). Each model layer represents a particular hydrostratigraphic unit (HSU) with the exception of the following:

- Layer 1 represents the Condamine Alluvium to the east and the Gubberamunda Sandstone to the west. These two HSUs represent the uppermost aquifers in the model which are disconnected laterally by pinch outs. Surficial geology is not represented within the model as shallow units do not form regionally significant aquifers and detailed simulation of the shallow groundwater system is not the focus of this study.
- Layer 6 represents a numerical layer created by splitting the Wambo seam into two layers. It is only present locally in the area of mesh refinement encompassing Lot 40 DY85, where vertical resolution is important for simulating the exchange of fluxes between HSUs in the vertical direction e.g. downward leakage induced by CSG depressurisation.

All model layers except for layers 12 and 13 (Eurombah Formation and Hutton Sandstone) have pinch outs, as their lateral extents are not continuous throughout the model domain. The model is not discretised vertically down to the level of individual seams, which would not be practical at the scale of the model. Rather, the individual seams and interburdens are grouped into units whose properties are representative of the aquifers at their respective position within the Walloon Coal Measures. This is appropriate for the intended use of the model, as the individual model layers below Lot 40 DY85 have thicknesses typically ranging from 15 to 50 m, which are comparable to the minimum cell dimension in the horizontal direction.

Table 3-1 HSUs and model layers

Model layer	Hydrostratigraphic units	Cell count	Pinch out	MF-USG layer type
1	Condamine Alluvium / Gubberamunda Sandstone	2,145	Yes	4 – Convertible Upstream
2	Westbourne Formation	13,490	Yes	4 – Convertible Upstream
3	Springbok Sandstone	13,639	Yes	4 – Convertible Upstream
4	Walloon Coal Measures (Kogan)	13,634	Yes	4 – Convertible Upstream
5	Walloon Coal Measures (Macalister)	13,892	Yes	4 – Convertible Upstream
6	Walloon Coal Measures (Wambo)	9,183	Yes	4 – Convertible Upstream
7	Walloon Coal Measures (Wambo)	14,178	Yes	4 – Convertible Upstream
8	Walloon Coal Measures (Argyle)	14,346	Yes	4 – Convertible Upstream
9	Walloon Coal Measures (Tangalooma Sandstone)	14,365	Yes	4 – Convertible Upstream
10	Walloon Coal Measures (Upper Taroom)	14,579	Yes	4 – Convertible Upstream
11	Walloon Coal Measures (Condamine)	14,723	Yes	4 – Convertible Upstream
12	Eurombah Formation	14,766	No	4 – Convertible Upstream
13	Hutton Sandstone	14,766	No	4 – Convertible Upstream

Figure 3-2 presents an east to west cross-section from the numerical model, showing the general dip of the strata to the west and sub-cropping of the Walloon Coal Measures beneath the Condamine Alluvium to the east. The lateral extent of each model layer is presented in Appendix A.

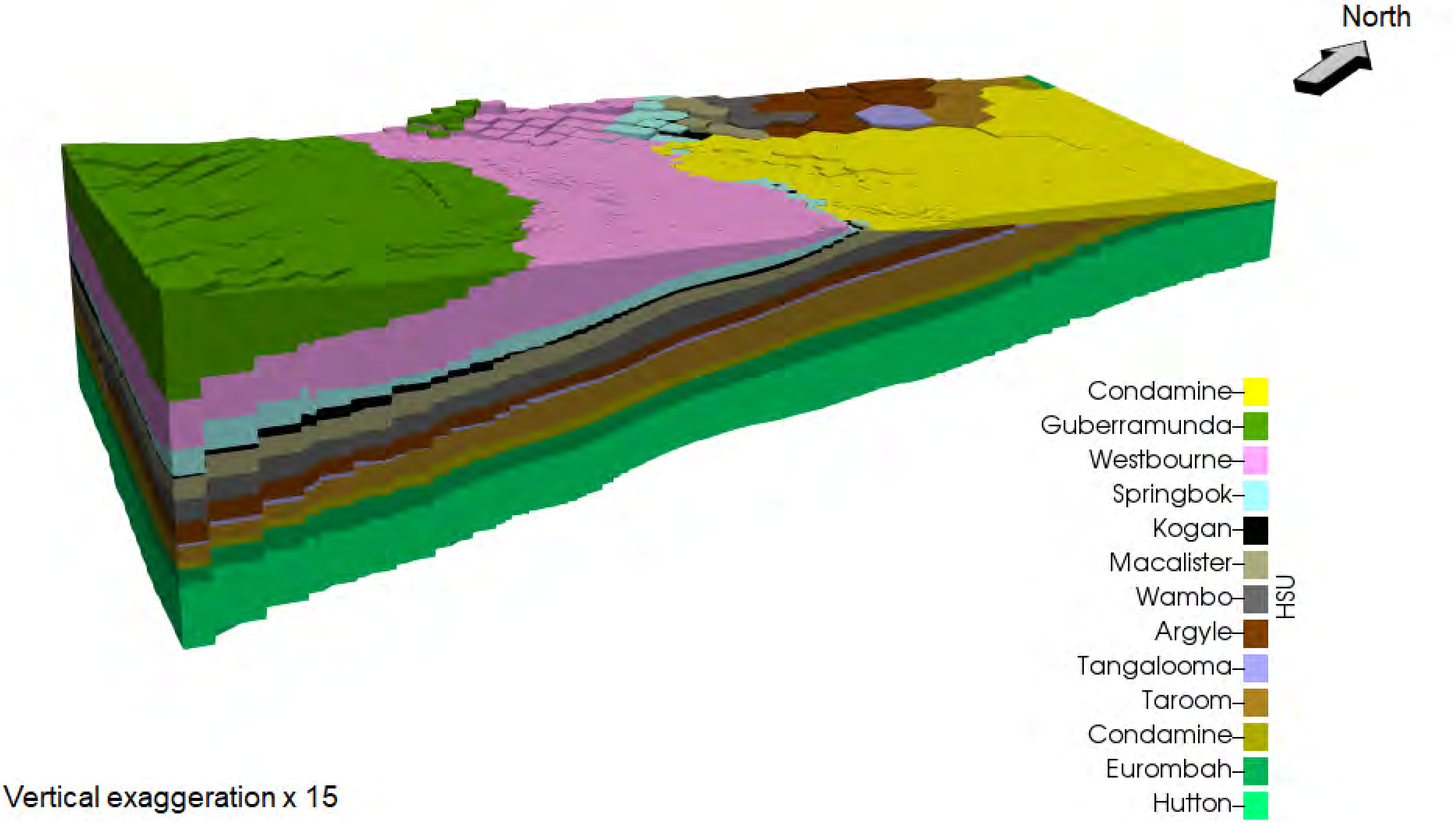


Figure 3-2 Model cross-section

3.2.4 Boundary conditions

General head boundary condition

The piezometric heads in the area surrounding the model domain are lowered over time by the regional CSG activities. In order to ensure the fluxes into and out of the model are consistent with this regional lowering of heads, General Head Boundaries (GHB) are prescribed along the model boundaries using time-varying heads from the 2016 groundwater model developed by the Office of Groundwater Impact Assessment (OGIA) for the Surat Cumulative Management Area (Surat CMA).

The GHB nodes have been mapped to the northern, western and southern model boundaries using the heads from the nearest OGIA model cell in the corresponding model layer (excluding a small number cells where the OGIA model heads were below cell bottom). The eastern model boundary is represented as a no flow boundary, where the Hutton Sandstone sub-crops and regional groundwater flow is driven by recharge (leakage from the Condamine Alluvium).

The conductance of each GHB node is calculated using the thickness, cell edge length and horizontal hydraulic conductivity.

Well boundary condition

The well (WEL) boundary condition is used to prescribe groundwater fluxes from the CSG production wells. For the non-Arrow production wells, the groundwater fluxes have been sourced from the drain fluxes used to simulate CSG groundwater extractions in the 2016 OGIA model. The drain fluxes indicate that groundwater extraction from the non-Arrow CSG wells occur from the Upper, Middle 1 and Middle 2 Walloon Coal Measures. As the 2016 OGIA model splits the Walloon Coal Measures into layers of approximately equal thickness, these fluxes have been apportioned equally to model layers 5 (Macalister seam) , layer 7 (Wambo seam) and layer 8 (Argyle seam) which broadly align with the Upper, Middle 1 and Middle 2 Walloon Coal Measures of the OGIA model respectively.

For the Hopeland pilot wells, where the bore construction details are known and measurements of groundwater fluxes and piezometric heads are available, a combination of the WEL package and Connected Linear Network (CLN) package are used. The CLN package allows a 1D cylindrical feature much smaller than the dimension of the cell, such as a well, to be simulated implicitly. In this study, the well fluxes are applied to the lowermost cell intersected by the well using the WEL package and the CLN node is connected to all of the overlying layers intersected by the well. This allows well fluxes assigned to the lowermost node to be distributed to all of the overlying layers screened by the well in a manner similar to MODFLOW’s Multi-Node Well (MNW) package without having to pre-assign appropriate fluxes per layer that may result in flow reductions if cells go dry.

Recharge

Recharge is assigned to layer nodes in a simple manner, using the recharge (RCH) package with a time constant recharge rate.

3.2.5 Model parameterisation

Parameterisation involves making choices about how the spatial distribution of aquifer properties will be represented in the model (Barnett et al., 2012). Models with the smallest number of parameters possible are described as parsimonious, whereas models with a large number of spatially varying parameters are described as highly parameterised. In modelling studies, a balance is sought between parsimony and complexity (highly parameterised spatial variability) that is consistent with the objective of modelling, the physical system of interest and supporting data.

In this study, the model has been parameterised on a HSU basis; however, hydraulic conductivities have been varied spatially within the key HSUs via interpolation of parameter values assigned to strategically positioned points called ‘pilot points’ (Doherty, 2003). Spatial variability in hydraulic conductivities, both horizontally and vertically, allows flexibility in the parametrisation of heterogeneous aquifers. This is particularly relevant where the observation data used to parameterize the model are sourced from a combination of sparse regional datasets and local monitoring network associated with key sites (such as the Hopeland pilot testing site), indicating spatial differences in groundwater behaviour across the model domain.

Specific yield and specific storage are assigned a constant value to each HSU, applying the principal of parsimony where appropriate and introducing complexity (spatial variability) as necessary to simulate the physical system of interest in a manner consistent with the data available.

4. Model Calibration

4.1 Calibration approach

4.1.1 Calibration set up

Model calibration involves changing the values of model parameters within bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012). The quality of model calibration is typically assessed against a predefined value of goodness of fit between simulated and observed values, using statistical measures such as the Scaled Root Mean Squared (SRMS) error. However, other criteria such as low mass balance errors and sensible model outputs consistent with the expected groundwater behaviour can be used to assess whether or not the model is fit for purpose.

The key calibration targets in this study are measured piezometric heads in groundwater bores distributed across the model domain, including temporal trends associated with CSG depressurisation activities and vertical head differences at nested monitoring sites. Model calibration targets also include new monitoring data obtained through the Groundwater Characteristics Monitoring Program.

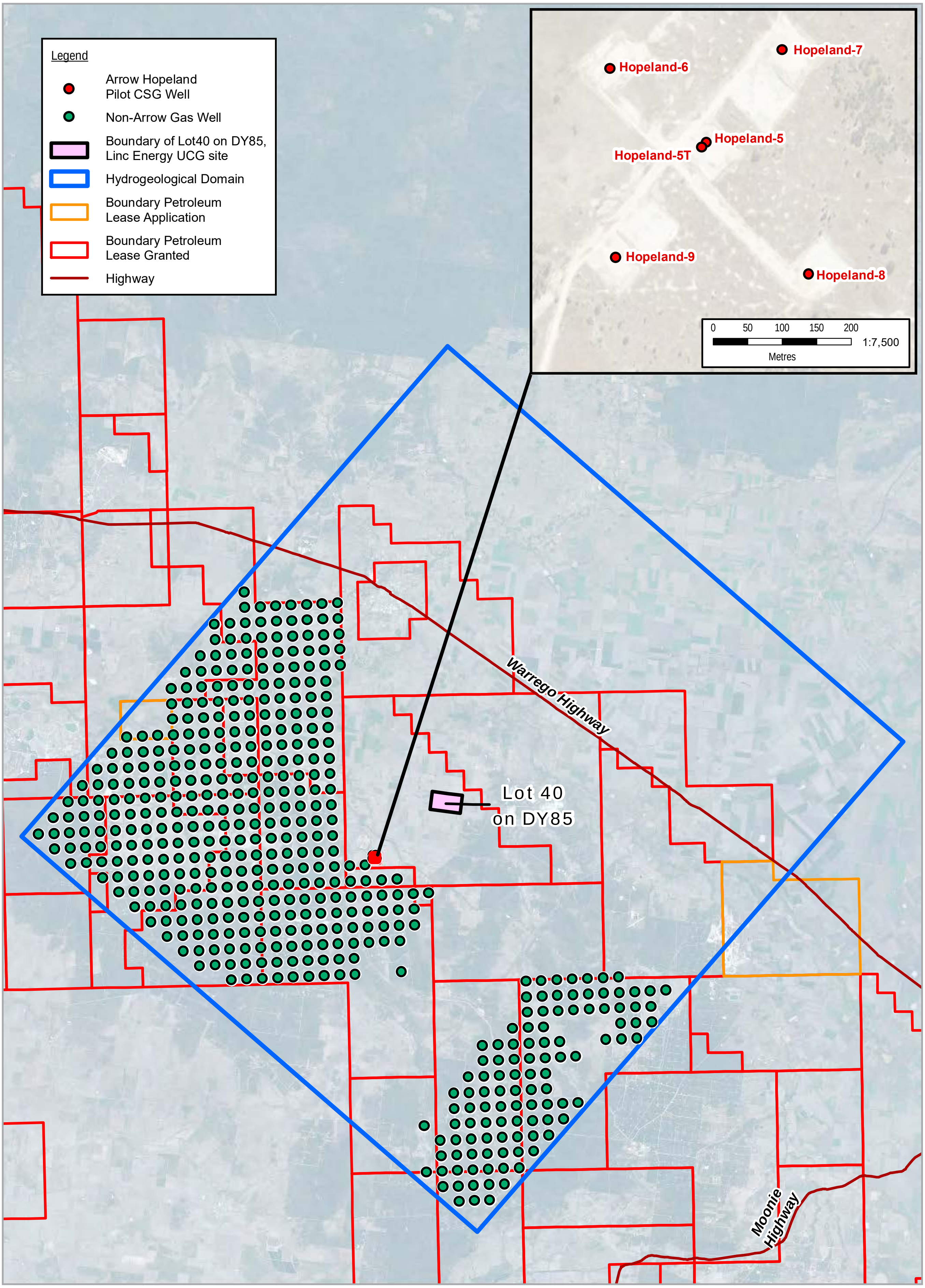
The heads computed by the 2016 OGIA model indicate that the effect of CSG activities reaches the model boundary at around year 2004. For this reason, the calibration period has been extended back to 2000 to incorporate a quasi-steady state pre-development condition with a steady state solution providing a set of initial heads. The transient calibration period extends for 19 years, using a yearly stress period from 2000 to end of 2013, reducing to monthly stress periods thereafter, corresponding with the timing of commencement of Arrow's Hopeland pilot testing program. A total of 74 stress periods were used.

4.1.2 CSG extractions

As described in Section 3.2.4, the influence of historical non-Arrow CSG activities is simulated in two ways:

1. Using the heads from the 2016 OGIA model as time-varying GHBs along model boundaries
2. Using the drain fluxes from the 2016 OGIA model as prescribed flux boundaries within the model domain using the WEL package.

The CSG activities associated with Arrow's project are limited to the Hopeland pilot study area on PL253, where measured groundwater extraction rates from 6 CSG wells are available from March 2014 to end of 2018. These extraction rates have been converted into monthly average rates in accordance with the monthly stress periods. The location of CSG wells incorporated during the calibration period are presented on Figure 4-1.



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Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

CSG Wellfields
Calibration Phase

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-1

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Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

4.1.3 Calibration targets

The piezometric heads used as calibration targets have been supplied by Arrow. These include a combination of manual measurements collected from landholder bores (typically limited to one to three readings) and time series of measurements from dedicated monitoring bores/piezometers. The calibration targets have been limited to those from bores/piezometers where either the target depth or screened/intersecting HSU is known. Where a large number of data logger measurements are available, these have been reduced to one reading per week to minimise the number of observation targets (well within the monthly stress periods used for the calibration).

A total of 98 head target locations and 3,321 head observations are utilised for calibration. Additionally, head difference targets, representing the change in head over time, have been incorporated as calibration targets to focus the calibration efforts on temporal trends. Head calibration targets are displayed according to HSU on Figure 4-2, while a tabulated summary is provided in Appendix B.

While the groundwater extraction rates from the Hopeland CSG wells have been prescribed to the model, these have also been incorporated as calibration targets. When the autoflow reduction capability of MF-USG is enabled, the prescribed extraction rate from each WEL node is automatically reduced when the head in the corresponding cell reaches the cell bottom. This capability prevents pumping from being sustained in dry cells (an unrealistic condition) but also creates an opportunity for the model to be calibrated to a set of parameters that result in reduced extraction rates. Incorporating the well fluxes as flow calibration targets ensures that only the model parameters that can sustain the prescribed fluxes are used in the calibrated model.

4.1.4 Calibration parameters

The model has been parameterised using a combination of zone based and pilot point parameters. Pilot points are used to introduce spatial variability in horizontal hydraulic conductivities for the key HSUs of interest, including the Springbok Sandstone (layer 3), Macalister seam (layer 5), Wambo seam (layers 6 and 7), Argyle seam (layer 8), Upper Taroom seam (layer 10) and Condamine seam (layer 11). A total of 193 adjustable pilot points have been used to parameterise the horizontal hydraulic conductivity of these 7 layers (note the same values were spatially interpolated to layers 6 and 7, both belonging to the Wambo seam).

The vertical hydraulic conductivities have been calculated from the horizontal hydraulic conductivities using a vertical hydraulic conductivity factor (multiplier) calibrated for each HSU. For layers with spatially variable horizontal hydraulic conductivities, this approach ensures that the spatial variability in the vertical direction is consistent with that in the horizontal direction.

A parameter zone is also assigned to the nodes intersected by each of the Hopeland gas wells. This approach, combined with the WEL and CLN packages, is intended to achieve a sensible balance between the near field heads and fluxes measured during the pilot testing program, which can be otherwise difficult to simulate in a single-phase flow model.

A total of 252 adjustable parameters have been estimated during calibration, using lower and upper bound parameter estimates based on the literature range of values such as those documented in the OGIA 2016 hydrogeological conceptualisation report. For the model layers with pilot points, the initial pilot point values have been derived from the 2016 OGIA model. This means the initial spatial distributions of horizontal hydraulic conductivity for the key HSUs are similar to those of the 2016 OGIA model and departure from these initial distributions has been introduced at locations deemed necessary during calibration based on the information contained in the observation dataset. For vertical hydraulic conductivities, a global minimum value of 1 x 10^{-8} m/d has been set when undertaking the conversion from horizontal to vertical hydraulic conductivities based on the realistic minimum value from the literature.

The range of calibration parameters are discussed further in Section 4.2.4.

4.1.5 Calibration procedure

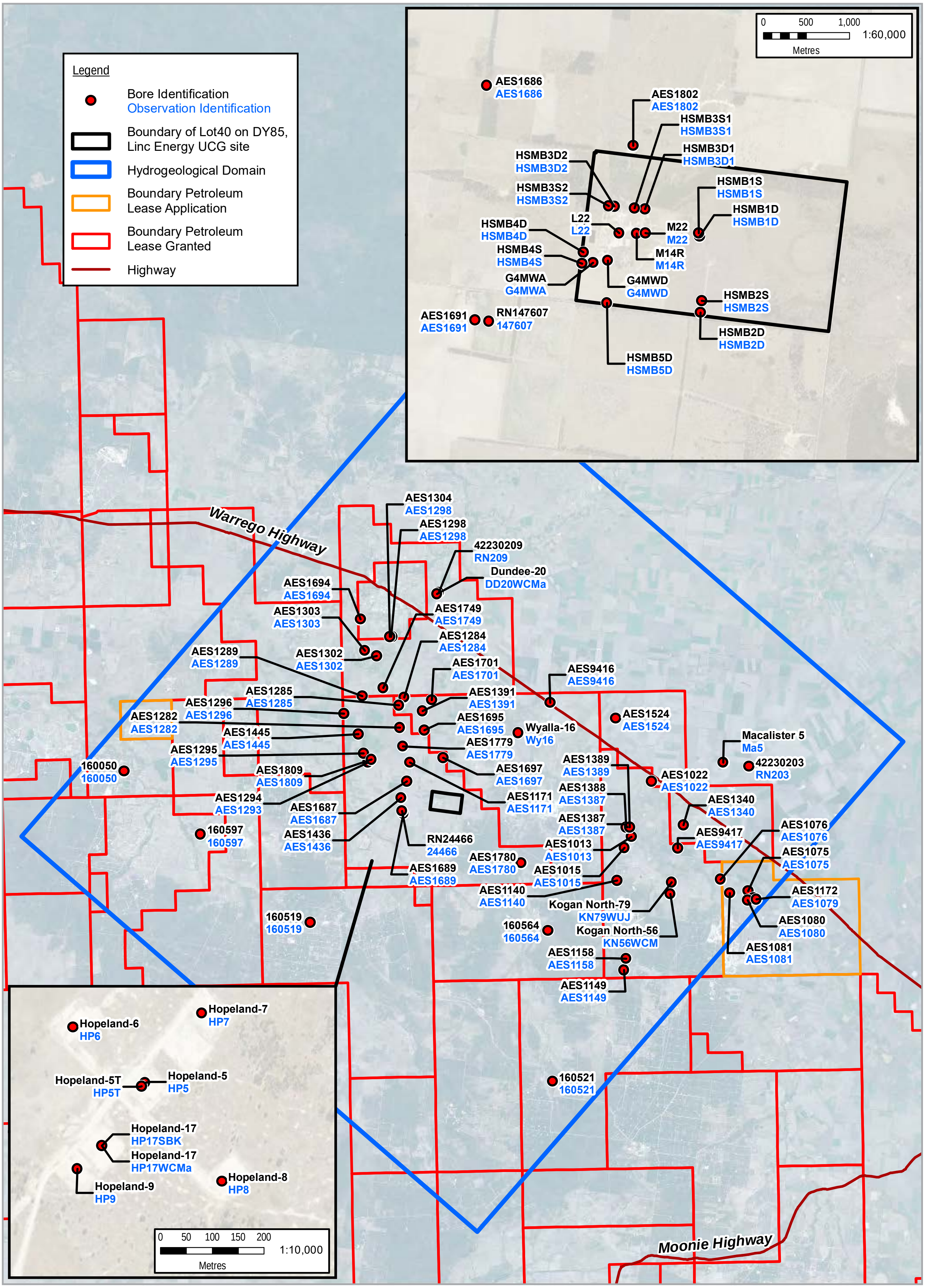
Calibration has been undertaken rigorously using the automated parameter estimation procedures of PEST (Doherty, 2016) and PEST_HP in a parallelized computing environment (Doherty, 2017). As there are a large number of adjustable parameters, PEST's Singular Value Decomposition (SVD) assisted inversion has been used to reduce the number of estimable parameters from 252 to 88 super-parameters.

The automated calibration process utilised a number of PEST utilities to facilitate pre- and post-processing efforts including:

- PAR2PAR (Doherty, 2016b) that converts the hydraulic conductivity at the location of GHB node into a unique conductance value. This approach ensures that the GHB conductance is consistent with the edge length, thickness and hydraulic conductivity of the GHB cell each time PEST adjusts the hydraulic conductivity during calibration iterations.
- PLPROC (Doherty, 2016d) that undertakes spatial interpolation of horizontal hydraulic conductivities from pilot points to the model mesh.
- USGMOD2OBS (Doherty, 2016c) that extracts computed hydraulic heads at the time and location of observations and SMPDIFF (Doherty, 2016b) that converts computed heads into head differences at the location of observations.

In addition to the PEST utilities, an in-house utility has been used to convert horizontal hydraulic conductivities into vertical hydraulic conductivities from the calibrated vertical hydraulic conductivity factor (the ratio of horizontal to vertical hydraulic conductivities) and USGS ZONEBUDGET utility is used to extract CSG extraction rates from the cell-by-cell flow file.

A single batch file has been prepared to run PEST, pre-processing utilities, MF-USG models and post-processing utilities in the sequential order. More than 4,000 model runs have been completed during the automated parameter estimation procedure.



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0 5 10 15 20

Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Calibration Targets

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-2

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Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: jvancooten

4.2 Calibration performance

4.2.1 Calibration statistics

Figure 4-3 presents a scatter plot of observed heads against the computed heads. The SRMS error of the model is 5.2 %, below the 10 % target threshold typically adopted for calibrating sub-regional scale models. The model calibration is considered appropriate, particularly considering that the model simulates temporal trends induced by complex CSG extraction activities and does not account explicitly for dual phase flow.

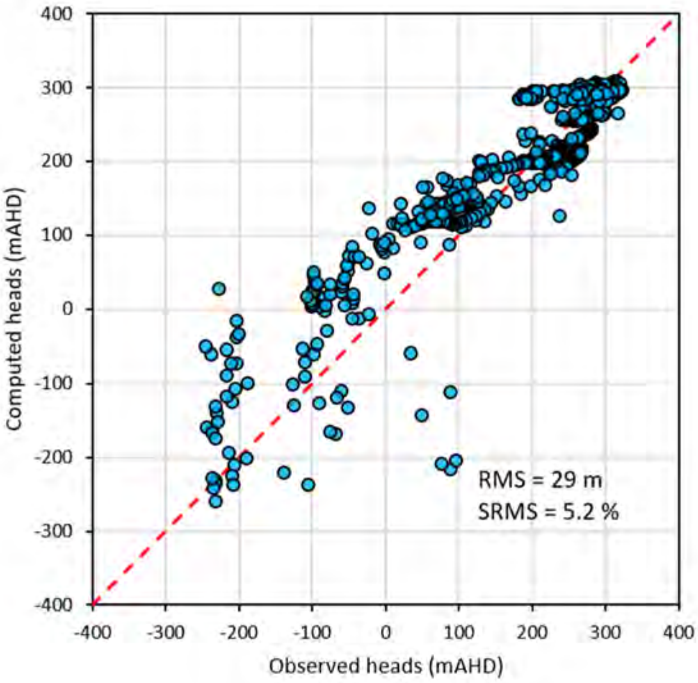


Figure 4-3 Calibration scatter plot

The mass balance error is less than 0.04 % for all time steps of the transient calibration and the cumulative mass balance error is less than 0.01 %. The mass balance errors are well below the threshold of 1 % recommended in the Australian Groundwater Modelling guidelines (Barnett et al., 2012). For both the steady state and transient models, the model required convergence in heads to within 0.001 metres.

Table 4 provides a breakdown of the cumulative and average water balance during the calibration period (in mega litres).

Table 4-1 Transient water balance (calibration period)

Component	Cumulative (ML)		Average (ML/d)	
	Inflow	Outflow	Inflow	Outflow
Recharge	45,039		6.49	
Well		42,950		14.41
GHB	122,072	349,078	25	88
Storage	232,651	7,765	74	3
Total	399,762	399,793	105	105

4.2.2 Calibration hydrographs

Hydrographs of computed and observed heads at all bore locations are provided in Appendix C. Figure 4-4 presents some of the key hydrographs, including those at the Hopeland pilot testing sites where the calibration efforts have been targeted. The hydrographs indicate that:

- The computed piezometric heads are within the measured range of piezometric heads across the model domain.
- The regional lowering of the piezometric heads by the surrounding non-Arrow CSG extractions has been appropriately simulated, demonstrated by the lowering of heads measured at the nested site (Dundee-20/DD20) constructed within the Walloon Coal Measures approximately 10 km north of PL253 and other bores such as 160050 and RN24466 (see Appendix C).
- The range of heads and temporal trends observed at each of the 6 Hopeland CSG wells are appropriately simulated based on the measured groundwater extraction rates, including those at the nested monitoring site Hopeland-17 located within the Hopeland testing site. This includes the downward vertical hydraulic gradient across the Walloon Coal Measures, as measured at the Hopeland-17 site (see Figure 4-5).

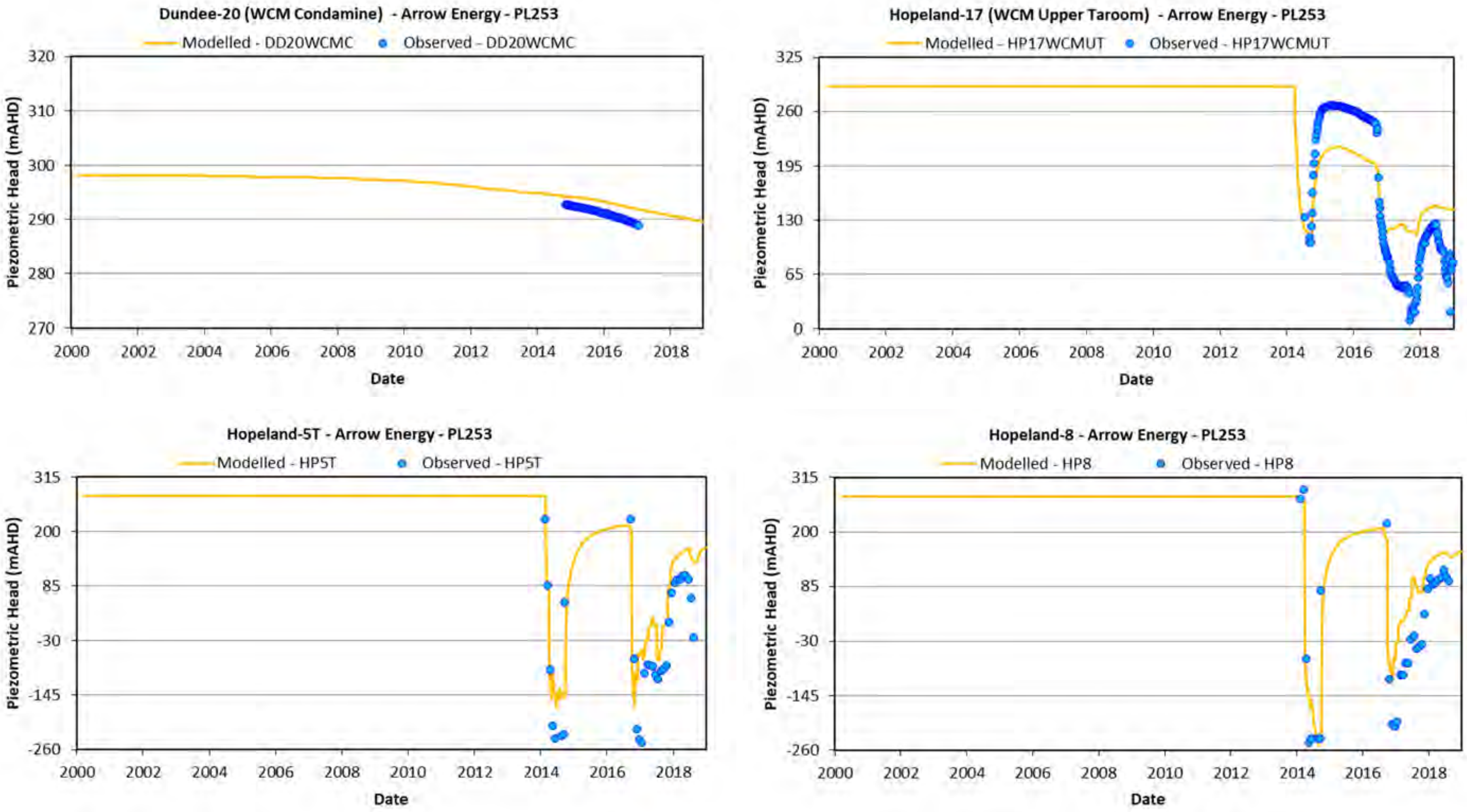


Figure 4-4 Selected calibration hydrographs

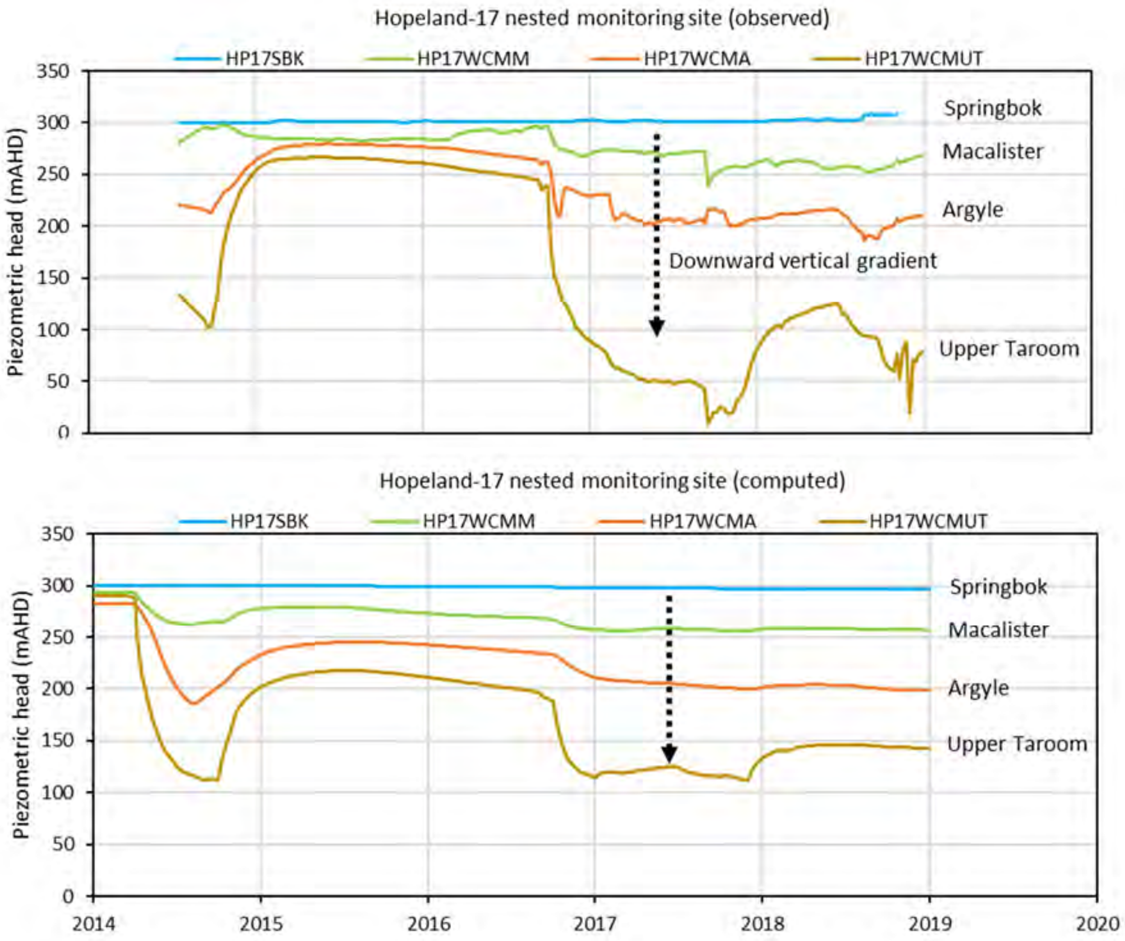
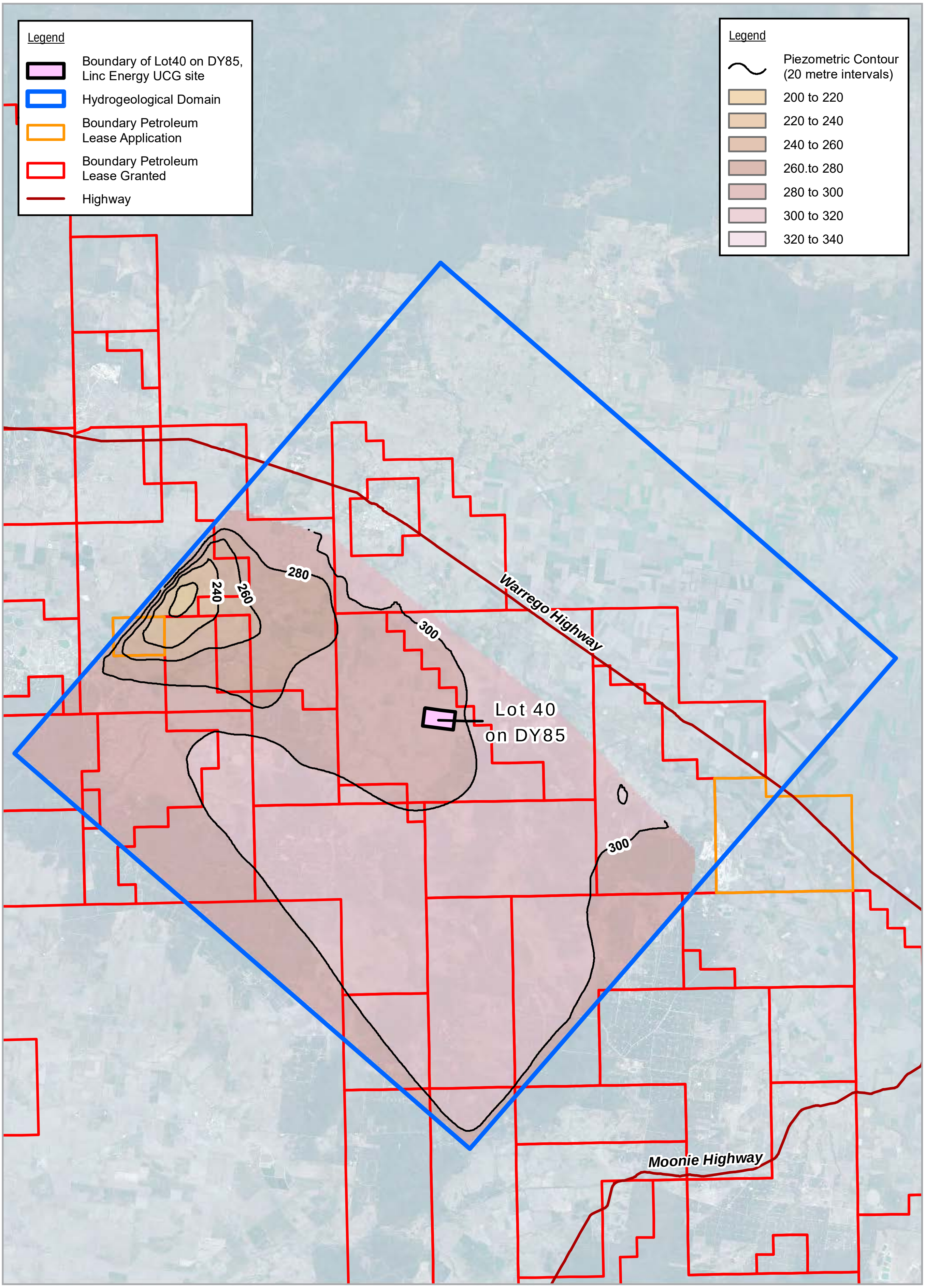


Figure 4-5 Hopeland-17 vertical hydraulic gradient

4.2.3 Calibration contours

Piezometric head contours at the end of the calibration period are plotted on Figure 4-6 (Springbok Sandstone), Figure 4-7 (WCM – Macalister), Figure 4-8 (WCM – Argyle), and Figure 4-9 (WCM – Upper Taroom), showing the contours consistent with the regional hydraulic gradients and westerly flow directions induced by the CSG activities.



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0 5 10 15 20

Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

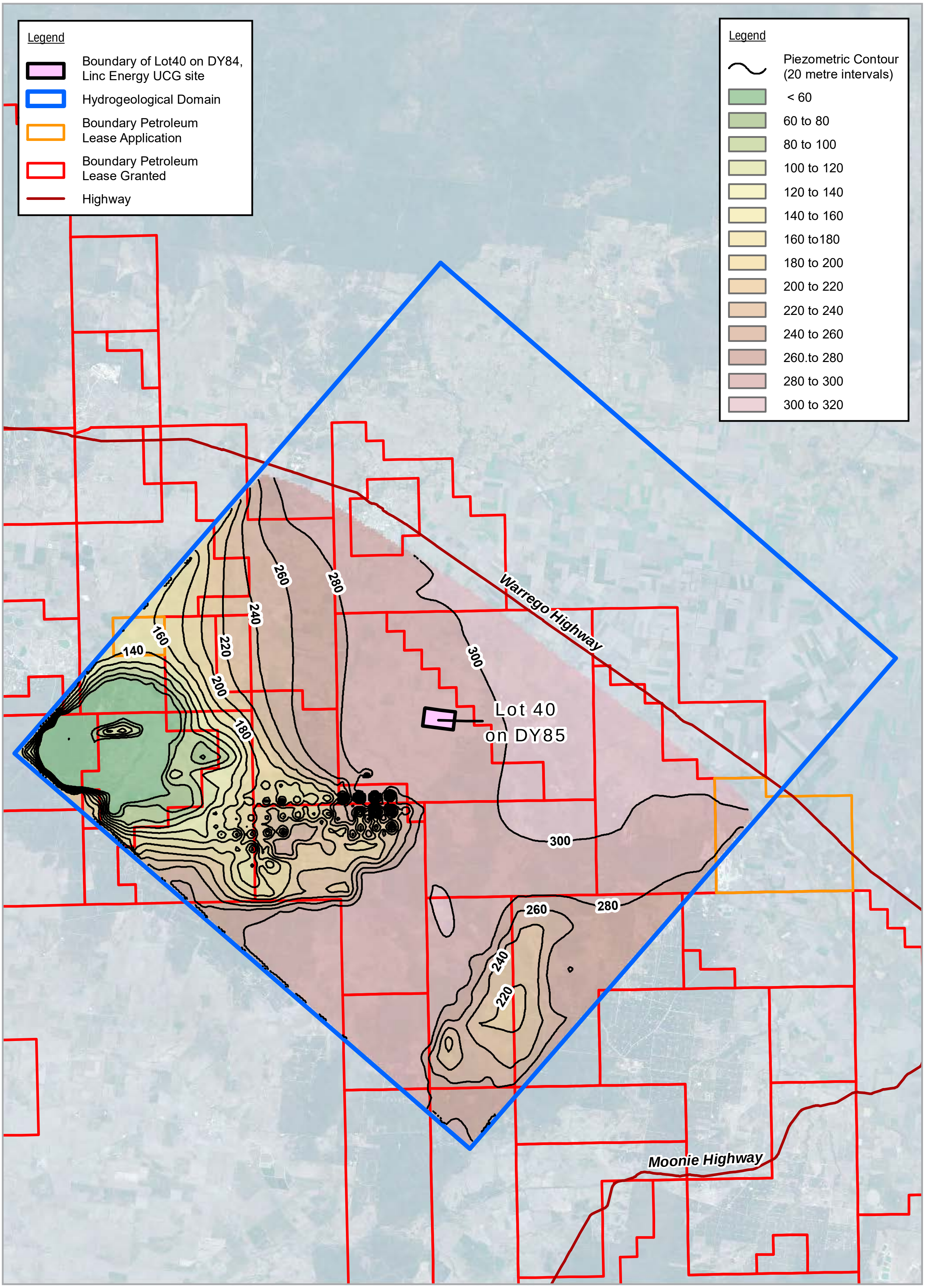
Piezometric Heads
(end of calibration phase)
Springbok Sandstone

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-6

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-09_piezoHeads_Springbok_revA.mxd
Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre, Imagery (2019); GHD: analysis and modelling (Oct 2019). Created by: jvancooten



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0 5 10 15 20

Kilometres

N

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

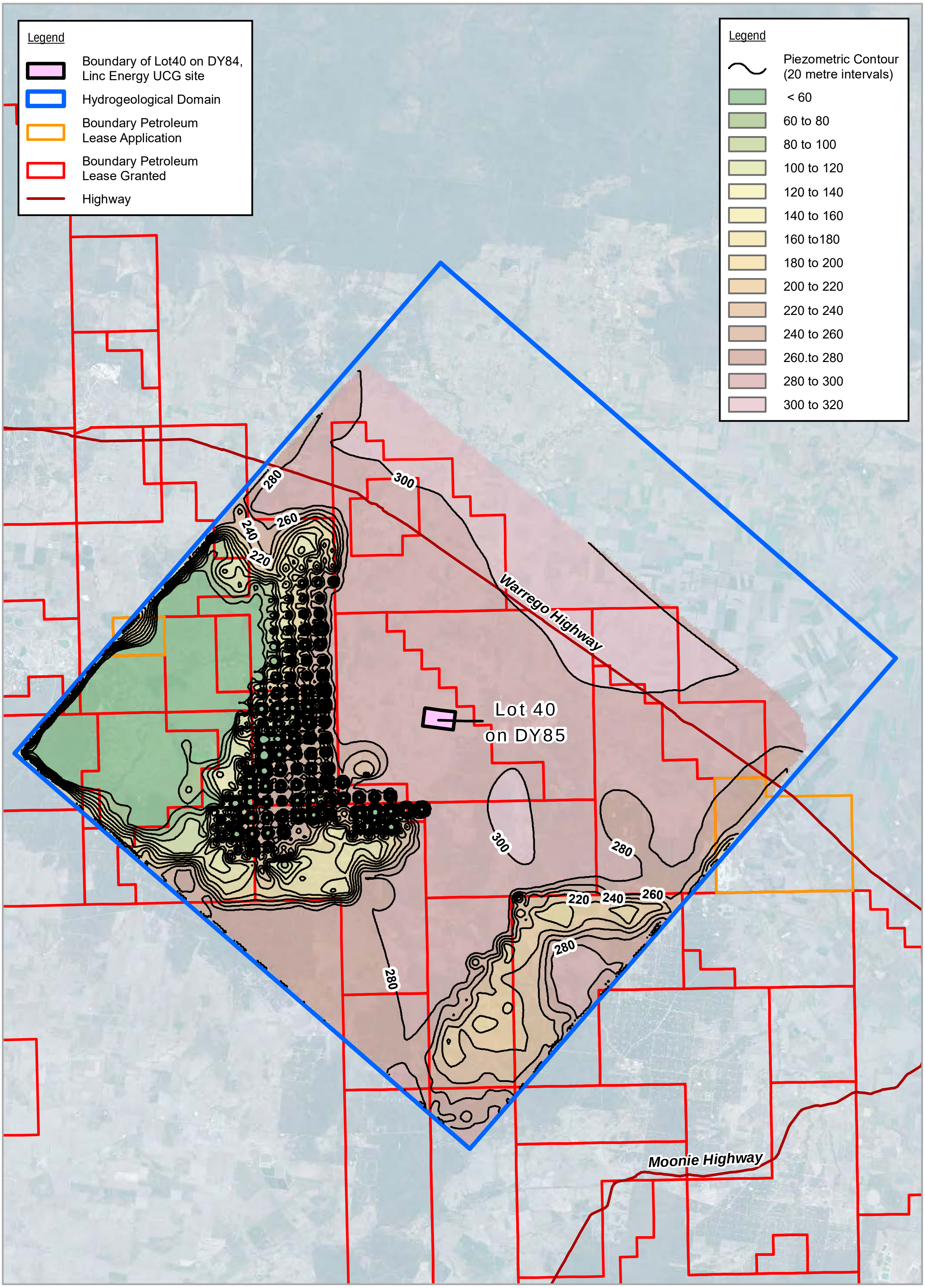
Piezometric Heads
(end of calibration phase)
WCM : Macailster

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-7

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-10_piezoHeads_Macalister_revA.mxd
Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre, Imagery (2019); GHD: analysis and modelling (Oct 2019). Created by: jvancooten



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0 5 10 15 20

Kilometres

N

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

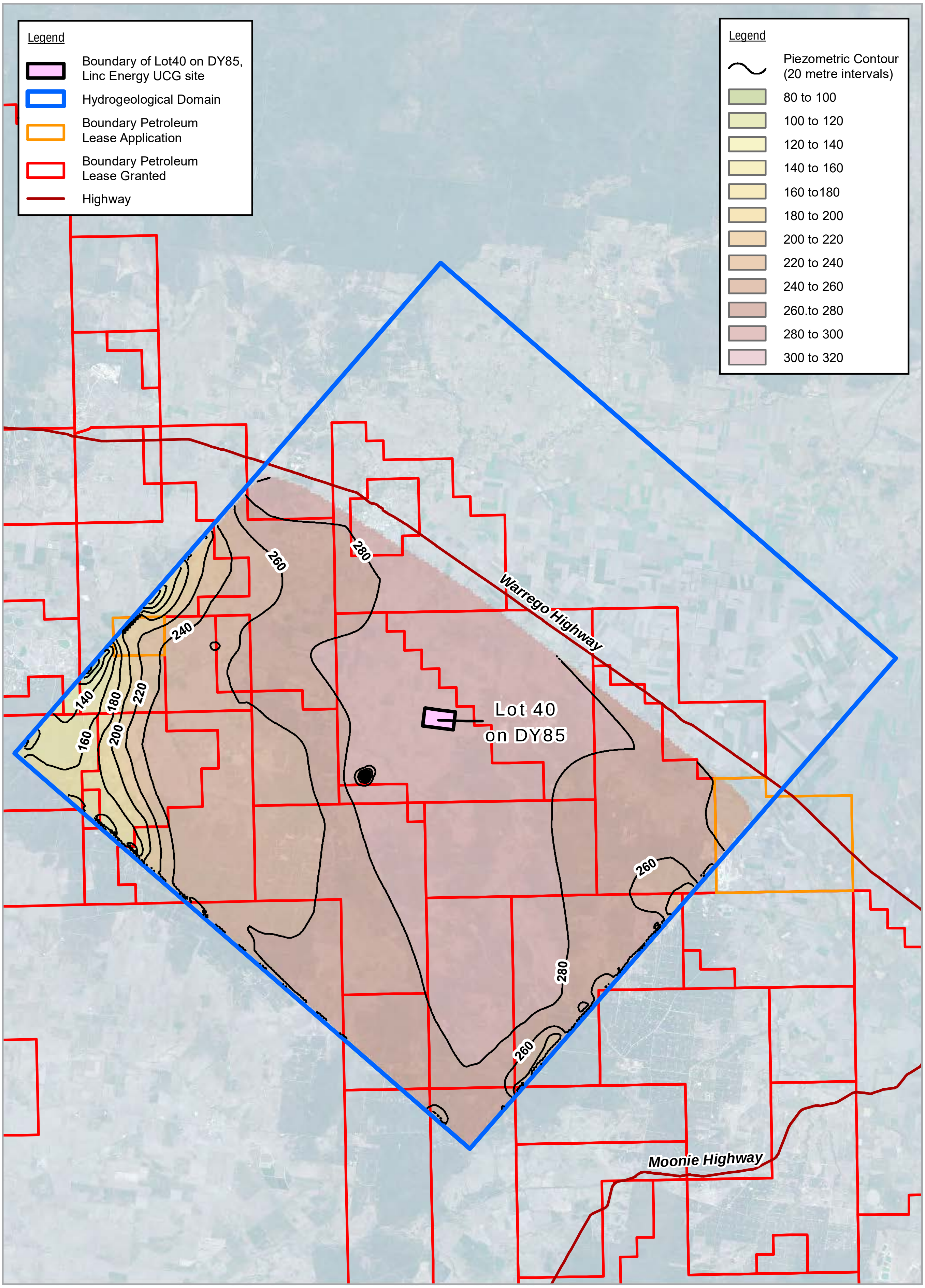
Piezometric Heads
(end of calibration phase)
WCM: Macalister

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-8

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-11_piezoHeads_Argyle_revA.mxd
Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre, Imagery (2019); GHD: analysis and modelling (Oct 2019). Created by: jvancooten



1:500,000 (Paper Size A4)

0 5 10 15 20

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Piezometric Heads
(end of calibration phase)
WCM: Upper Taroom

Project No.	41-32187
Revision No.	B
Date	21 Oct 2019

FIGURE 4-9

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-12_piezoHeads_UpperTaroom_revA.mxd
Print date: 21 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre, Imagery (2019); GHD: analysis and modelling (Oct 2019). Created by: jvancooten

4.2.4 Calibrated parameters

The calibrated model parameters, including the initial estimate and the upper and lower bounds permitted during model calibration, are presented in a series of graphs included in Figure 4-10 to Figure 4-12. For zone based parameters, the first two letters in the parameter ID “sy”, “ss”, and “kx” imply specific yield, specific storage and horizontal hydraulic conductivity respectively while “kzf” implies vertical hydraulic conductivity factor. These are followed by letters representing the HSU e.g. “gbm” for Gubberamunda, “wtb” for Westbourne, “tgl” for Tangalooma…etc. The exception to this are the zones defined at the Hopeland well nodes, which are followed by the well name e.g. “hp5” for Hopeland well 5. For the pilot point parameters, the number following “kx” in the parameter ID indicates the layer number, followed by a unique number for each pilot point e.g. “kxp3p1” means pilot point 1 in model layer 3 (Springbok Sandstone).

Table 4-2 below summarises the minimum, maximum and average hydraulic conductivities of the key HSUs where spatial variability has been introduced via interpolation of pilot point values. The range of hydraulic conductivity values are broadly consistent with those of the 2016 OGIA model, with both models indicating vertical hydraulic conductivities in the Walloon Coal Measures that are several orders of magnitude lower than the horizontal hydraulic conductivities. The spatial distribution of horizontal hydraulic conductivity for each layer is presented in Appendix D.

The calibrated recharge rate is 1 mm/year, consistent with the low recharge rate reported in the literature.

Figure 4-13 presents the plots of PEST-generated parameter sensitivities with respect to the head and head difference observations, calculated by running the calibrated model 252 times (the number of adjustable parameters). The sensitivities are presented for the 40 most sensitive parameters. For both observation groups, the most sensitive parameters are specific storage that controls the transient response of confined aquifers to pumping and hydraulic conductivity at each of the 6 CSG wells. This is as expected, given the focused calibration effort on the Hopeland pilot testing site where measurements of groundwater extraction rates, near field heads and more than six years of continuous heads at the nested monitoring site are available.

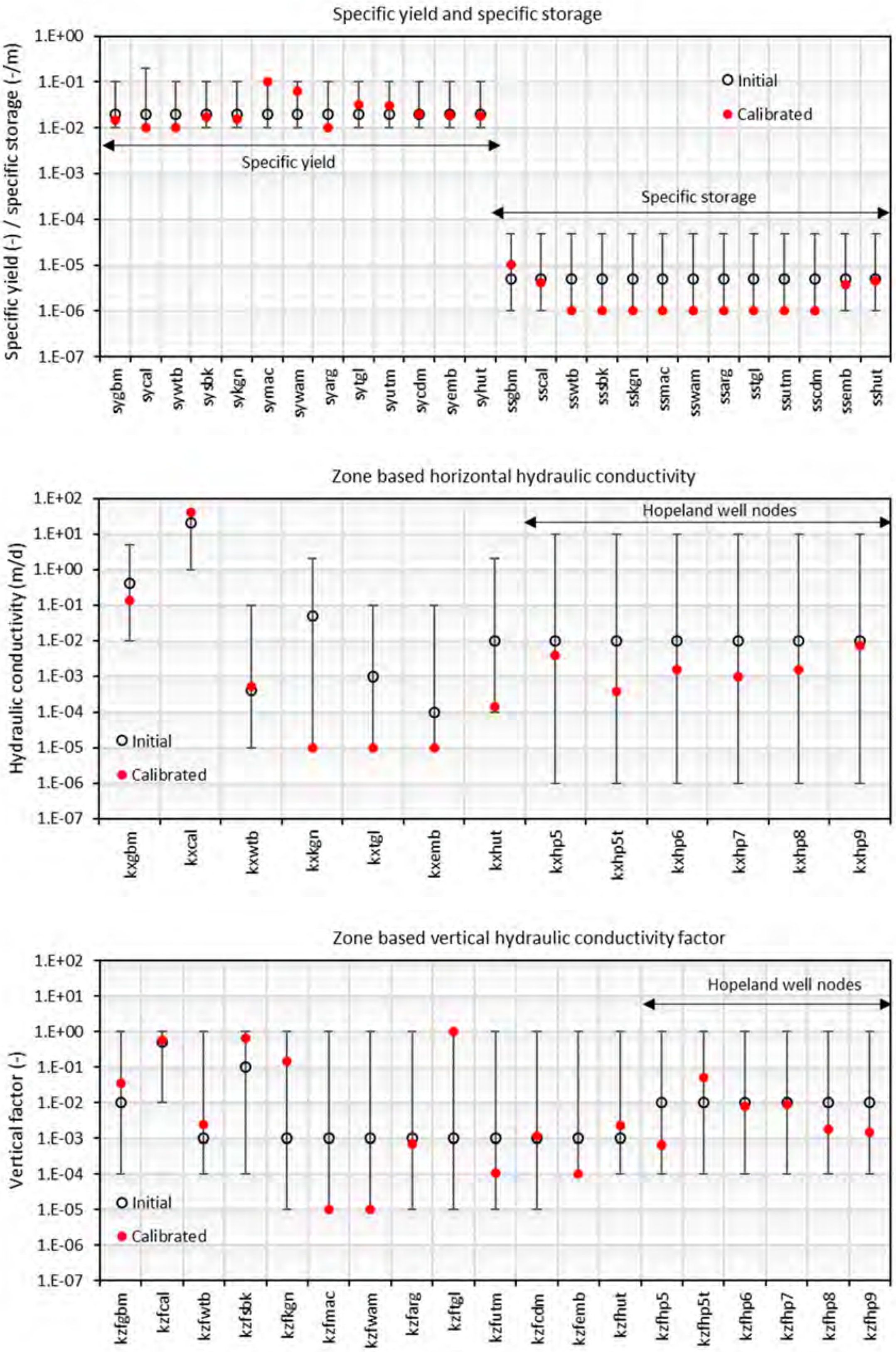


Figure 4-10 Calibrated zone based parameters

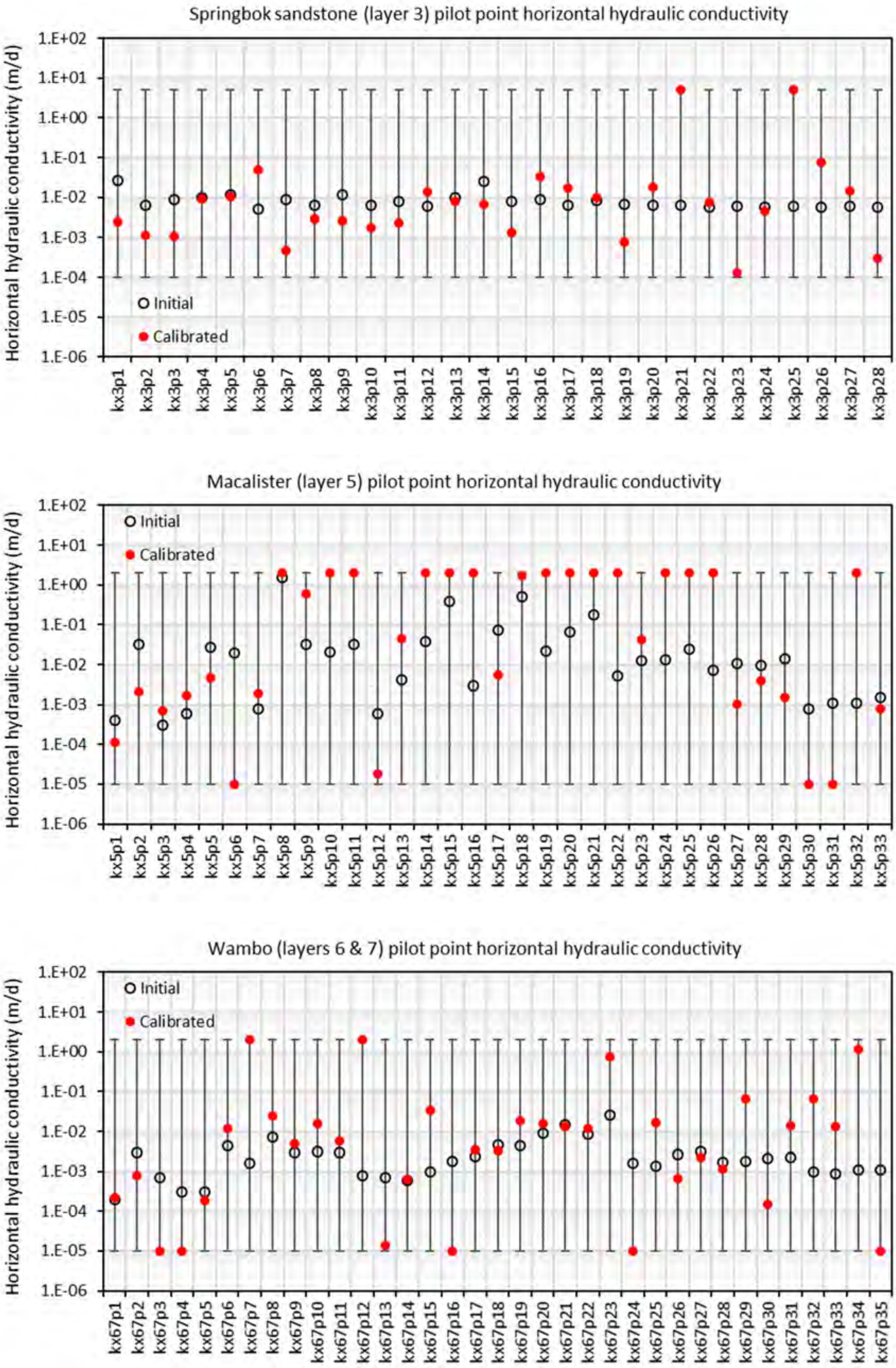


Figure 4-11 Calibrated pilot point parameters – layers 3, 5, 6 and 7

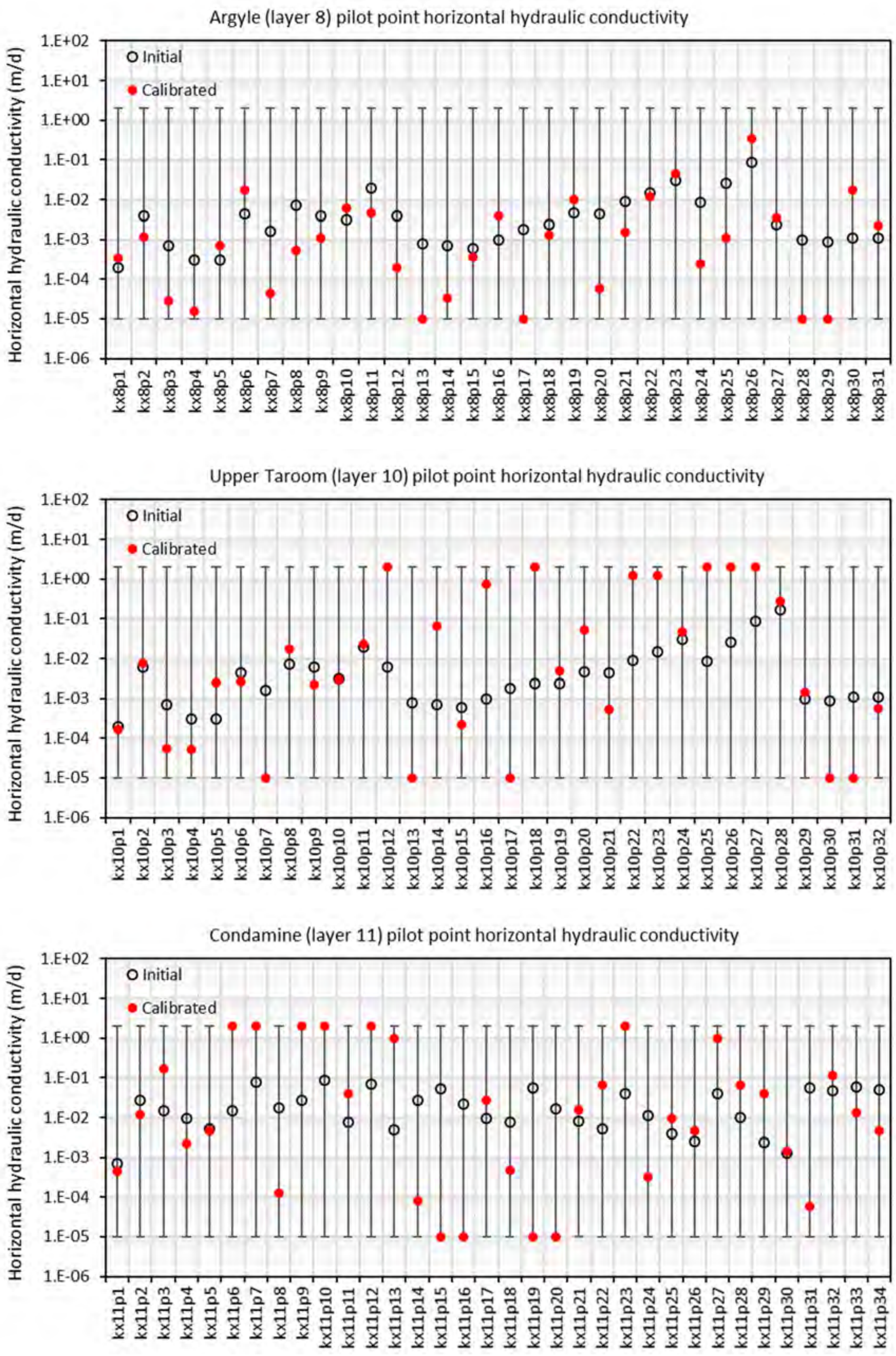


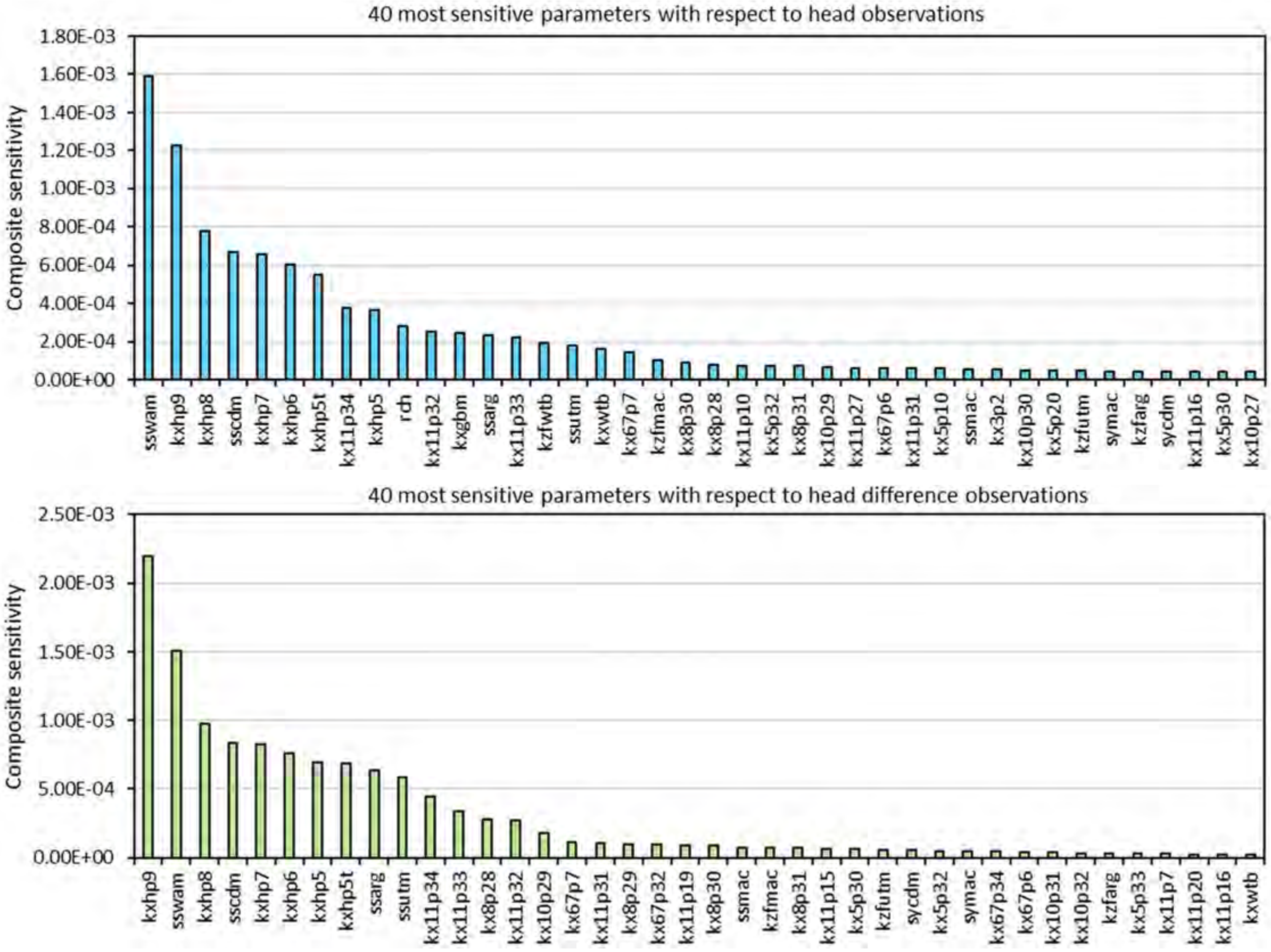
Figure 4-12 Calibrated pilot point parameters – layers 9, 10 and 11

Table 4-2 Calibrated pilot point hydraulic conductivities

HSU	Layer	Parameter	Calibrated (m/d)			2016 OGIA (m/d)^		
			Min	Max	Average	Min	Max	Average
Springbok	3	Kx	1.37×10^{-4}	4.90	2.81×10^{-1}	$1.21 \times 10^{-3*}$	$5.66 \times 10^{-2*}$	$6.40 \times 10^{-3*}$
		Kz	8.82×10^{-5}	3.16	1.81×10^{-1}	$4.29 \times 10^{-7*}$	$6.09 \times 10^{-4*}$	$8.46 \times 10^{-6*}$
Macalister	5	Kx	2.85×10^{-6}	3.39	5.90×10^{-1}	1.78×10^{-4}	1.55	3.21×10^{-2}
		Kz	1.00×10^{-8}	3.39×10^{-5}	5.90×10^{-6}	1.26×10^{-8}	2.65×10^{-5}	3.49×10^{-6}
Wambo	6, 7	Kx	7.94×10^{-6}	2.79	4.77×10^{-2}	1.94×10^{-4}	1.86×10^{-1}	3.03×10^{-3}
		Kz	1.00×10^{-8}	2.79×10^{-5}	4.80×10^{-7}	1.15×10^{-8}	1.28×10^{-5}	8.50×10^{-8}
Argyle	8	Kx	3.76×10^{-6}	2.40×10^{-1}	3.28×10^{-3}	1.94×10^{-4}	2.82×10^{-1}	3.92×10^{-3}
		Kz	1.00×10^{-8}	1.66×10^{-4}	2.26×10^{-6}	1.15×10^{-8}	1.28×10^{-5}	9.42×10^{-8}
Upper Taroom	10	Kx	6.16×10^{-6}	2.38	2.74×10^{-1}	1.94×10^{-4}	4.70×10^{-1}	6.06×10^{-3}
		Kz	1.00×10^{-8}	2.59×10^{-4}	2.99×10^{-5}	1.15×10^{-8}	1.28×10^{-5}	1.12×10^{-7}
Condamine	11	Kx	1.01×10^{-5}	6.23	3.80×10^{-1}	3.77×10^{-4}	7.50×10^{-1}	2.70×10^{-2}
		Kz	1.19×10^{-8}	7.36×10^{-3}	4.49×10^{-4}	2.22×10^{-8}	7.10×10^{-6}	3.24×10^{-7}

^ Parameter values interpolated from the 2016 OGIA model to the model domain

* 2016 OGIA model splits the Springbok Sandstone into upper and lower units. The range of values and the averages are calculated from the combined upper and lower units


40 most sensitive parameters with respect to head observations

40 most sensitive parameters with respect to head difference observations

Para ID	Description
kxhp5	Kx Hopeland-5 well zone
kxhp5t	Kx Hopeland-5T well zone
kxhp6	Kx Hopeland-6 well zone
kxhp7	Kx Hopeland-7 well zone
kxhp8	Kx Hopeland-8 well zone
kxhp9	Kx Hopeland-9 well zone
kx3p2	Kx pilot point layer 3
kx5p10	Kx pilot point layer 5
kx5p20	Kx pilot point layer 5
kx5p30	Kx pilot point layer 5
kx5p32	Kx pilot point layer 5
kx5p33	Kx pilot point layer 5
kx67p32	Kx pilot point layers 6 & 7
kx67p34	Kx pilot point layers 6 & 7
kx67p6	Kx pilot point layers 6 & 7
kx67p7	Kx pilot point layers 6 & 7
kx8p28	Kx pilot point layer 8
kx8p29	Kx pilot point layer 8
kx8p30	Kx pilot point layer 8
kx8p31	Kx pilot point layer 8
kx10p27	Kx pilot point layer 10
kx10p29	Kx pilot point layer 10
kx10p30	Kx pilot point layer 10
kx10p31	Kx pilot point layer 10
kx10p32	Kx pilot point layer 10

Para ID	Description
kx11p7	Kx pilot point layer 11
kx11p10	Kx pilot point layer 11
kx11p15	Kx pilot point layer 11
kx11p16	Kx pilot point layer 11
kx11p19	Kx pilot point layer 11
kx11p20	Kx pilot point layer 11
kx11p27	Kx pilot point layer 11
kx11p31	Kx pilot point layer 11
kx11p32	Kx pilot point layer 11
kx11p33	Kx pilot point layer 11
kx11p34	Kx pilot point layer 11
kxgbm	Kx Gubberamunda zone layer 1
kxwtb	Kx Westbourne zone layer 2
kzfwtb	Kz factor Westbourne zone layer 2
kzfmac	Kz factor Macalister zone layer 5
kzfarg	Kz factor Argyle zone layer 8
kzfutm	Kz factor Upper Taroom zone layer 10
rch	Recharge
ssmac	Specific storage Macalister zone layer 5
sswam	Specific storage Wambo zone layers 6 & 7
ssarg	Specific storage Argyle zone layer 8
ssutm	Specific storage Upper Taroom zone layer 10
sscdm	Specific storage Condamine zone layer 11
symac	Specific yield Macalister zone layer 5
sycdm	Specific yield Condamine zone layer 11

Figure 4-13 Parameter sensitivity

5. Model predictions

5.1 Predictive scenario representation

Two predictive scenarios have been developed and represented:

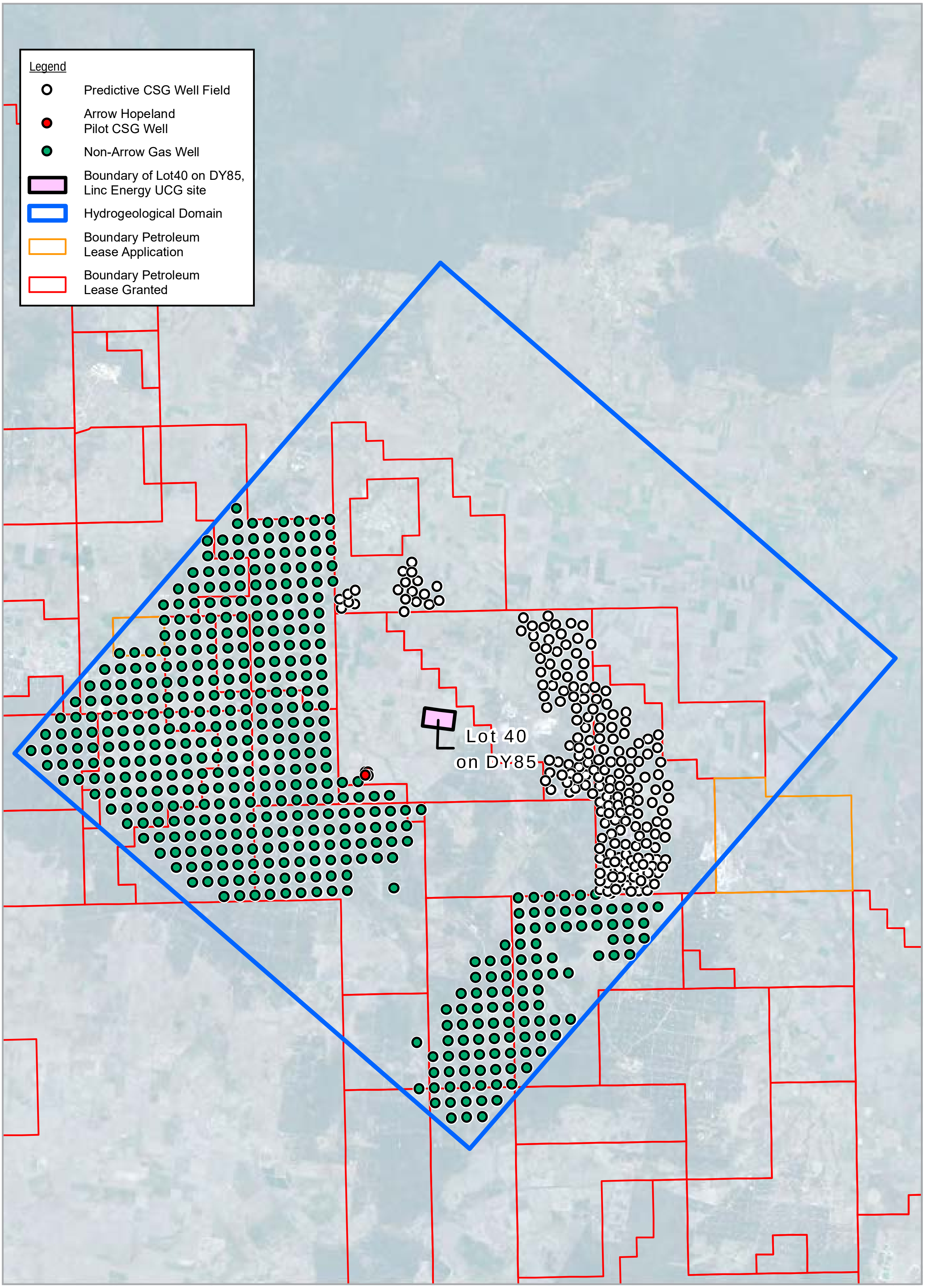
- Scenario 1: Assessment of the impact that the operation of the Hopeland pilot plant has on groundwater within the vicinity of Lot 40 DY85
- Scenario 2: Assessment of the impact of approved Arrow operations on PL185 and PL493 on groundwater within the vicinity of Lot 40 DY85.

5.2 Predictive model set up

In order to assess potential changes in the groundwater flow conditions in the vicinity of Lot 40 DY85 associated with the approved Arrow CSG development on PL253, PL185 and PL493, the following model runs have been completed:

- A “**base case”** with ongoing groundwater extractions from the non-Arrow CSG wells and existing Arrow CSG activity at the Hopeland pilot testing site.
- A “**no Hopeland case**”, in which the existing Arrow CSG activity at the Hopeland pilot testing site is excluded from the model both during the calibration and predictive simulation periods. For the calibration phase, this produces model outputs that represent what the historical conditions would have been if the existing Arrow CSG activity had not occurred at the Hopeland pilot testing site. For the predictive phase, the model outputs represent future changes resulting solely from the non-Arrow CSG extractions. The “no Hopeland case” is intended to demonstrate the incremental impacts of Arrow’s existing CSG activity at the Hopeland pilot plant.
- A “**10a blue case**” that incorporates Arrow’s approved CSG extractions to the southeast, east and north of PL253 into the base case model (production in PL185 and PL493).

The wellfield configurations used in the predictive modelling are displayed on Figure 5-1



1:500,000 (Paper Size A4)

0 5 10 15 20

Kilometres

N

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No.	41-32187
Revision No.	A
Date	28 Oct 2019

Predictive Model
Arrow 10a Blue Wellfield

FIGURE 5-1

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-13_predictiveModelCSGwellfield_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre, Imagery (2019); GHD: analysis and modelling (Oct 2019). Created by: JVanCooten

5.2.1 Scenario 1

Scenario 1 assesses the incremental impacts of Arrow Energy's approved CSG operations on PL253, which comprises of the historical operation of the Hopeland pilot and future approved CSG abstraction at the Hopeland site. The assessment of the impact has been completed by comparing the results from the "no Hopeland case" against the calibrated model for the calibration period and against the "base case" model for the prediction period.

The model set up is as per the calibration period described in Section 3, with further details provided in Section 5.2.2 below. For the "no Hopeland case", the CSG abstraction activities are limited to the non-Arrow CSG wells.

5.2.2 Scenario 2

The differences in model outputs between the "base case" and the "Arrow 10a blue case" enable assessment of the influence of Arrow Energy's activities on the adjacent leases PL185 and PL493.

The set up of the two predictive runs are similar to that of the calibration period and includes:

- Non-Arrow CSG extractions based on the drain fluxes from the 2016 OGIA model, apportioned equally to model layers 5, 7 and 8 using the WEL package.
- Time-varying GHBs along the model boundaries based on heads interpolated from the 2016 OGIA model.
- Time-constant CSG extraction from the Hopeland CSG wells based on the average extraction rates from 2016 to 2018 (when the wells were switched back on following a temporary shutdown). The extraction rates are assumed to continue for 20 years based on a typical lifespan of CSG wells.
- Arrow CSG extractions based on the timing, well locations and production rates for the 10a blue case provided by Arrow. As per the non-Arrow CSG extractions, the production rates are apportioned equally to model layers 5, 7 and 8 using the WEL package except where the layers are absent in which case the rates are apportioned equally to the remaining layers i.e. where layer 5 is pinched out, flow is apportioned equal to layers 7 and 8.

The predictive period is set for 100 years, from 2019 to the end of 2018. Annual stress periods are used until the end of 2069, followed by five-yearly stress periods consistent with the 2016 OGIA model. Time-constant recharge is applied at 1 mm/year.

Figure 5-2Figure 5-1 presents the number, timing and production rates of Arrow CSG wells included in the 10a blue case. The productions rates have been annualised to be consistent with the length of the stress periods.

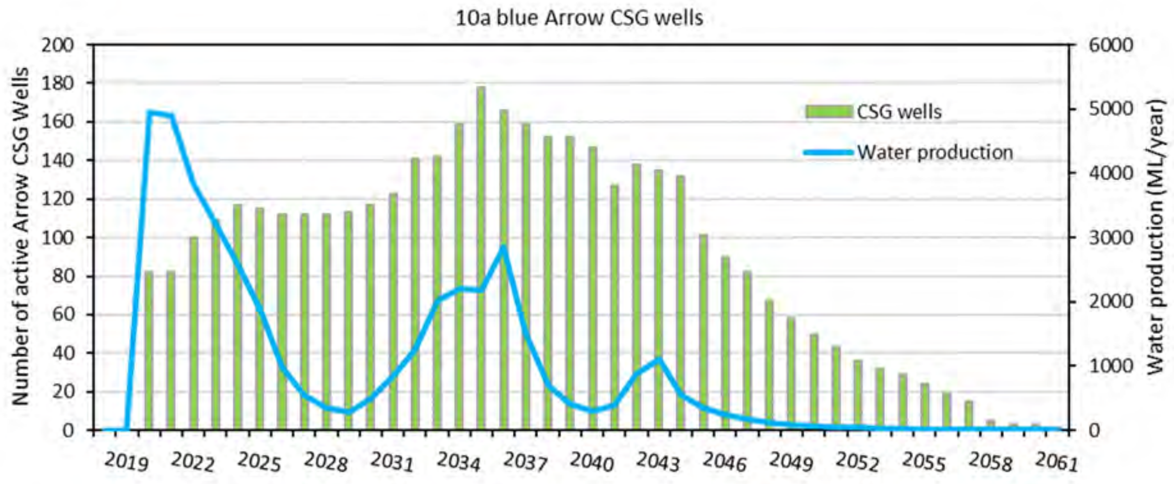


Figure 5-2 Arrow 10a blue CSG extractions

5.3 Presentation of results

5.3.1 Overview

The primary objective of the predictive modelling described in this report is to characterise changes in groundwater flow conditions on and around Lot 40 DY85 due to Arrow Energy operating approved CSG wellfields on PL253, PL185 and PL493. This is important because the migration of contaminants from the former Linc Energy site is dependent on advective transport i.e. the physical movement of groundwater. For Arrow Energy's operations to alter the advective transport of contaminants from the former Linc Energy site, the operations must induce changes to hydraulic gradients and groundwater flow on and in the vicinity of Lot 40 DY85.

Plots of piezometric head contour have been presented on a series of figures in Section 5.4 to enable comparison of head distributions and hydraulic gradients with and without Arrow Energy's operations. Groundwater seepage calculations have also been completed to assess the incremental impacts of Arrow Energy's operations on advective transport. Results have been presented for scenarios 1 and 2.

Given the small incremental changes to the modelled hydraulic gradients and seepage rates, detailed fate and transport modelling has not been completed as part of this study.

5.3.2 Groundwater seepage calculations

Groundwater seepage rates have been calculated across MDL309 by extracting heads from a series of points located approximately 2 km from the centre of the former Linc Energy operations. Seepage velocities have been calculated utilising Darcy's Law, as detailed below:

$$v_d = k\ i$$

Where:

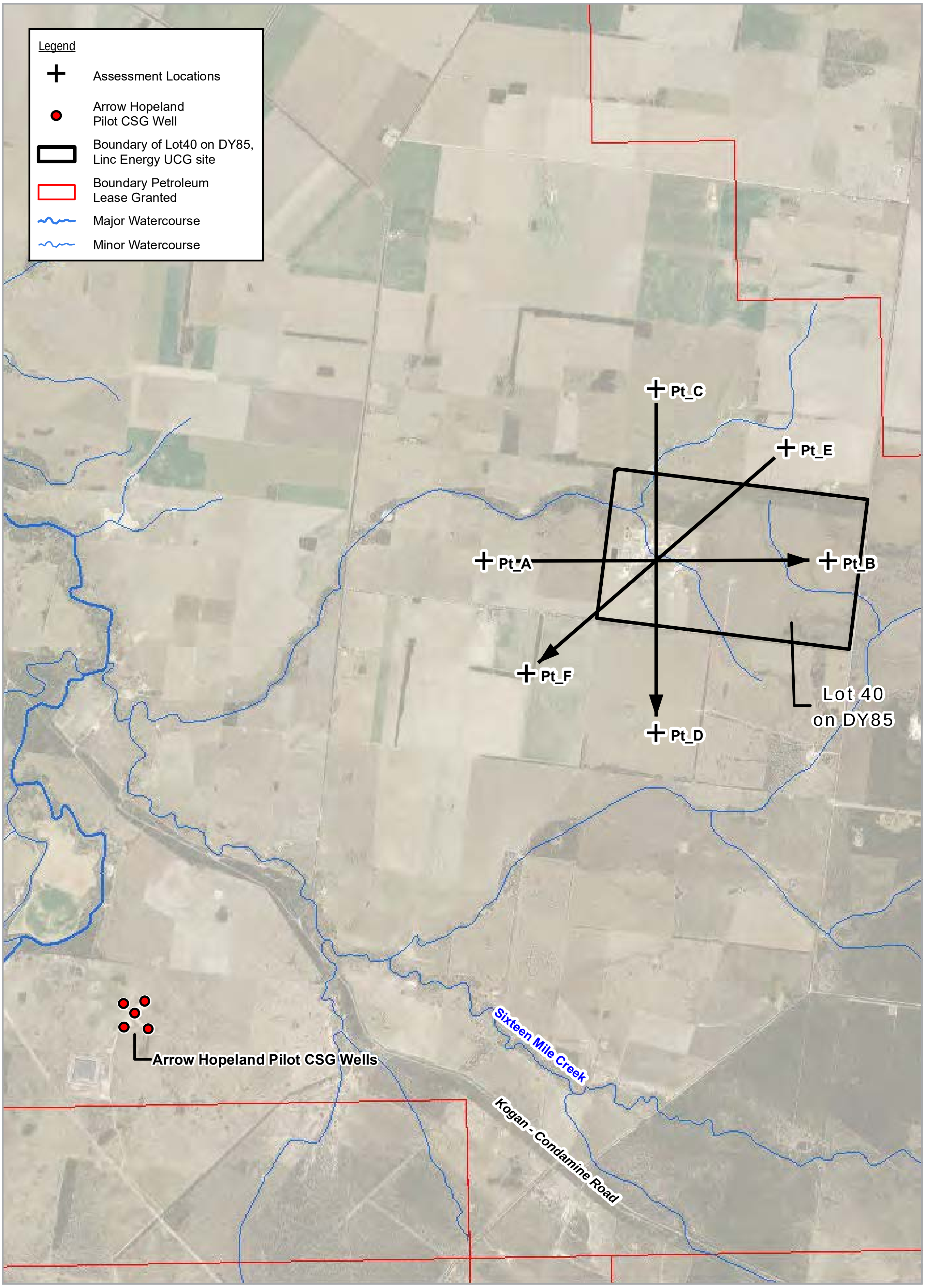
v_d is the Darcian velocity (m/d)

k is the hydraulic conductivity

i is the hydraulic gradient

Groundwater seepage velocity has been calculated as a Darcian velocity. Darcian velocity, also called specific discharge, is a measure of groundwater flow per unit of cross-sectional aquifer area. To convert Darcian velocity into a groundwater seepage velocity, v_d needs to be divided by the effective porosity. To enable comparison with seepage calculations presented previously (Arrow, 2018), Darcian velocity has been utilised.

Note that the incremental difference in seepage velocities is entirely dependent on the changes in the hydraulic gradient (since hydraulic conductivity is constant). The groundwater velocity has been calculated for each model output time based on the hydraulic gradients computed across three transects over MDL309: Pt_A – Pt_B in the east – west direction; Pt_C – Pt_D in the north – south direction; and Pt_E – Pt_F, which is aligned with the direction of the Hopeland pilot. The transects are displayed on Figure 5-3. Seepage assessment results and supporting information, including the adopted hydraulic conductivity values, are presented in Appendix F.



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0 500 1,000 1,500 2,000

Meters

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No. 41-32187
Revision No. B
Date 28 Oct 2019

Seepage Rate Assessment Locations

FIGURE 5-3

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-15_gradientAssmtLocs_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: JVanCooten

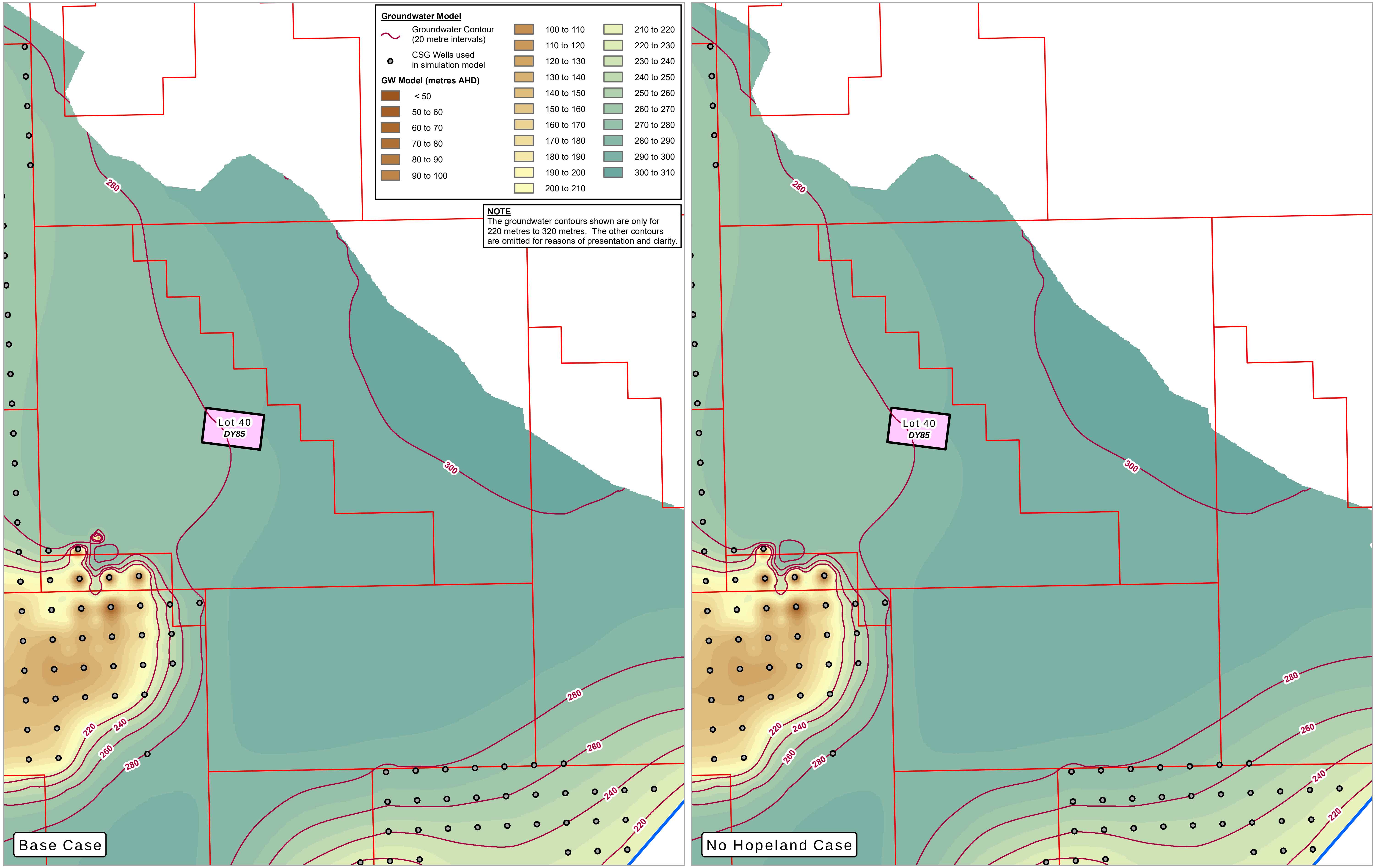
5.4 Predictive model outputs

5.4.1 Scenario 1 predictive model outputs

The outputs from the predictive modelling of scenario 1 are presented on two figures displaying the modelled piezometric head contours for the end of 2038, corresponding to the end of the modelled period of operation for Hopeland CSG wells. Results are presented for the Macalister seam (Figure 5-4) and the Argyle seam (Figure 5-5), with contours from the 'base case' and the 'no Hopeland' models presented side-by-side to enable visual comparison of the two runs.

Seepage assessment calculations are presented in Table F1 and Table F2 in Appendix F, covering the historical operation of the Hopeland pilot between 2014 and 2018; and the future Hopeland operation between 2019 and 2038 respectively. Results indicate that the operation of the Hopeland pilot facility is predicted to have contributed to approximately 0.026 m of additional groundwater seepage historically. A further predicted 0.25 m of groundwater seepage is predicted due to the future operation of the Hopeland facility. When considered in the context of seepage associated with the 'base case' models, the Hopeland operation accounts for less than 10% of the total groundwater seepage. As discussed in Section 5.3.2, groundwater seepage calculations are based on a Darcian velocity, and do not account for porosity.

Comparison of the head contours on Figure 5-4 and Figure 5-5 indicate negligible changes in hydraulic gradients, supported by the small incremental increases in the seepage rate calculated from the seepage assessment.



Legend

🟦 Hydrogeological Domain

▨ Boundary of Lot40 on DY85, Linc Energy UCG site

🟧 Boundary Petroleum Lease Application

🟥 Boundary Petroleum Lease Granted

1:175,000 Paper Size A3

0 2 4 6 8

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

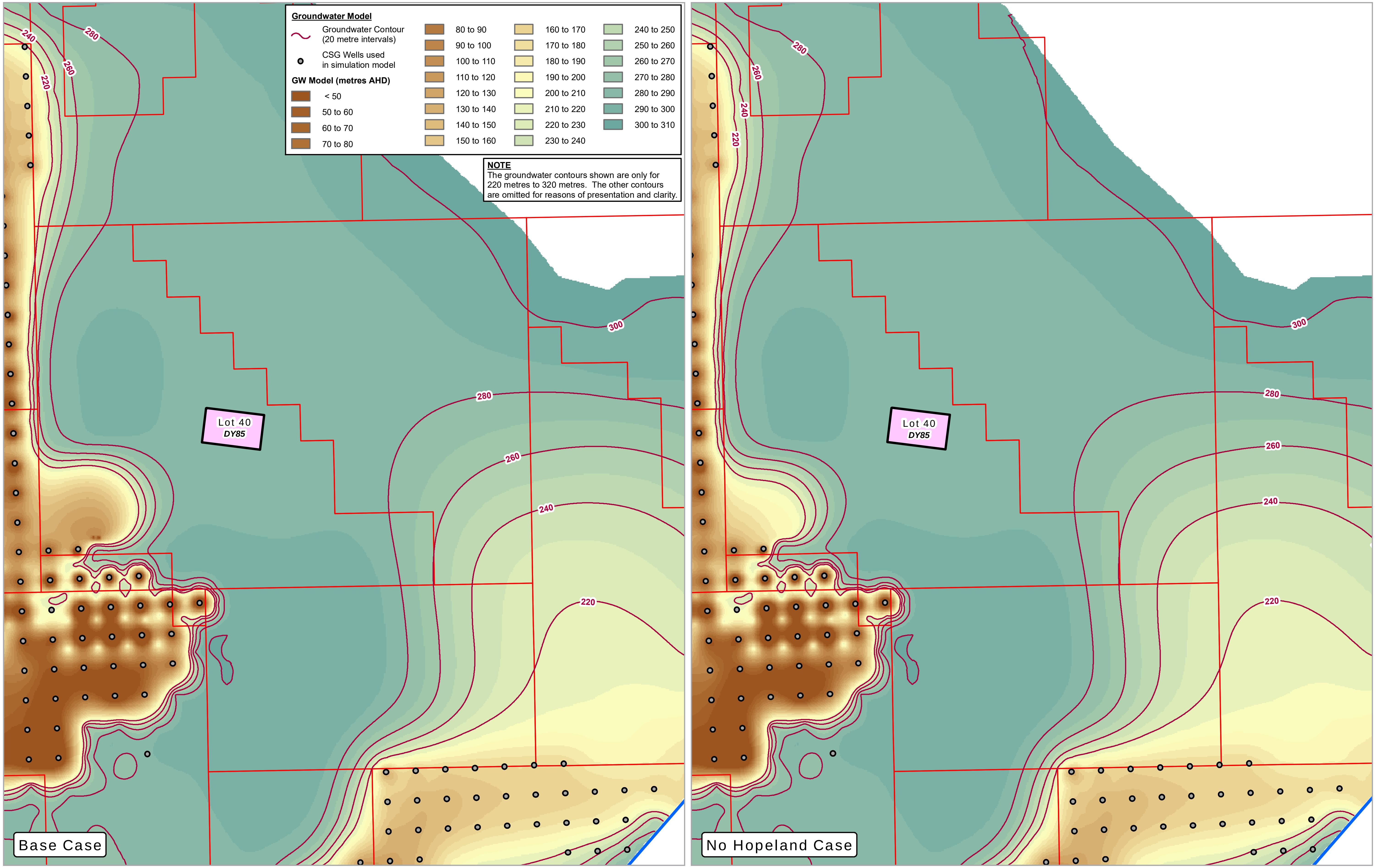
Piezometric heads
Base Case vs No Hopeland Case
Year 2038 : Macalister Seam (Layer 5)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE 5-4

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-16_piezoHeads_Base_vs_NoHopeland_2038_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

▭	Hydrogeological Domain
▭	Boundary of Lot40 on DY85, Linc Energy UCG site
▭	Boundary Petroleum Lease Application
▭	Boundary Petroleum Lease Granted

1:175,000 Paper Size A3

0 2 4 6 8

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Piezometric heads
Base Case vs No Hopeland Case
Year 2038 : Argyle Seam (Layer 8)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE 5-5

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-17_piezoHeads_Base_vs_NoHopeland_2038_Argyle_revA.mxd
Print date: 28 Oct 2019

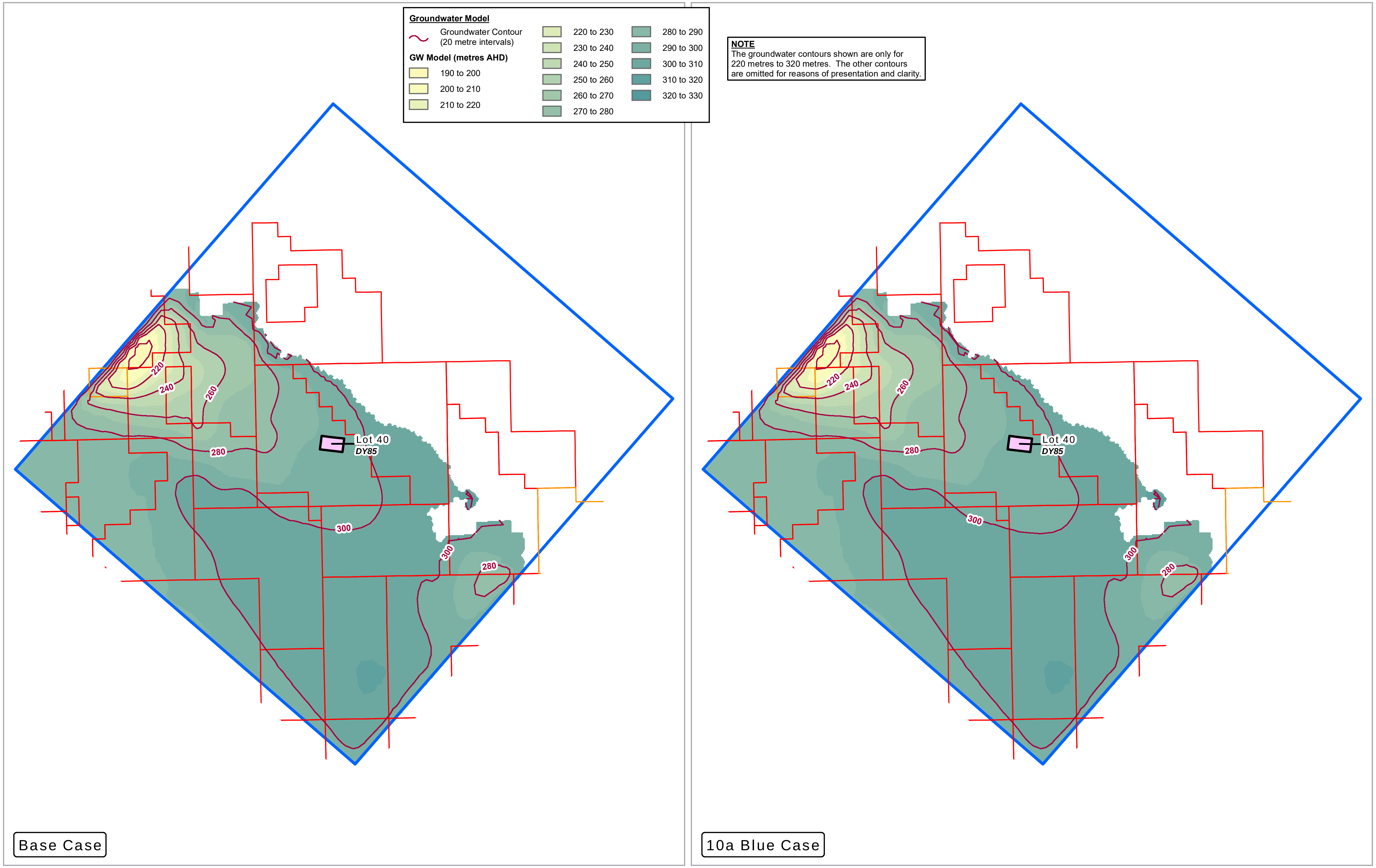
Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten

5.4.2 Scenario 2 predictive model outputs

The outputs of predictive modelling are presented using a series of modelled piezometric head contours from the 'base case' and '10a blue' model runs. Modelled head contours are presented side-by-side to enable visual comparison of the two runs. For the purpose of reporting, the contours are limited to the Springbok Sandstone, Macalister seam and Argyle seam for year 2025, 2035, 2045 and end of simulation (post-CSG extractions). Figures are presented in Appendix E (Figure E-1 to Figure E-12), while results for 2035 are presented on Figure 5-6 to Figure 5-8 (2035 was the period of greatest predicted hydraulic gradients across Lot 40 DY85)

Seepage assessment calculations are presented in Table F3 in Appendix F, covering the 40 year period from 2019 to 2058. Results indicate a predicted 0.248 m of additional groundwater seepage in the vicinity of Lot 40 DY85 due to the future operation of Arrow Energy's CSG abstraction activities on PL185 and PL493. When considered in the context of the seepage associated with the 'base case' model, Arrow Energy's operations on PL185 and PL493 are predicted to account for less than 10% of the total groundwater seepage.

Seepage results from the current modelling works are similar to historical estimates provided in the *Conceptual Model and Assessment* (Arrow, 2018). The peak incremental additional seepage rate due to the operation of the '10a blue' case was reported at $6.16\text{x}10^{-4}$ m/d in 2018, and $1.7\text{x}10^{-5}$ m/d during the current study. Both studies indicate negligible additional groundwater seepage due to approved Arrow Energy operation on PL185 and PL493. As discussed in Section 5.3.2, groundwater seepage calculations are based on a Darcian velocity, and do not account for porosity.



Legend

🟦	Hydrogeological Domain
■	Boundary of Lot40 on DY85, Linc Energy UCG site
🟧	Boundary Petroleum Lease Application
🟥	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

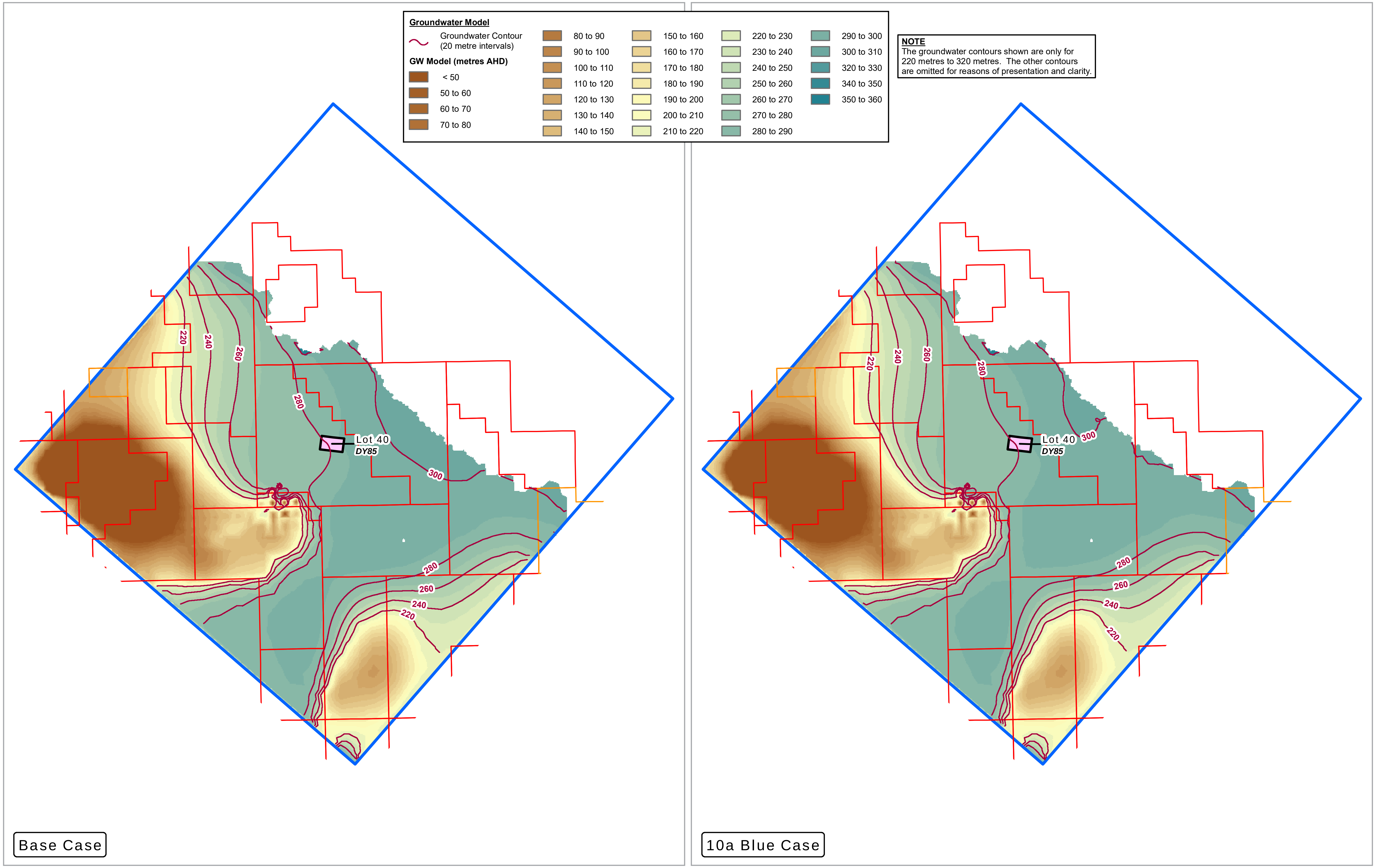
Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Springbok Sansdstone (Layer 3)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE 5-6

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-18_piezoHeads_Base_vs_10aBlue_2035_Springbok_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Groundwater Model

Groundwater Contour (20 metre intervals)

GW Model (metres AHD)

< 50	80 to 90	150 to 160	220 to 230	290 to 300
50 to 60	90 to 100	160 to 170	230 to 240	300 to 310
60 to 70	100 to 110	170 to 180	240 to 250	320 to 330
70 to 80	110 to 120	180 to 190	250 to 260	340 to 350
	120 to 130	190 to 200	260 to 270	350 to 360
	130 to 140	200 to 210	270 to 280	
	140 to 150	210 to 220	280 to 290	

NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

Hydrogeological Domain

Boundary of Lot40 on DY85, Linc Energy UCG site

Boundary Petroleum Lease Application

Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

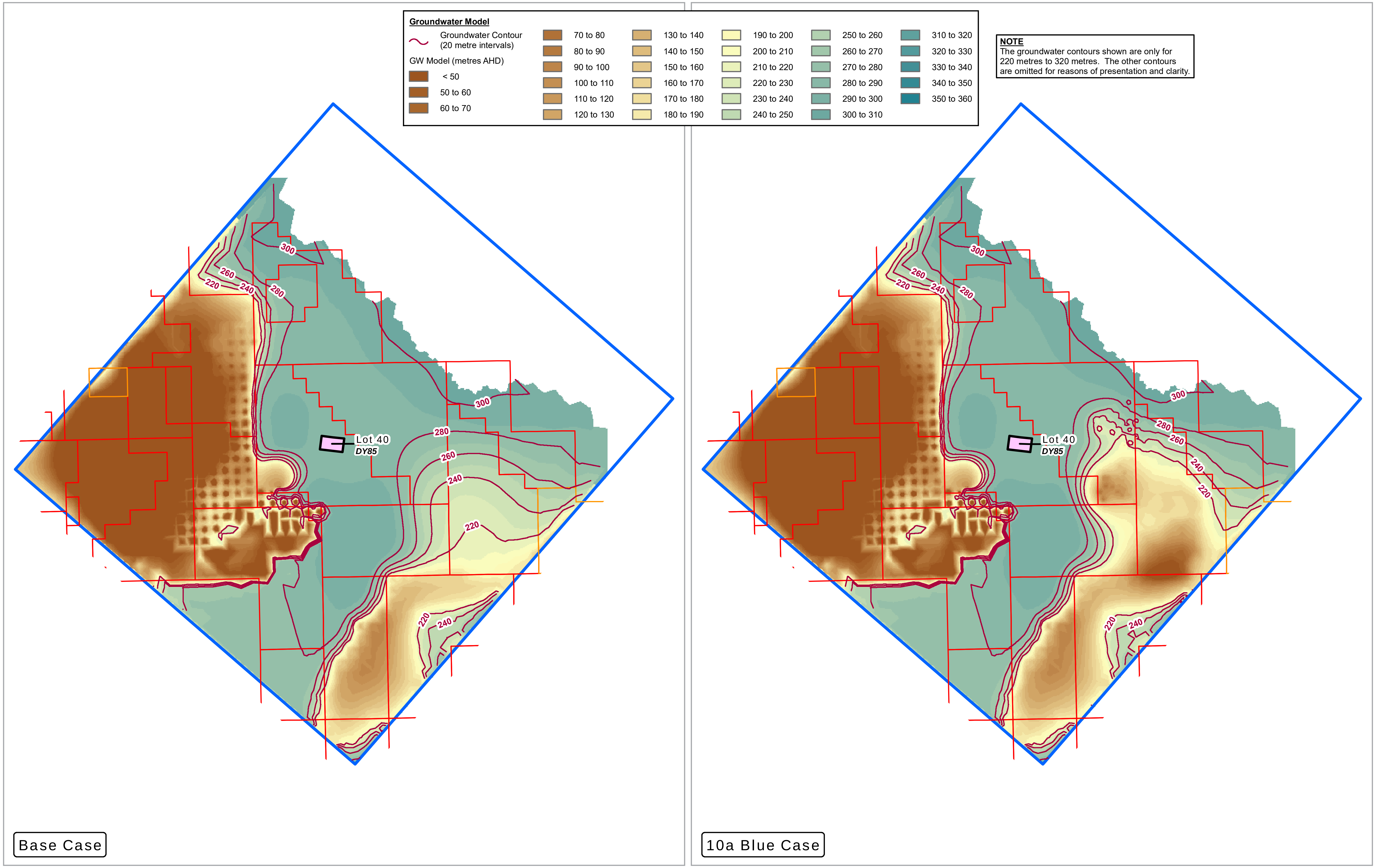
Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Macalister Seam (Layer 5)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE 5-7

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-19_piezoHeads_Base_vs_10aBlue_2035_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

- Hydrogeological Domain
- Boundary of Lot40 on DY85, Linc Energy UCG site
- Boundary Petroleum Lease Application
- Boundary Petroleum Lease Granted

1:450,000 Paper Size A3
0 5 10 15 20
Kilometers
N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Argyle Seam (Layer 8)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE 5-8

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-20_piezoHeads_Base_vs_10aBlue_2035_Argyle_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten

6. Conclusions

A new numerical groundwater model has been developed for an area encompassing PL253, using the unstructured grid version of MODFLOW called MODFLOW-USG. The model mesh has been carefully designed with fine mesh resolution in the areas of interest (Lot 40 DY85 and Hopeland pilot testing site) to enable rigorous transient calibration to groundwater data collected as part of the Groundwater Characteristics Monitoring Program. A sensible balance between groundwater extraction rates and near field heads at the Hopeland pilot testing site has been achieved using a combination of the WEL and CLN packages with well node parameter adjustments, enabling calibration against more than five years of head data collected at the nested monitoring site. The regional depressurisation effects induced by non-Arrow CSG extractions have been incorporated into the model based on the 2016 OGIA model, calibrated against the lowering of piezometric heads observed in regional monitoring bores/piezometers located some distance from PL253.

The calibrated model provides the basis for undertaking predictions of CSG extraction impacts. In this study, the potential effect of Arrow's '10a blue' CSG extraction activities has been assessed, along with the historical and future operation of the Hopeland facility. Results have been presented using a series of piezometric head contours maps showing the incremental effects of Arrow's CSG extractions in areas around PL253, and well as a through a groundwater seepage assessment. Predictions indicate a slight steepening of the hydraulic gradient arround Lot 40 DY85. Future approved operations are predicted to result in a negligible (less than 10%) increase in groundwater seepage from the former Linc Energy site.

7. References

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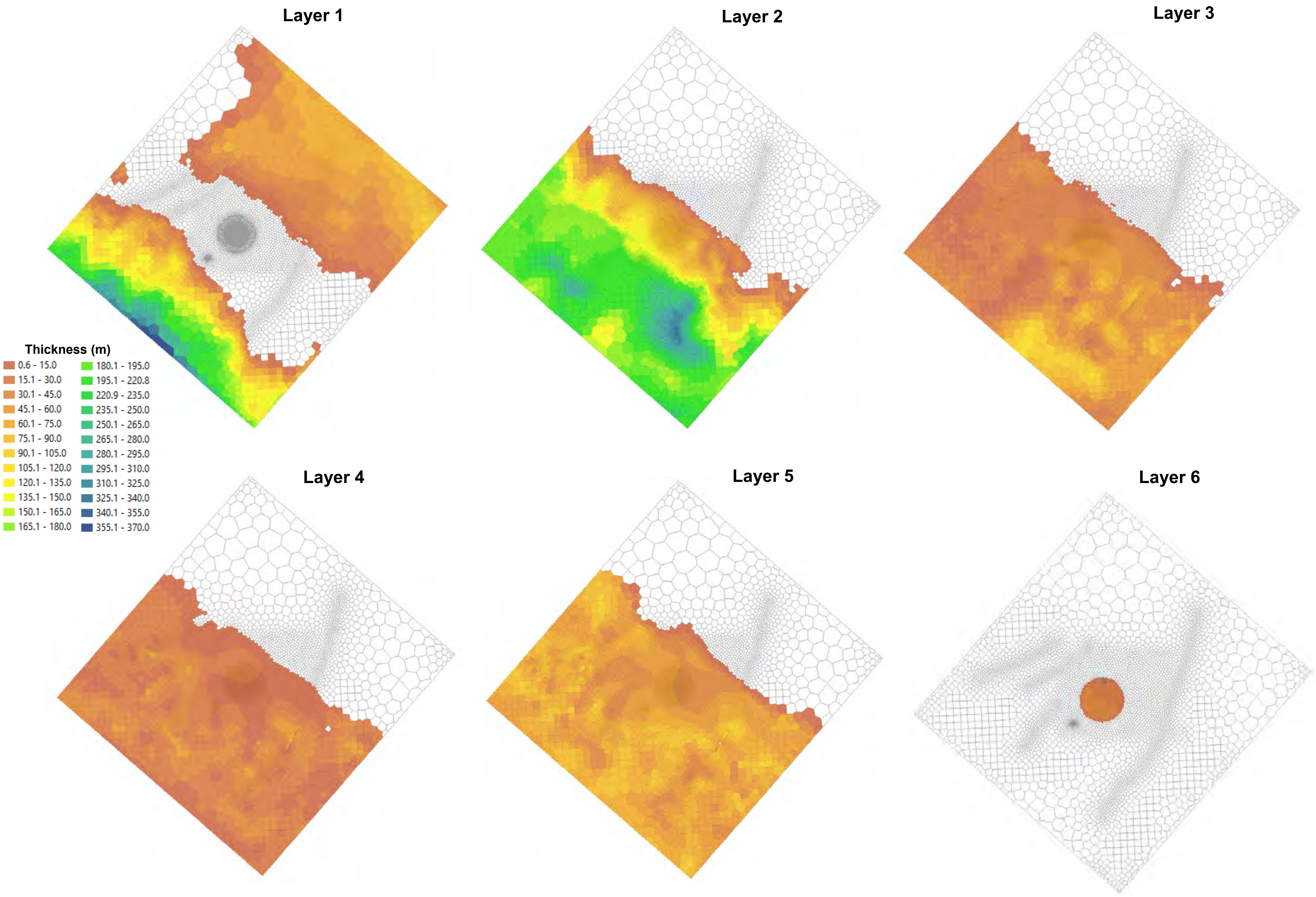
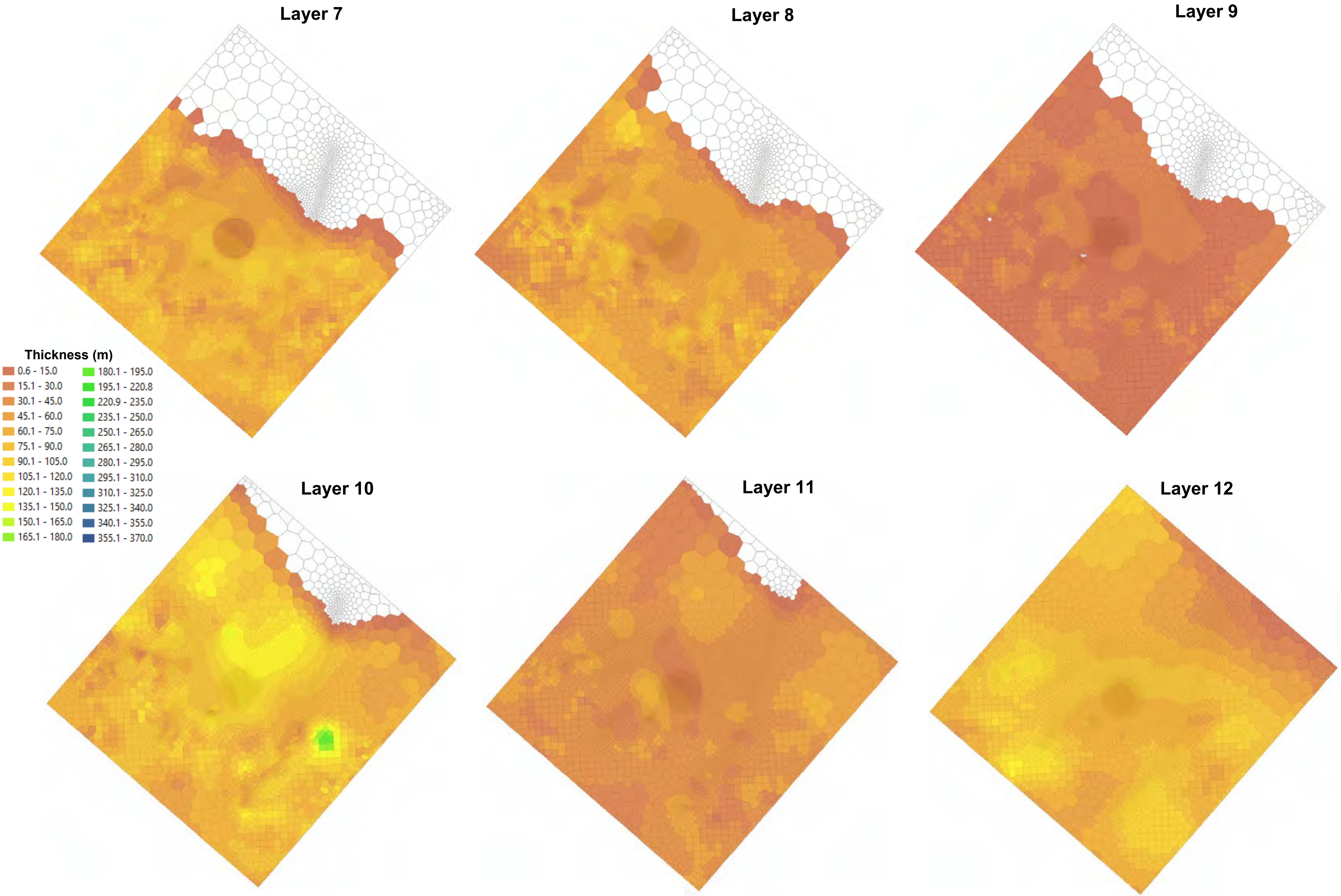
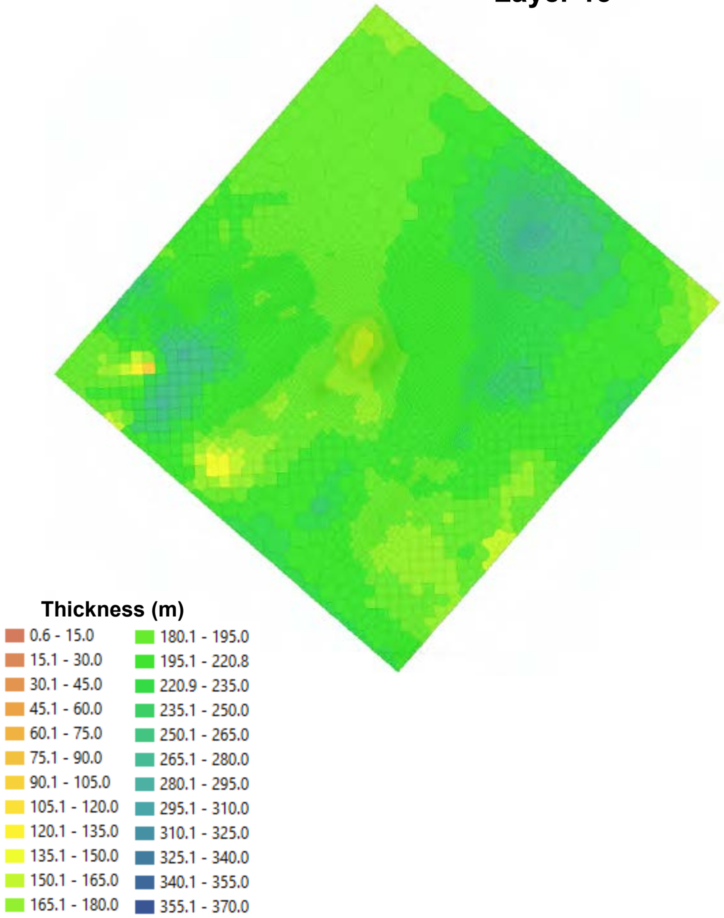
Appendices

Appendix A – Hydrostratigraphic Unit Distribution by Layer and Layer Thickness


Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Thickness (m)
0.6 - 15.0
15.1 - 30.0
30.1 - 45.0
45.1 - 60.0
60.1 - 75.0
75.1 - 90.0
90.1 - 105.0
105.1 - 120.0
120.1 - 135.0
135.1 - 150.0
150.1 - 165.0
165.1 - 180.0
180.1 - 195.0
195.1 - 220.8
220.9 - 235.0
235.1 - 250.0
250.1 - 265.0
265.1 - 280.0
280.1 - 295.0
295.1 - 310.0
310.1 - 325.0
325.1 - 340.0
340.1 - 355.0
355.1 - 370.0


Layer 7
Layer 8
Layer 9
Layer 10
Layer 11
Layer 12
Thickness (m)
0.6 - 15.0
15.1 - 30.0
30.1 - 45.0
45.1 - 60.0
60.1 - 75.0
75.1 - 90.0
90.1 - 105.0
105.1 - 120.0
120.1 - 135.0
135.1 - 150.0
150.1 - 165.0
165.1 - 180.0
180.1 - 195.0
195.1 - 220.8
220.9 - 235.0
235.1 - 250.0
250.1 - 265.0
265.1 - 280.0
280.1 - 295.0
295.1 - 310.0
310.1 - 325.0
325.1 - 340.0
340.1 - 355.0
355.1 - 370.0

Layer 13


Thickness (m)
0.6 - 15.0
15.1 - 30.0
30.1 - 45.0
45.1 - 60.0
60.1 - 75.0
75.1 - 90.0
90.1 - 105.0
105.1 - 120.0
120.1 - 135.0
135.1 - 150.0
150.1 - 165.0
165.1 - 180.0
180.1 - 195.0
195.1 - 220.8
220.9 - 235.0
235.1 - 250.0
250.1 - 265.0
265.1 - 280.0
280.1 - 295.0
295.1 - 310.0
310.1 - 325.0
325.1 - 340.0
340.1 - 355.0
355.1 - 370.0

Appendix B – Head Calibration Targets

Head Calibration Targets

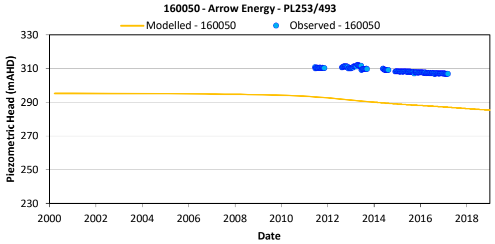
Bore ID	OBS ID	Easting (Z56)	Northing (Z56)	HSU	Layer	GlobalCellID	Obs count	From	To
42230203	RN203	299,306	7,023,164	Condamine Alluvium	1	2101	1	29/04/2018	
42230209	RN209	269,254	7,040,011	Condamine Alluvium	1	1434	186	13/03/2013	19/10/2016
AES1013	AES1013	287,933	7,016,371	Condamine Alluvium	1	1961	1	12/07/2012	
AES1015	AES1015	287,253	7,015,284	Condamine Alluvium	1	1963	1	12/07/2012	
AES1075	AES1075	299,194	7,011,099	Condamine Alluvium	1	2091	1	17/08/2012	
AES1076	AES1076	296,532	7,012,227	Condamine Alluvium	1	2073	1	17/08/2012	
AES1298	AES1298	264,716	7,035,731	Condamine Alluvium	1	1295	2	15/07/2013	3/07/2017
AES1302	AES1302	263,235	7,033,879	Condamine Alluvium	1	1234	1	17/07/2013	
AES1303	AES1303	262,090	7,034,390	Condamine Alluvium	1	1230	1	18/07/2013	
AES1304	AES1304	264,515	7,035,724	Condamine Alluvium	1	1295	1	23/07/2013	
Macalister5	Ma5	296,819	7,023,544	Condamine Alluvium	1	2087	1	29/04/2018	
Wyalla-16	Wy16	276,967	7,026,409	Condamine Alluvium	1	921	2	13/04/2018	13/04/2018
Hopeland-17	HP17SBK	262,959	7,014,291	Springbok Sandstone	3	21337	216	19/07/2014	3/11/2018
160050	160050	238,796	7,022,705	Springbok Sandstone	3	25882	211	20/06/2011	13/03/2017
160519	160519	256,802	7,008,061	Springbok Sandstone	3	26767	292	26/09/2011	26/06/2017
160521	160521	280,292	6,992,670	Springbok Sandstone	3	28840	265	28/11/2011	26/06/2017
160564	160564	279,842	7,007,257	Springbok Sandstone	3	28884	158	10/03/2014	13/03/2017
160597	160597	246,203	7,016,628	Springbok Sandstone	3	24499	222	1/04/2013	26/06/2017
AES1149	AES1149	287,198	7,003,457	Springbok Sandstone	3	29168	1	9/01/2013	
AES1158	AES1158	287,388	7,004,541	Springbok Sandstone	3	29217	1	15/01/2013	
AES1293	AES1293	262,487	7,023,578	Springbok Sandstone	3	26183	1	11/07/2013	
AES1294	AES1294	262,387	7,023,552	Springbok Sandstone	3	26183	1	7/11/2013	
AES1436	AES1436	265,619	7,020,142	Springbok Sandstone	3	23620	1	16/01/2014	
AES1687	AES1687	266,177	7,021,736	Springbok Sandstone	3	24879	1	30/03/2016	
AES1780	AES1780	277,273	7,013,827	Springbok Sandstone	3	28424	1	20/06/2017	
HSMB1S	HSMB1S	269,831	7,019,783	Springbok Sandstone	3	17607	4	30/05/2018	6/09/2018
HSMB2S	HSMB2S	269,867	7,018,998	Springbok Sandstone	3	18243	4	31/05/2018	6/09/2018
HSMB3S1	HSMB3S1	269,086	7,020,075	Springbok Sandstone	3	16878	11	29/05/2018	10/12/2018
HSMB3S2	HSMB3S2	268,785	7,020,101	Springbok Sandstone	3	16744	4	28/05/2018	6/09/2018
HSMB4S	HSMB4S	268,473	7,019,431	Springbok Sandstone	3	16208	4	1/06/2018	6/09/2018
AES1171	AES1171	266,473	7,023,559	Walloon Coal Measures (Kogan)	4	40676	1	19/02/2013	
AES1282	AES1282	265,509	7,026,931	Walloon Coal Measures (Kogan)	4	41277	1	8/09/2017	
AES1284	AES1284	265,917	7,029,869	Walloon Coal Measures (Kogan)	4	41666	9	23/03/2016	1/05/2018
AES1285	AES1285	265,414	7,029,104	Walloon Coal Measures (Kogan)	4	41546	7	9/07/2013	26/10/2017
AES1289	AES1289	261,849	7,030,001	Walloon Coal Measures (Kogan)	4	41914	5	10/07/2013	17/01/2018
AES1292	AES1292	262,716	7,023,787	Walloon Coal Measures (Kogan)	4	40052	1	11/07/2013	
AES1295	AES1295	261,984	7,024,441	Walloon Coal Measures (Kogan)	4	40275	1	11/07/2013	
AES1296	AES1296	260,097	7,028,277	Walloon Coal Measures (Kogan)	4	41531	1	12/07/2017	
AES1391	AES1391	267,688	7,028,551	Walloon Coal Measures (Kogan)	4	41926	8	28/10/2013	19/09/2017
AES1445	AES1445	261,479	7,026,280	Walloon Coal Measures (Kogan)	4	40839	1	1/05/2018	
AES1686	AES1686	267,370	7,021,503	Walloon Coal Measures (Kogan)	4	36989	1	30/03/2016	
AES1689	AES1689	265,831	7,018,595	Walloon Coal Measures (Kogan)	4	36265	1	31/03/2016	
AES1691	AES1691	267,233	7,018,777	Walloon Coal Measures (Kogan)	4	33725	1	31/03/2016	
AES1695	AES1695	267,869	7,026,687	Walloon Coal Measures (Kogan)	4	41556	4	27/04/2016	19/10/2017
AES1697	AES1697	269,660	7,024,008	Walloon Coal Measures (Kogan)	4	40810	1	27/04/2016	
AES1701	AES1701	268,571	7,029,591	Walloon Coal Measures (Kogan)	4	42132	1	28/04/2016	
AES1749	AES1749	263,902	7,030,763	Walloon Coal Measures (Kogan)	4	42028	1	27/10/2016	
AES1779	AES1779	265,798	7,025,109	Walloon Coal Measures (Kogan)	4	41005	1	14/11/2017	
AES1802	AES1802	269,070	7,020,802	Walloon Coal Measures (Kogan)	4	33277	1	19/09/2017	
RN147607	147607	267,393	7,018,760	Walloon Coal Measures (Kogan)	4	33408	6	9/06/2010	5/04/2018
RN24466	24466	265,702	7,018,874	Walloon Coal Measures (Kogan)	4	35985	3	31/03/2016	5/04/2018
G4MWA	G4MWA	268,603	7,019,438	Walloon Coal Measures (Macalister)	5	43208	2	7/06/2018	12/09/2018
G4MWD	G4MWD	268,776	7,019,466	Walloon Coal Measures (Macalister)	5	43005	2	6/06/2018	12/09/2018
Hopeland-17	HP17WCMm	262,959	7,014,291	Walloon Coal Measures (Macalister)	5	48610	224	19/07/2014	29/12/2018
HSMB1D	HSMB1D	269,841	7,019,744	Walloon Coal Measures (Macalister)	5	44878	4	30/05/2018	6/09/2018
HSMB2D	HSMB2D	269,850	7,018,863	Walloon Coal Measures (Macalister)	5	45721	4	31/05/2018	4/09/2018
HSMB3D1	HSMB3D1	269,205	7,020,062	Walloon Coal Measures (Macalister)	5	44310	12	30/05/2018	14/12/2018
HSMB3D2	HSMB3D2	268,854	7,020,094	Walloon Coal Measures (Macalister)	5	43743	4	29/05/2018	3/09/2018
HSMB4D	HSMB4D	268,491	7,019,561	Walloon Coal Measures (Macalister)	5	43629	4	1/06/2018	3/09/2018
HSMB5D	HSMB5D	268,767	7,018,974	Walloon Coal Measures (Macalister)	5	44272	4	4/06/2018	5/09/2018
Kogan North-79	KN79WUJ	291,797	7,011,959	Walloon Coal Measures (Macalister)	5	56780	1	31/08/2018	
Kogan North-56	KN56WCM	291,667	7,010,800	Walloon Coal Measures (Macalister)	5	56772	1	14/08/2018	
L22	L22	268,909	7,019,785	Walloon Coal Measures (Macalister)	5	43084	2	4/06/2018	10/09/2018
M14R	M14R	269,109	7,019,778	Walloon Coal Measures (Macalister)	5	43305	2	5/06/2018	10/09/2018
M22	M22	269,214	7,019,787	Walloon Coal Measures (Macalister)	5	43392	2	6/06/2018	11/09/2018
AES1074	AES1074	299,202	7,011,060	Walloon Coal Measures (Wambo)	7	80152	1	17/08/2012	
AES1078	AES1078	296,527	7,012,233	Walloon Coal Measures (Wambo)	7	80142	1	17/08/2012	
AES1079	AES1079	299,735	7,010,430	Walloon Coal Measures (Wambo)	7	80153	1	17/08/2012	
AES1080	AES1080	299,172	7,010,203	Walloon Coal Measures (Wambo)	7	80144	1	17/08/2012	

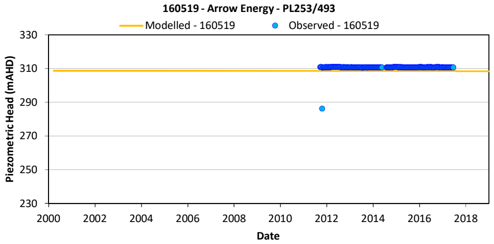
Head Calibration Targets

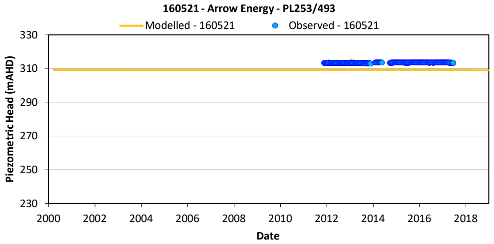
Bore ID	OBS ID	Easting (Z56)	Northing (Z56)	HSU	Layer	GlobalCellID	Obs count	From	To
AES1081	AES1081	297,441	7,010,906	Walloon Coal Measures (Wambo)	7	80143	1	17/08/2012	
AES1172	AES1172	300,032	7,010,290	Walloon Coal Measures (Wambo)	7	80153	1	19/02/2013	
AES1340	AES1340	292,940	7,017,495	Walloon Coal Measures (Wambo)	7	80139	1	21/08/2013	
AES1387	AES1387	287,517	7,017,292	Walloon Coal Measures (Wambo)	7	80078	1	24/10/2013	
AES1388	AES1388	287,418	7,017,291	Walloon Coal Measures (Wambo)	7	80078	1	24/10/2013	
AES1389	AES1389	287,726	7,017,285	Walloon Coal Measures (Wambo)	7	80080	1	24/10/2013	
AES1694	AES1694	261,675	7,037,435	Walloon Coal Measures (Wambo)	7	79412	1	27/04/2016	
AES9417	AES9417	292,416	7,015,242	Walloon Coal Measures (Wambo)	7	80131	1	5/07/2018	
AES1022	AES1022	289,871	7,021,740	Walloon Coal Measures (Argyle)	8	94449	1	16/07/2012	
Dundee-20	DD20WCMa	269,099	7,039,871	Walloon Coal Measures (Argyle)	8	93898	110	19/11/2014	25/01/2017
Hopeland-17	HP17WCMa	262,959	7,014,291	Walloon Coal Measures (Argyle)	8	85863	224	19/07/2014	29/12/2018
Hopeland-5	HP5	263,043	7,014,413	Walloon Coal Measures (Argyle)	8	84790	34	22/02/2014	22/08/2018
Kogan North-79	KN79WLJ	291,797	7,011,959	Walloon Coal Measures (Argyle)	8	94453	1	31/08/2018	
Wyalla-18	Wy18WCMa	276,971	7,026,425	Walloon Coal Measures (Argyle)	8	92733	203	6/12/2014	29/12/2018
AES1524	AES1524	286,385	7,027,807	Walloon Coal Measures (Tangalooma Sandstone)	9	108518	2	24/09/2014	11/04/2017
Dundee-20	DD20WCMut	269,099	7,039,871	Walloon Coal Measures (Upper Taroom)	10	122623	112	19/11/2014	25/01/2017
Hopeland-17	HP17WCMut	262,959	7,014,291	Walloon Coal Measures (Upper Taroom)	10	114574	224	19/07/2014	29/12/2018
Dundee-20	DD20WCMc	269,099	7,039,871	Walloon Coal Measures (Condamine)	11	137205	110	19/11/2014	25/01/2017
Hopeland-5T	HP5T	263,036	7,014,406	Walloon Coal Measures (Condamine)	11	127917	32	22/02/2014	22/08/2018
Hopeland-6	HP6	262,903	7,014,520	Walloon Coal Measures (Condamine)	11	129101	32	22/02/2014	22/08/2018
Hopeland-7	HP7	263,153	7,014,548	Walloon Coal Measures (Condamine)	11	129634	32	22/02/2014	22/08/2018
Hopeland-8	HP8	263,191	7,014,222	Walloon Coal Measures (Condamine)	11	130490	32	22/02/2014	22/08/2018
Hopeland-9	HP9	262,911	7,014,246	Walloon Coal Measures (Condamine)	11	129939	31	22/02/2014	23/07/2018
Kogan North-79	KN79WTM	291,797	7,011,959	Walloon Coal Measures (Condamine)	11	138050	1	31/08/2018	
Macalister8	Ma8	296,836	7,023,542	Walloon Coal Measures (Condamine)	11	138116	1	29/04/2018	
Wyalla-18	Wy18WCMc	276,971	7,026,425	Walloon Coal Measures (Condamine)	11	136023	203	29/11/2014	29/12/2018
AES1140	AES1140	286,526	7,012,143	Hutton Sandstone	13	167443	1	18/12/2012	
AES1809	AES1809	262,746	7,023,844	Hutton Sandstone	13	163718	1	5/12/2017	
AES9416	AES9416	280,051	7,029,364	Hutton Sandstone	13	166179	1	4/07/2018	

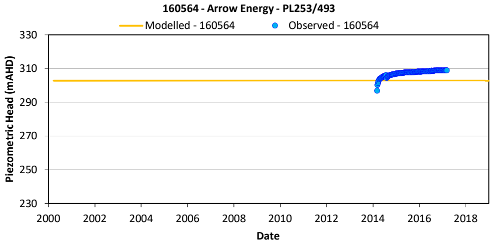
Appendix C – Calibration Hydrographs

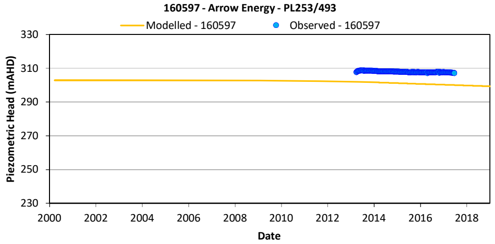
Calibration Hydrographs

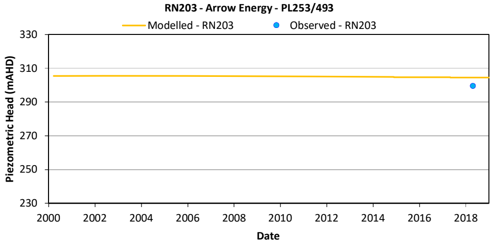

160050 - Arrow Energy - PL253/493

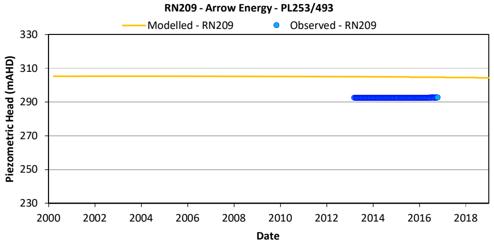

160519 - Arrow Energy - PL253/493

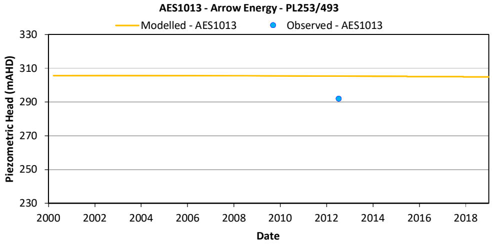

160521 - Arrow Energy - PL253/493

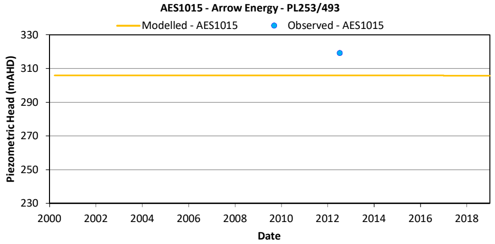

160564 - Arrow Energy - PL253/493

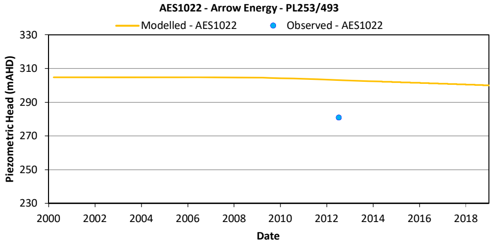

160597 - Arrow Energy - PL253/493

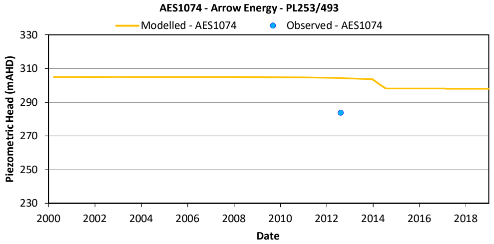

RN203 - Arrow Energy - PL253/493

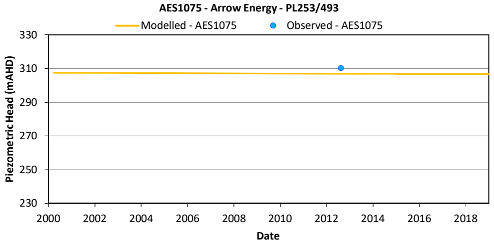

RN209 - Arrow Energy - PL253/493

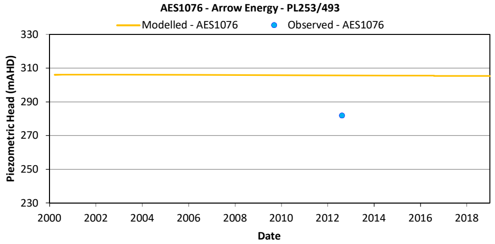

AES1013 - Arrow Energy - PL253/493

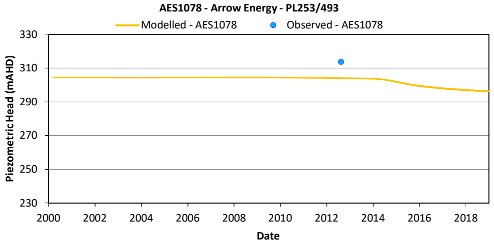

AES1015 - Arrow Energy - PL253/493

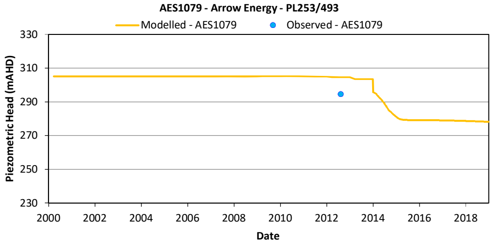

AES1022 - Arrow Energy - PL253/493

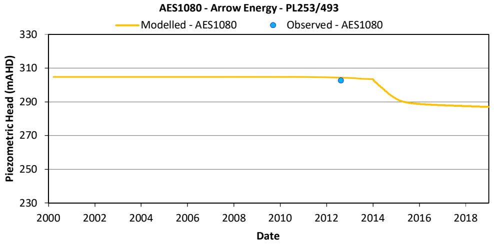

AES1074 - Arrow Energy - PL253/493


AES1075 - Arrow Energy - PL253/493


AES1076 - Arrow Energy - PL253/493

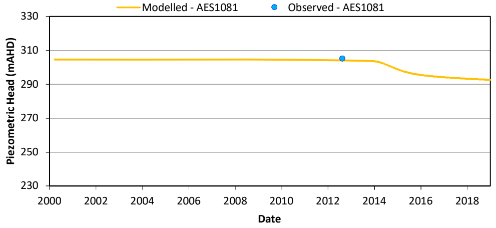

AES1078 - Arrow Energy - PL253/493


AES1079 - Arrow Energy - PL253/493

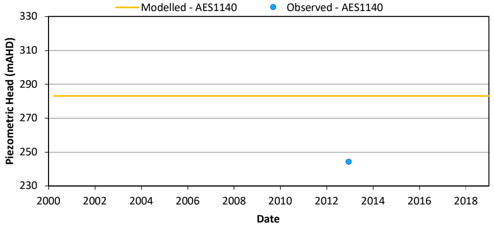

AES1080 - Arrow Energy - PL253/493

Calibration Hydrographs

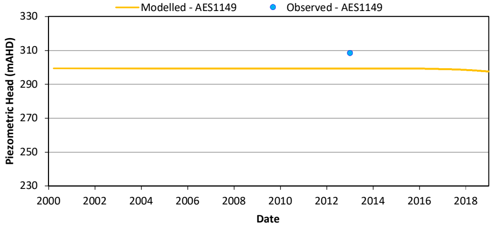
AES1081 - Arrow Energy - PL253/493



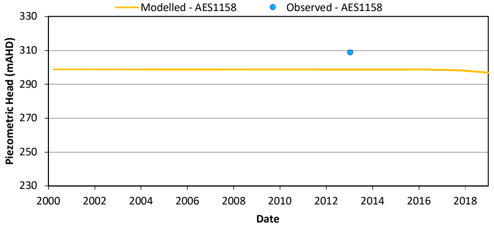
AES1140 - Arrow Energy - PL253/493



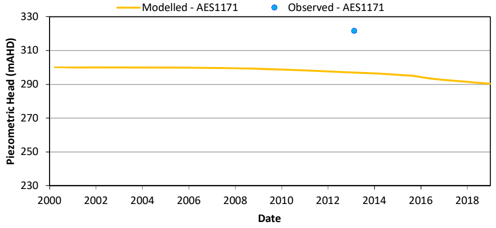
AES1149 - Arrow Energy - PL253/493



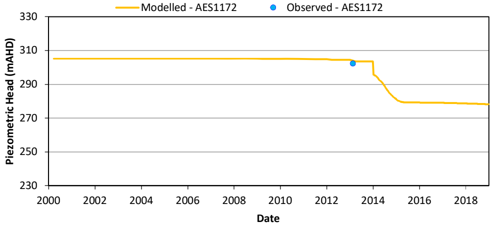
AES1158 - Arrow Energy - PL253/493



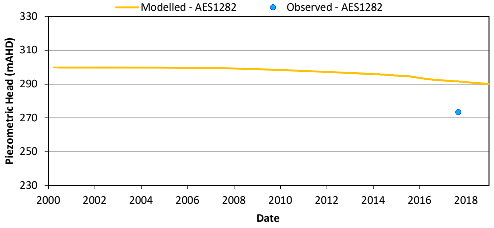
AES1171 - Arrow Energy - PL253/493



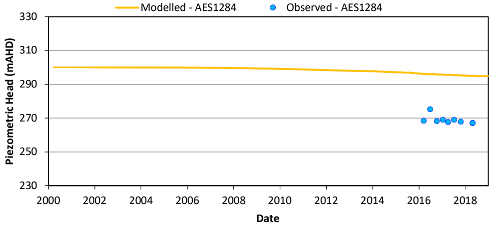
AES1172 - Arrow Energy - PL253/493



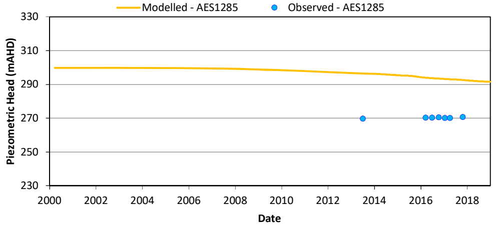
AES1282 - Arrow Energy - PL253/493



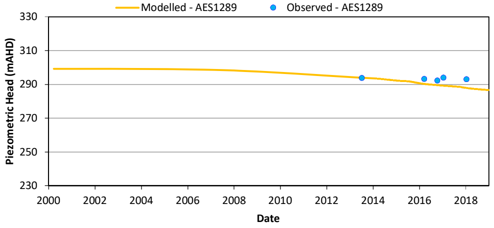
AES1284 - Arrow Energy - PL253/493



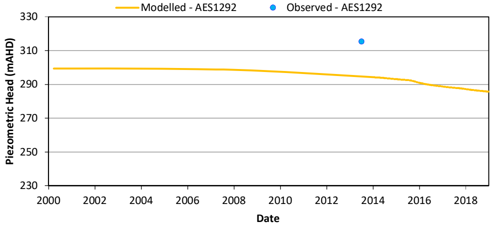
AES1285 - Arrow Energy - PL253/493



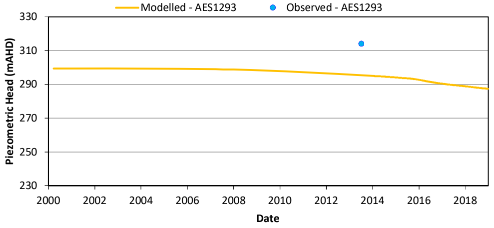
AES1289 - Arrow Energy - PL253/493



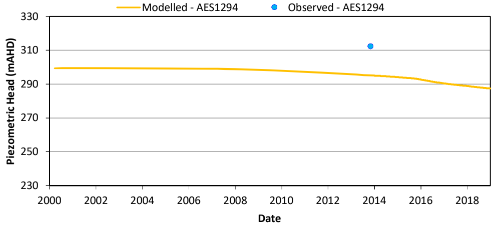
AES1292 - Arrow Energy - PL253/493



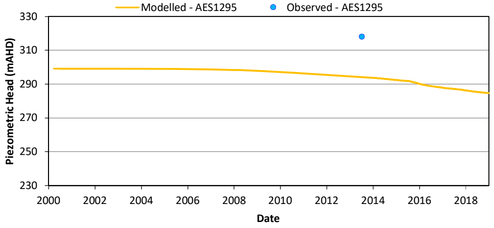
AES1293 - Arrow Energy - PL253/493



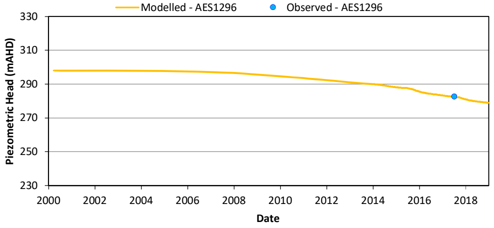
AES1294 - Arrow Energy - PL253/493



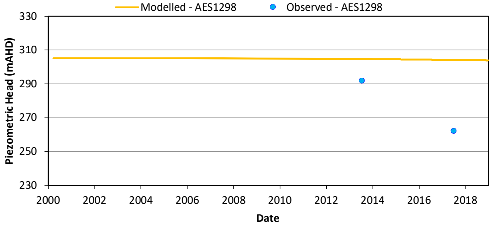
AES1295 - Arrow Energy - PL253/493



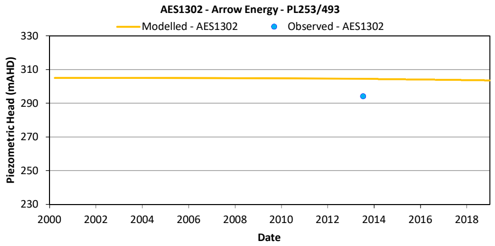
AES1296 - Arrow Energy - PL253/493

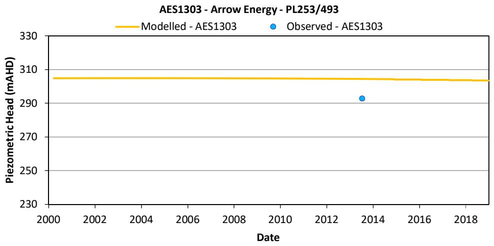


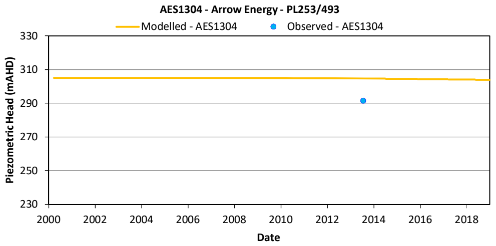
AES1298 - Arrow Energy - PL253/493

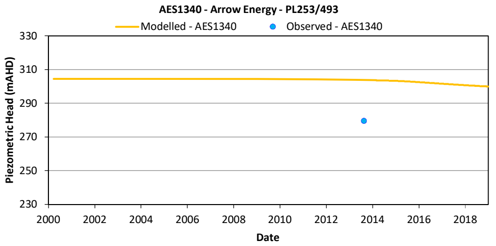


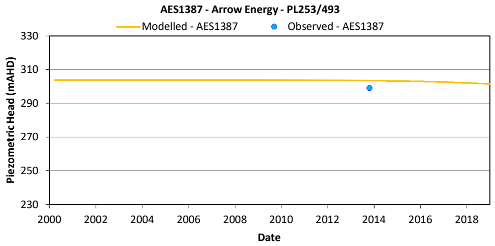
Calibration Hydrographs

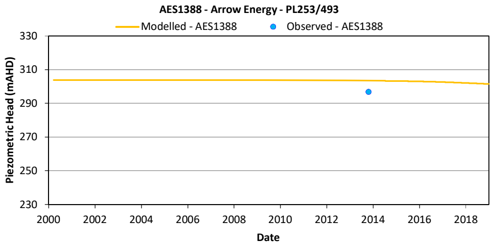

AES1302 - Arrow Energy - PL253/493

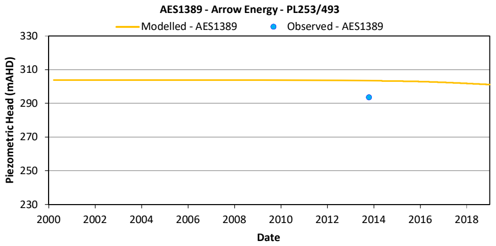

AES1303 - Arrow Energy - PL253/493

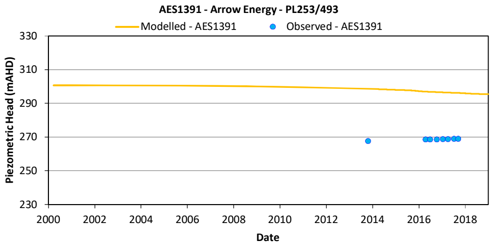

AES1304 - Arrow Energy - PL253/493

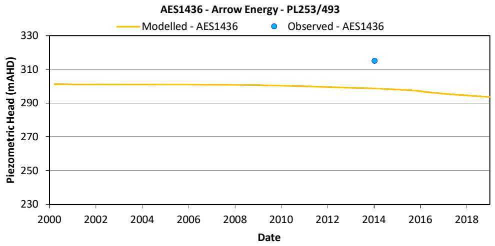

AES1340 - Arrow Energy - PL253/493

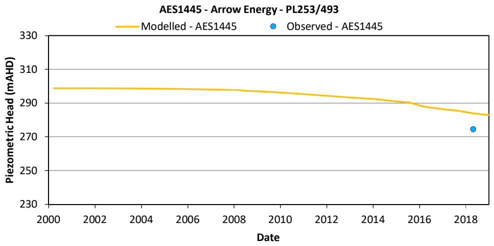

AES1387 - Arrow Energy - PL253/493

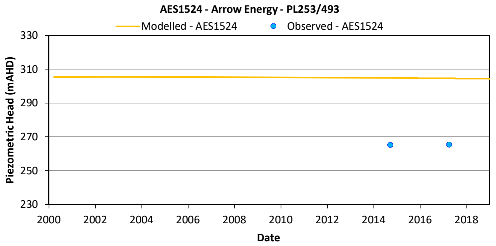

AES1388 - Arrow Energy - PL253/493

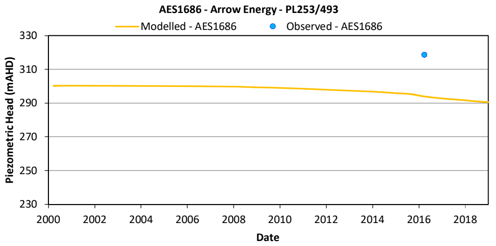

AES1389 - Arrow Energy - PL253/493

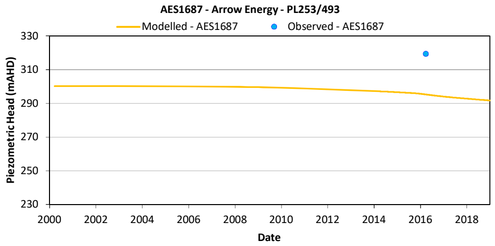

AES1391 - Arrow Energy - PL253/493

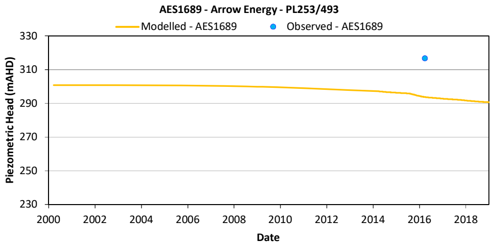

AES1436 - Arrow Energy - PL253/493

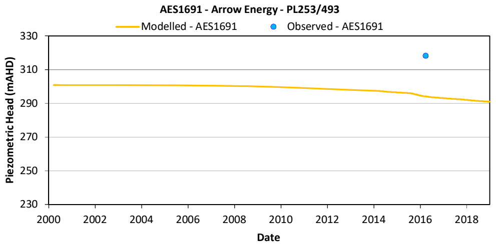

AES1445 - Arrow Energy - PL253/493

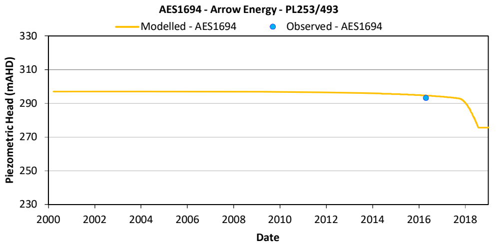

AES1524 - Arrow Energy - PL253/493


AES1686 - Arrow Energy - PL253/493

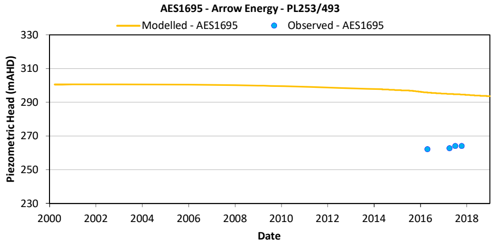

AES1687 - Arrow Energy - PL253/493

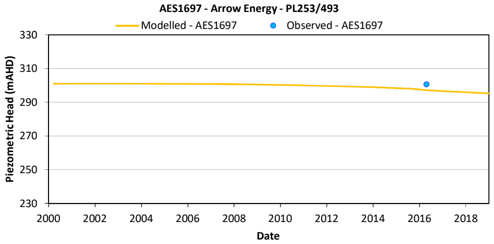

AES1689 - Arrow Energy - PL253/493

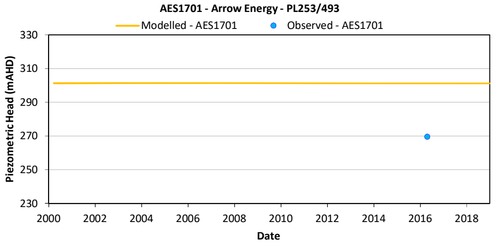

AES1691 - Arrow Energy - PL253/493

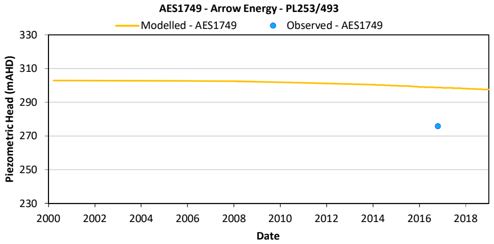

AES1694 - Arrow Energy - PL253/493

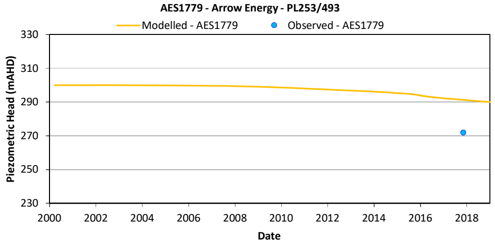
Calibration Hydrographs

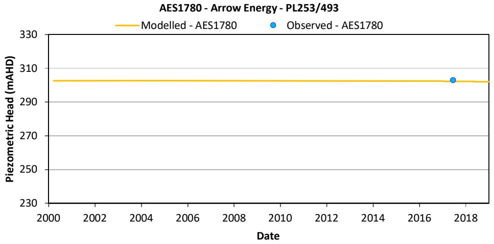


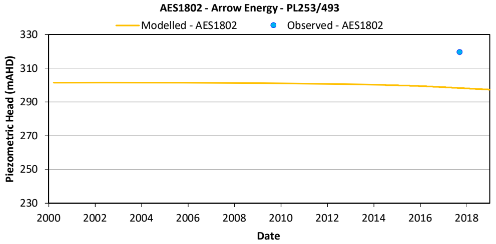


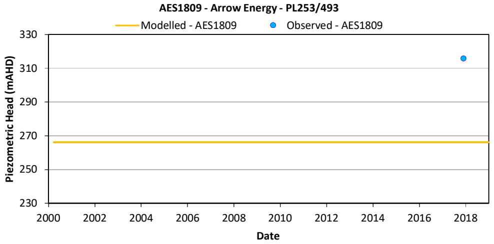


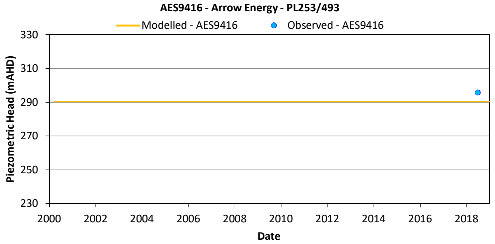


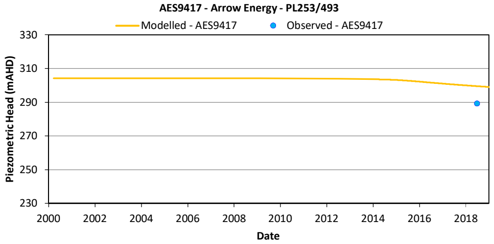


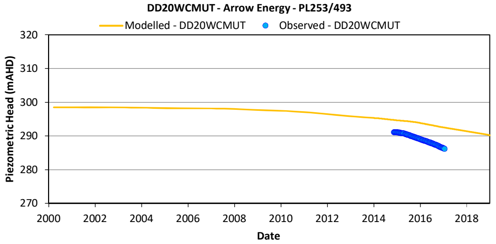


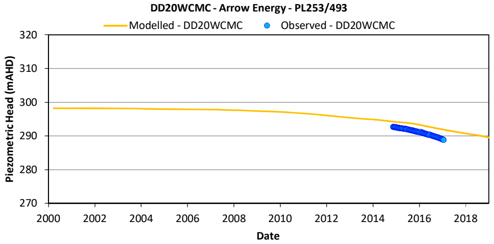


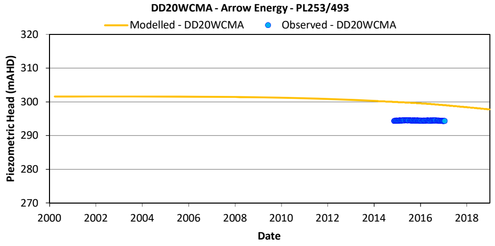


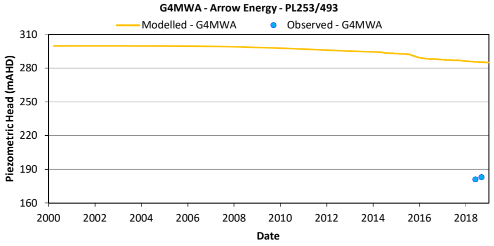


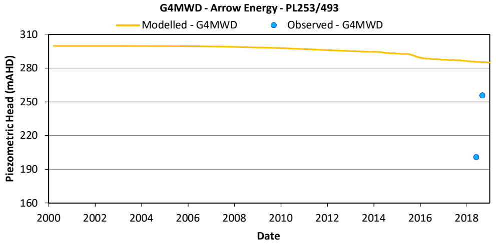


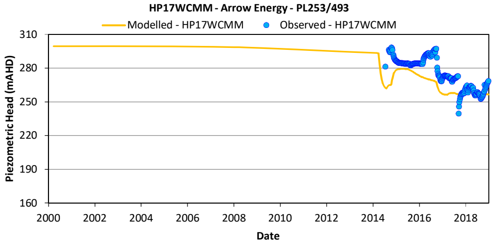




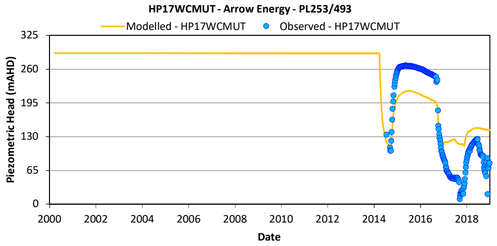


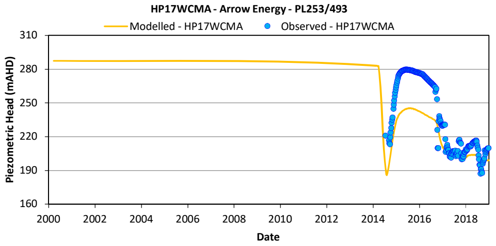


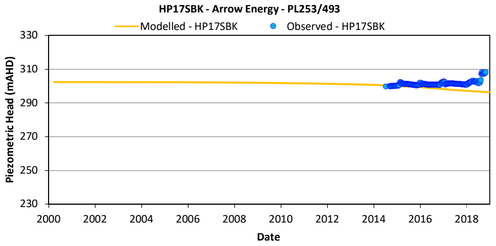




Calibration Hydrographs


HP17WCMUT - Arrow Energy - PL253/493


HP17WCMA - Arrow Energy - PL253/493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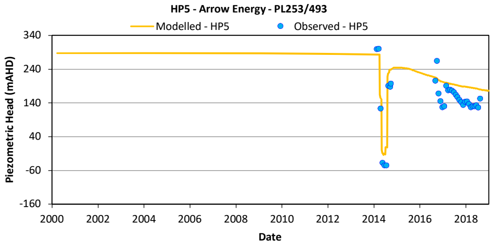
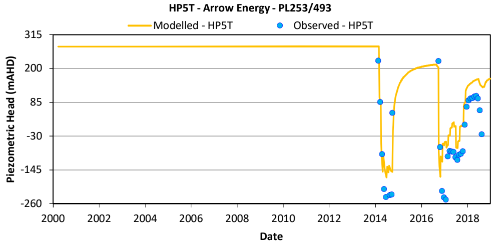
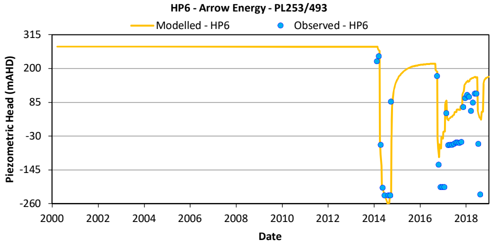
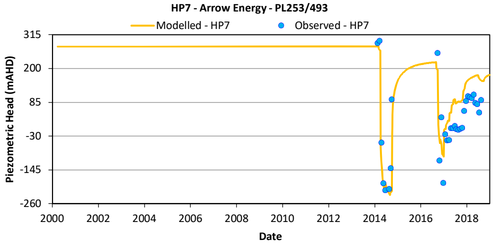
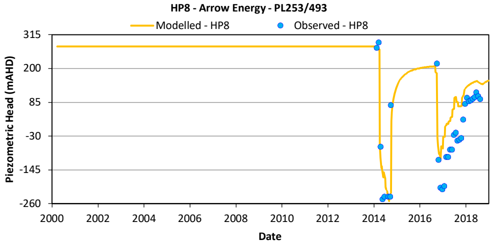
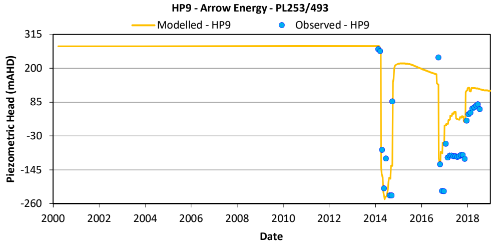

HP5 - Arrow Energy - PL253/493

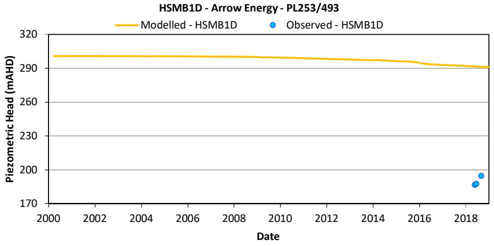

HP5T - Arrow Energy - PL253/493

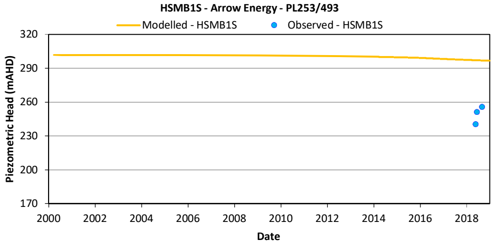

HP6 - Arrow Energy - PL253/493

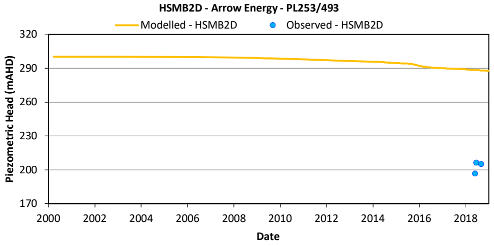

HP7 - Arrow Energy - PL253/493

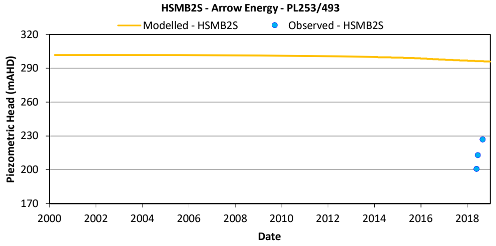

HP8 - Arrow Energy - PL253/493

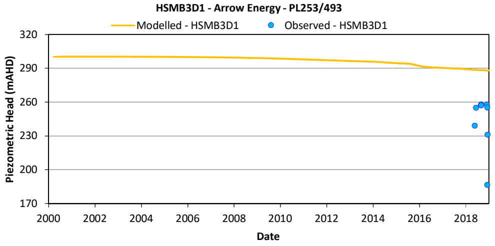

HP9 - Arrow Energy - PL253/493

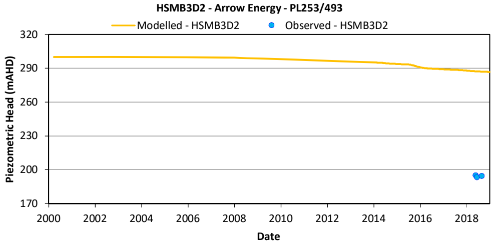

HSMB1D - Arrow Energy - PL253/493

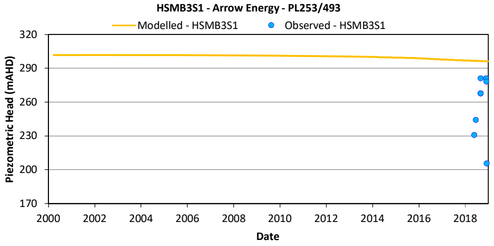

HSMB1S - Arrow Energy - PL253/493


HSMB2D - Arrow Energy - PL253/493


HSMB2S - Arrow Energy - PL253/493

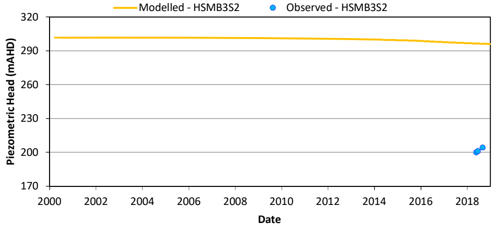

HSMB3D1 - Arrow Energy - PL253/493


HSMB3D2 - Arrow Energy - PL253/493

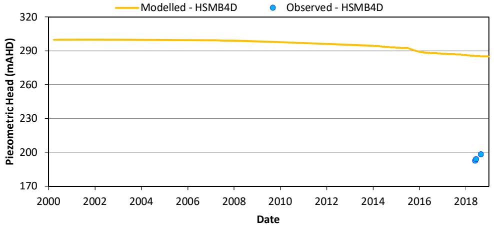

HSMB3S1 - Arrow Energy - PL253/493

Calibration Hydrographs

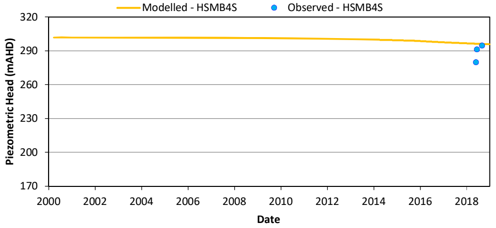
HSMB3S2 - Arrow Energy - PL253/493



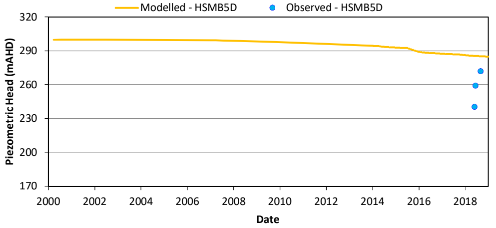
HSMB4D - Arrow Energy - PL253/493



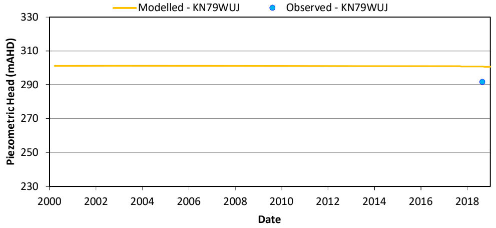
HSMB4S - Arrow Energy - PL253/493



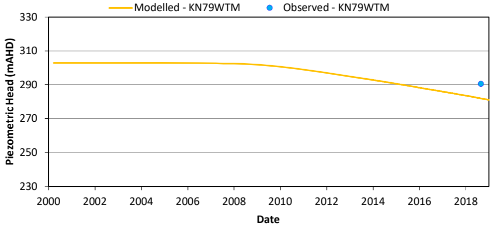
HSMB5D - Arrow Energy - PL253/493



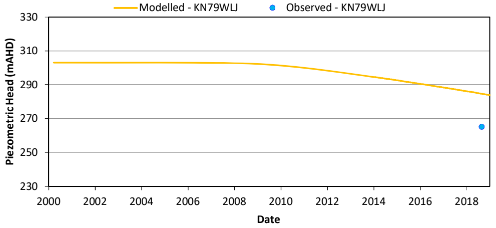
KN79WUJ - Arrow Energy - PL253/493



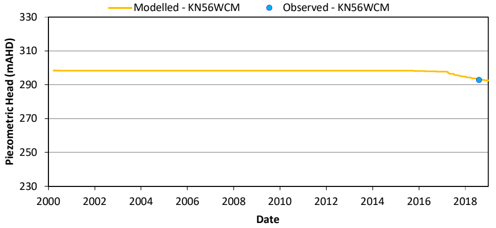
KN79WTM - Arrow Energy - PL253/493



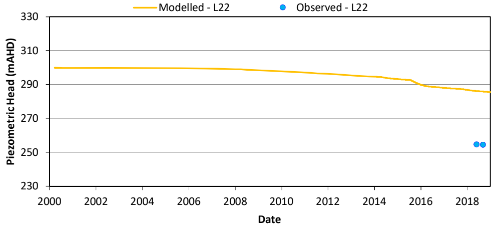
KN79WLJ - Arrow Energy - PL253/493



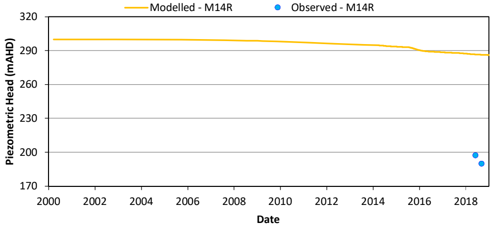
KN56WCM - Arrow Energy - PL253/493



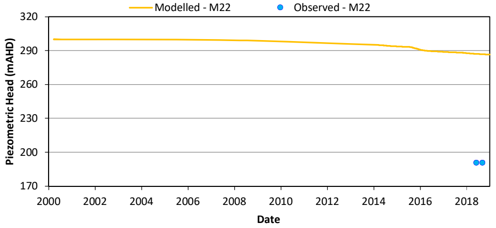
L22 - Arrow Energy - PL253/493



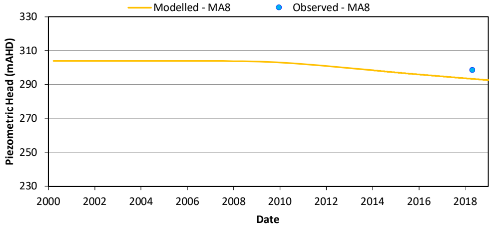
M14R - Arrow Energy - PL253/493



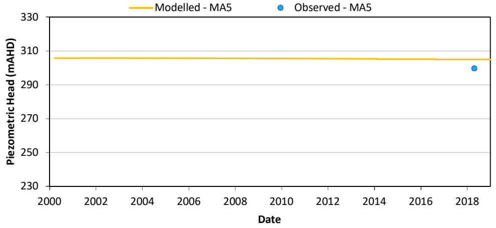
M22 - Arrow Energy - PL253/493



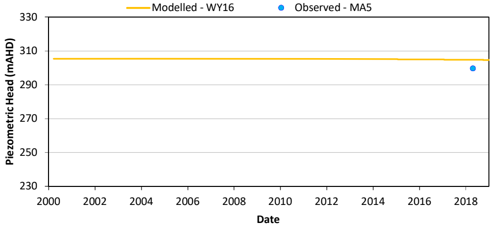
MA8 - Arrow Energy - PL253/493



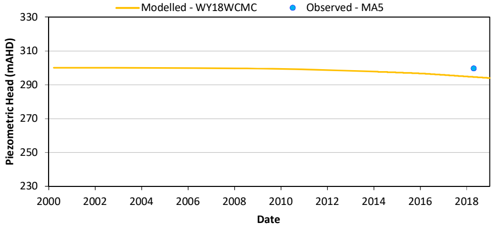
MA5 - Arrow Energy - PL253/493



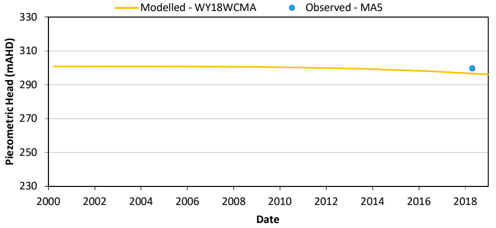
WY16 - Arrow Energy - PL253/493



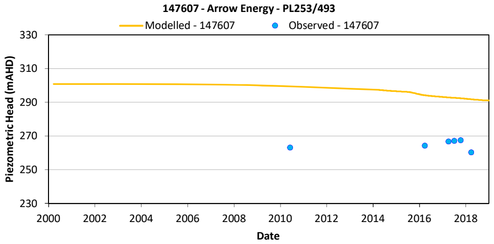
WY18WCMC - Arrow Energy - PL253/493

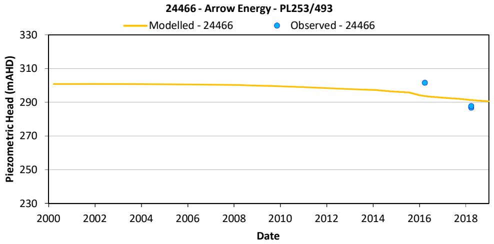


WY18WCMA - Arrow Energy - PL253/493

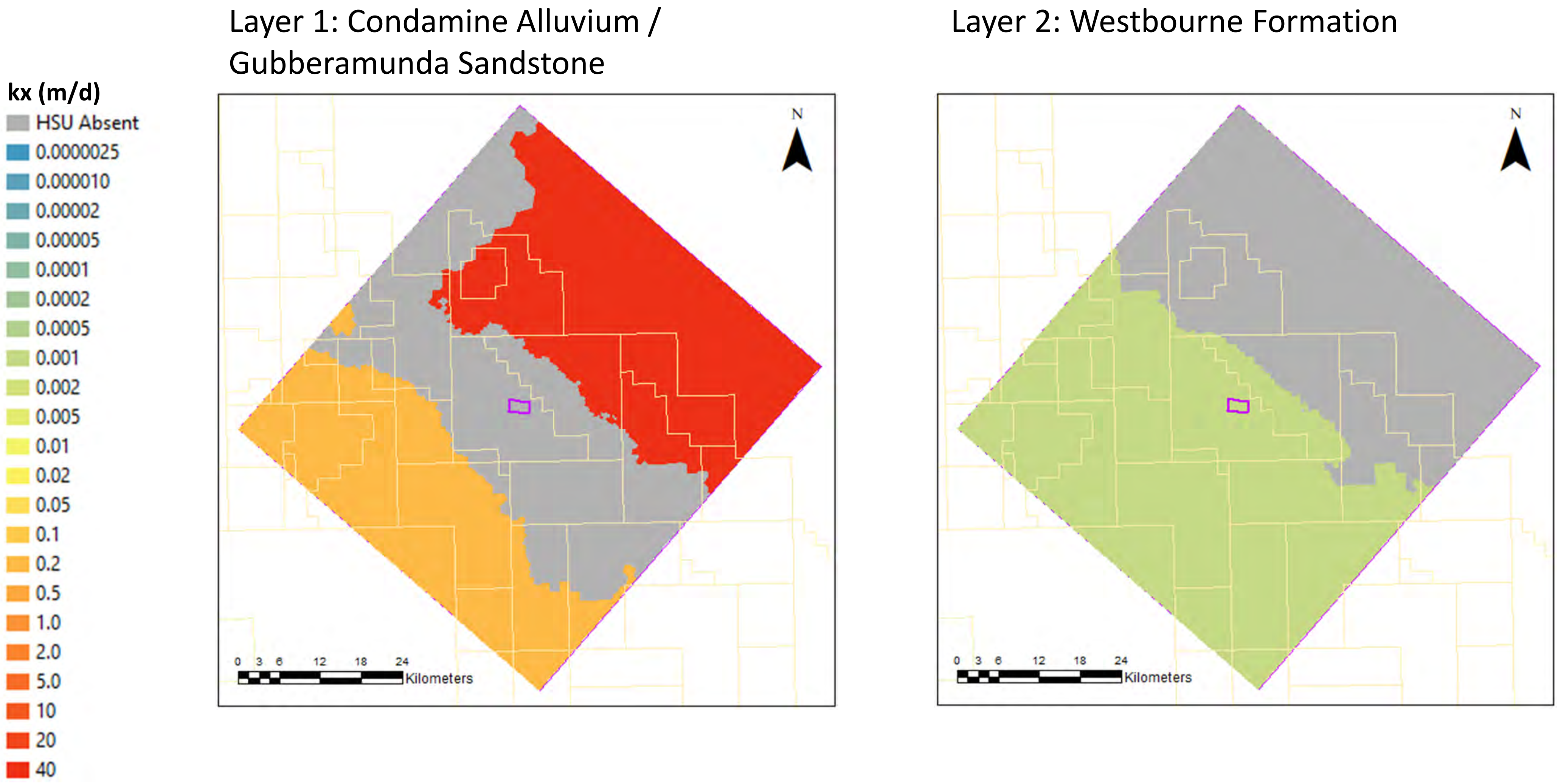


Calibration Hydrographs

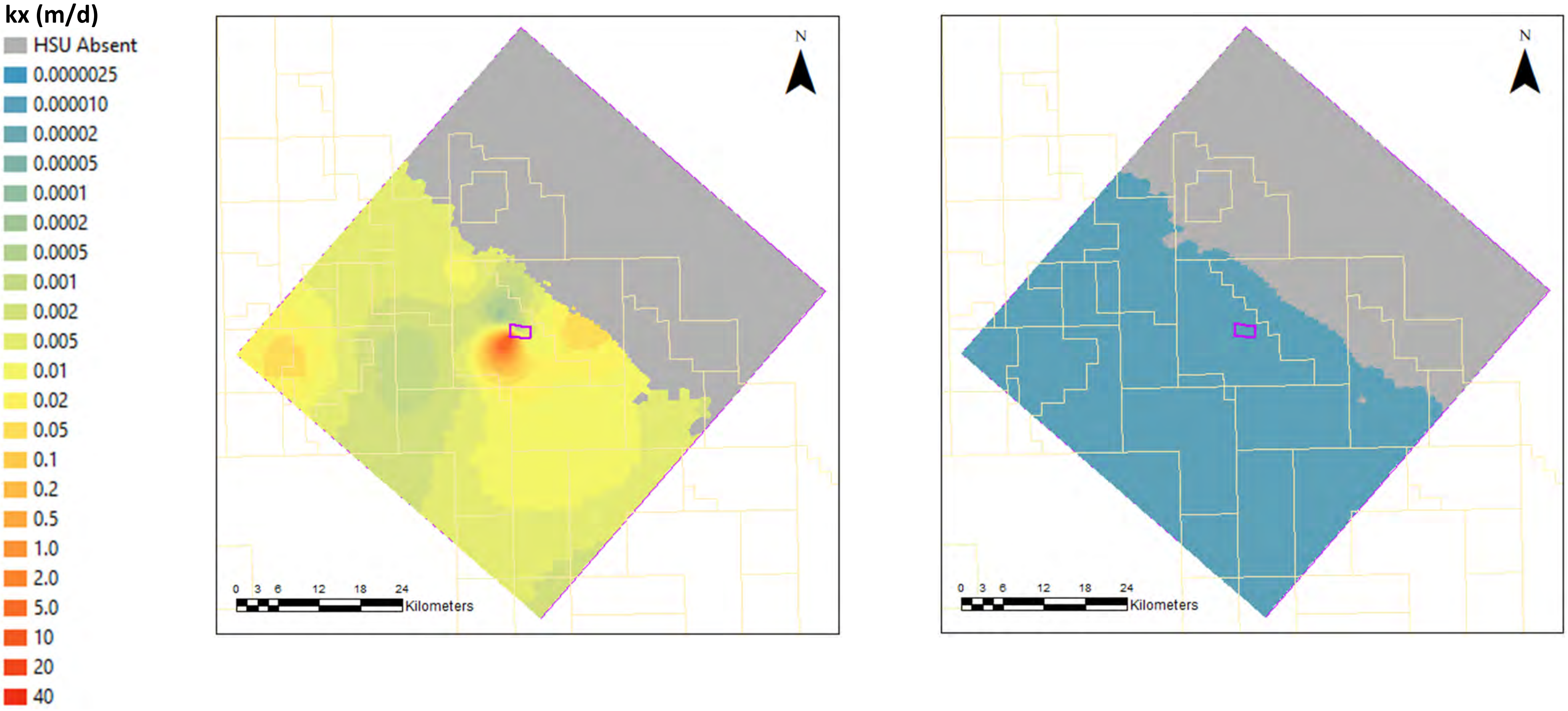




Appendix D – Calibrated kx Values

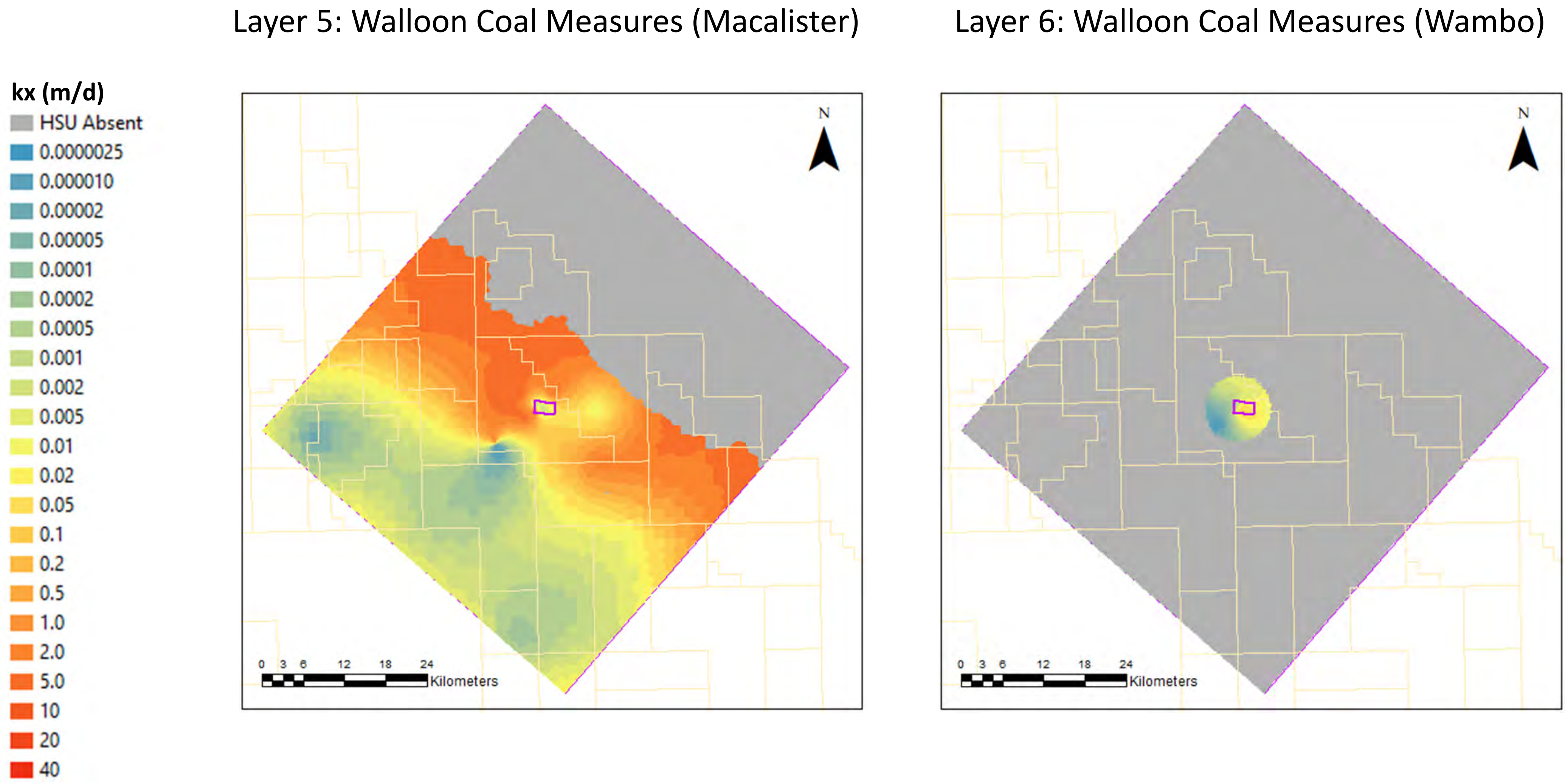

Layer 1: Condamine Alluvium / Gubberamunda Sandstone

Layer 2: Westbourne Formation



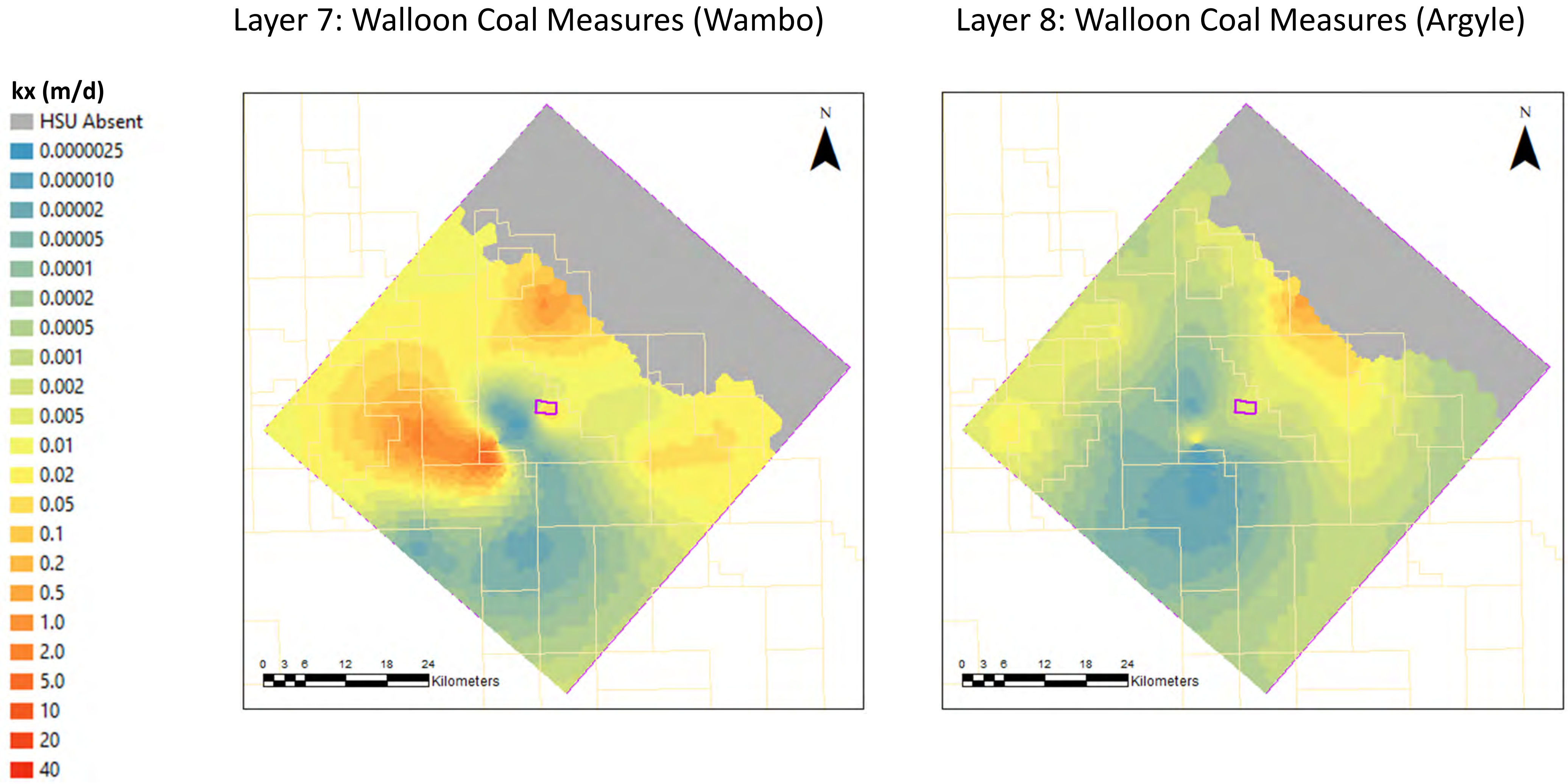
Layer 3: Springbok Sandstone

Layer 4: Walloon Coal Measures (Kogan)



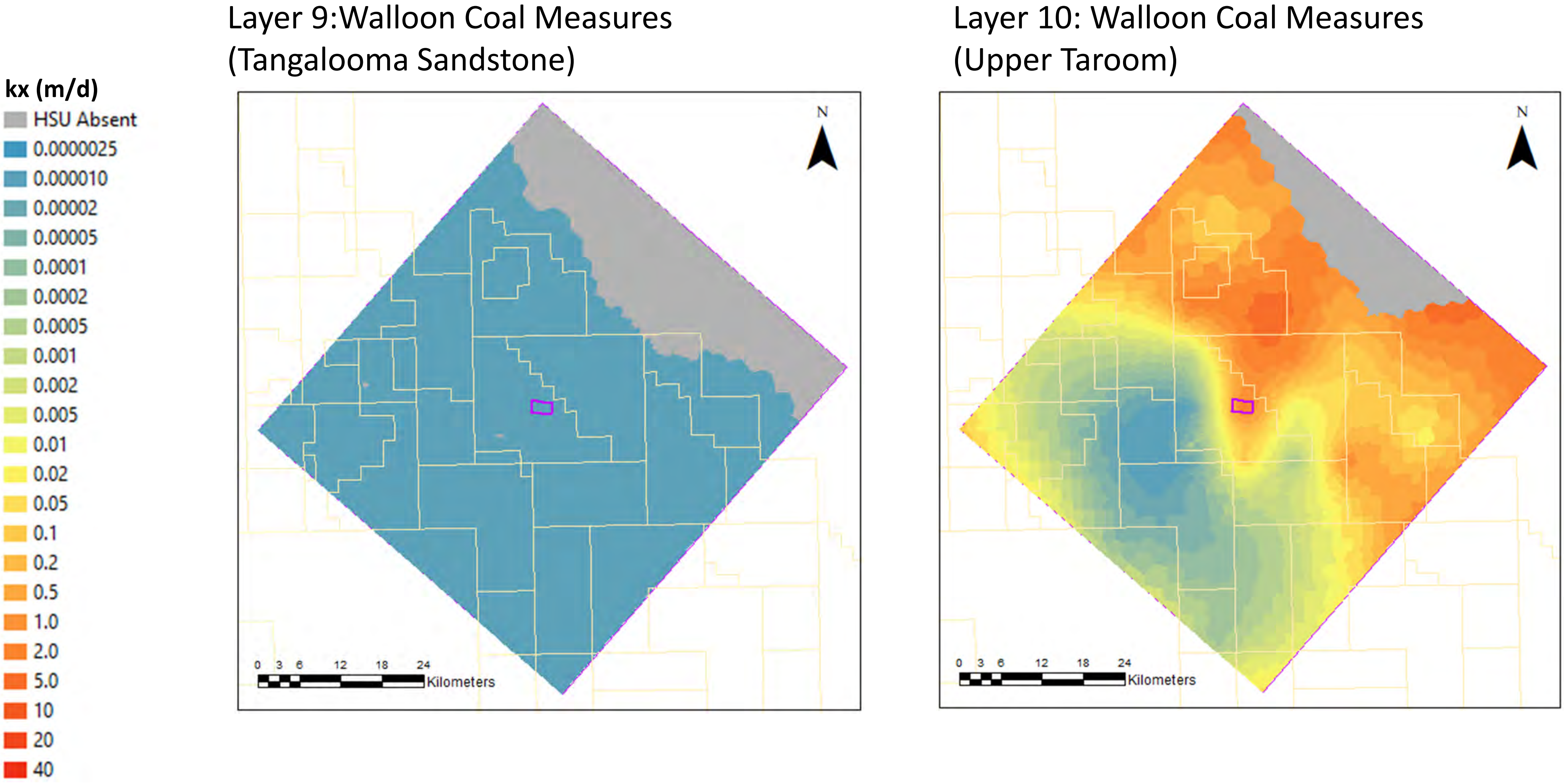
Layer 5: Walloon Coal Measures (Macalister)

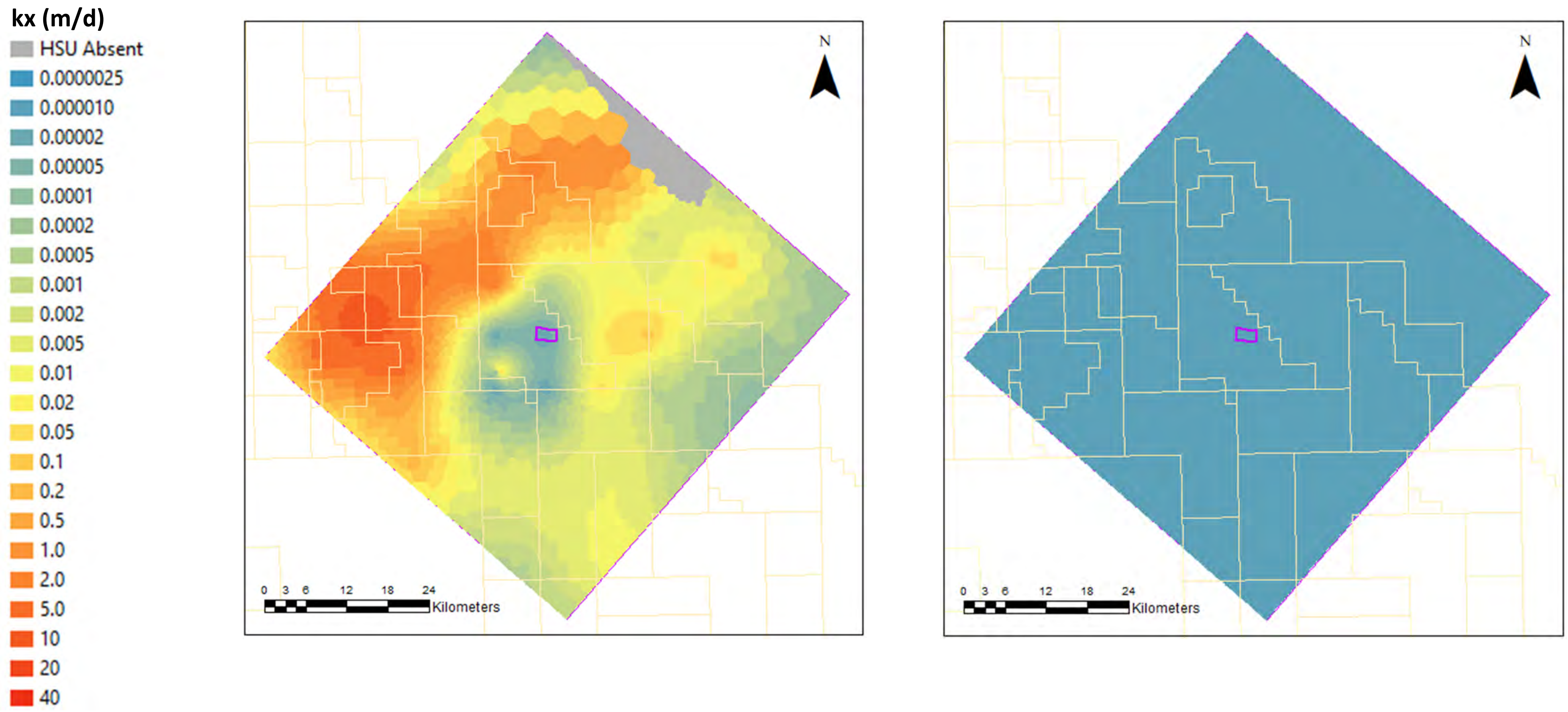
Layer 6: Walloon Coal Measures (Wambo)



Layer 7: Walloon Coal Measures (Wambo)

Layer 8: Walloon Coal Measures (Argyle)

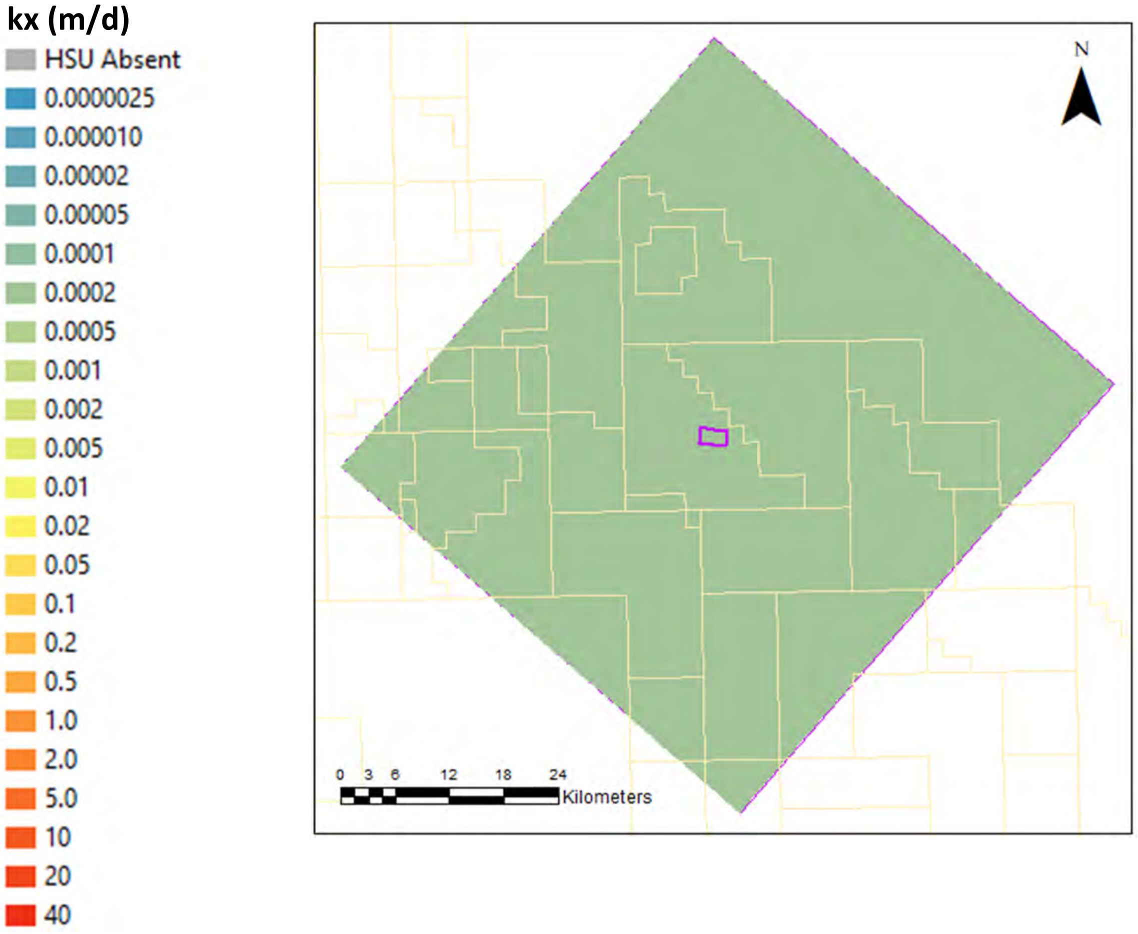
Layer 9:Walloon Coal Measures (Tangalooma Sandstone)
Layer 10: Walloon Coal Measures (Upper Taroom)
kx (m/d)
HSU Absent
0.0000025
0.000010
0.00002
0.00005
0.0001
0.0002
0.0005
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2.0
5.0
10
20
40
N
0 3 6 12 18 24
Kilometers
N
0 3 6 12 18 24
Kilometers



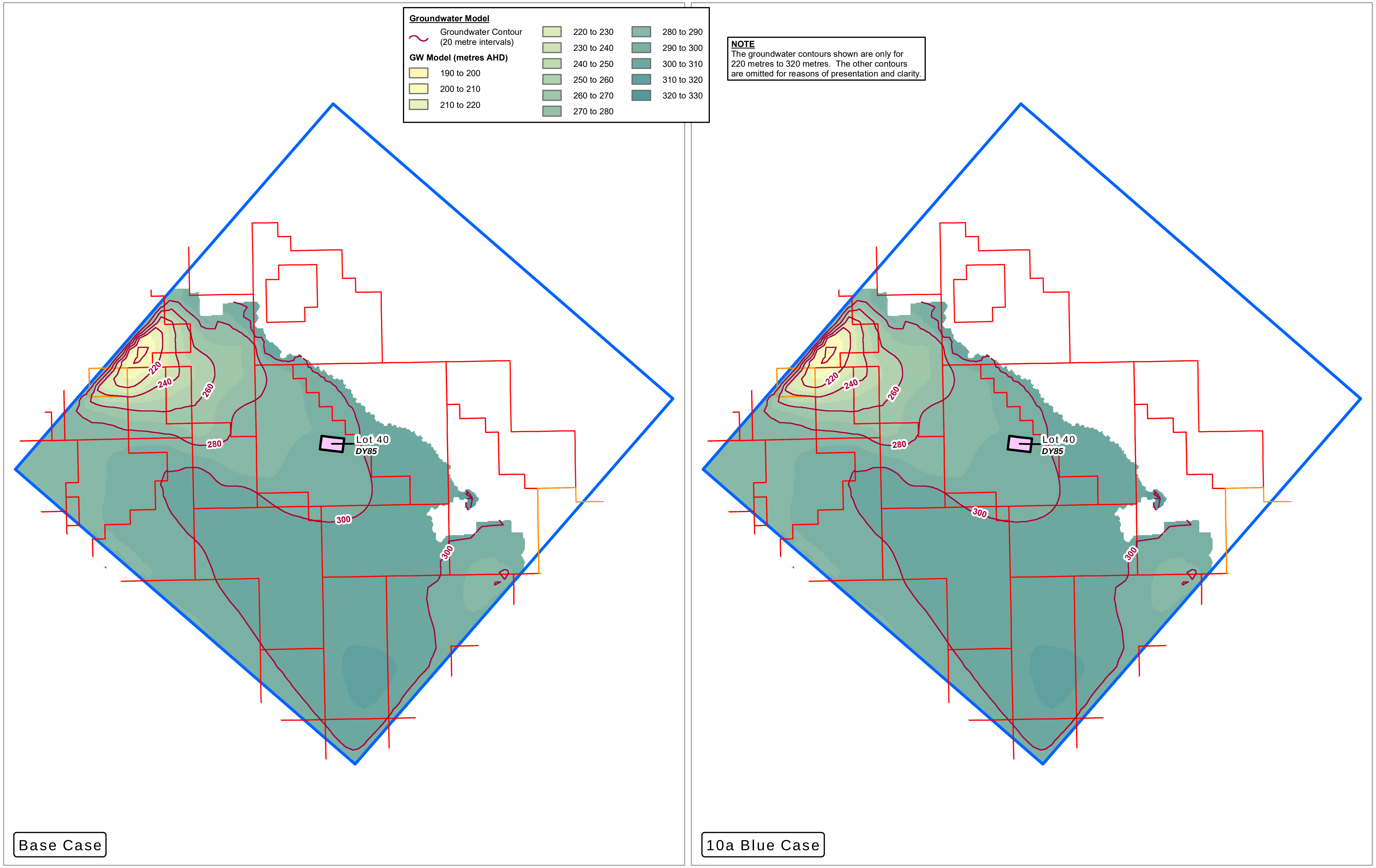
Layer 11: Walloon Coal Measures (Condamine)

Layer 12: Eurombah Formation

Layer 13: Hutton Sandstone



Appendix E – Scenario 2: Selected Piezometric Contour Maps



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

▭	Hydrogeological Domain
▭	Boundary of Lot40 on DY85, Linc Energy UCG site
▭	Boundary Petroleum Lease Application
▭	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3
0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Piezometric heads
Base Case vs 10a Blue Case
Year 2025 : Springbok Sandstone (Layer 3)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E1

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-21_piezoHeads_Base_vs_10aBlue_2025_Springbok_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten

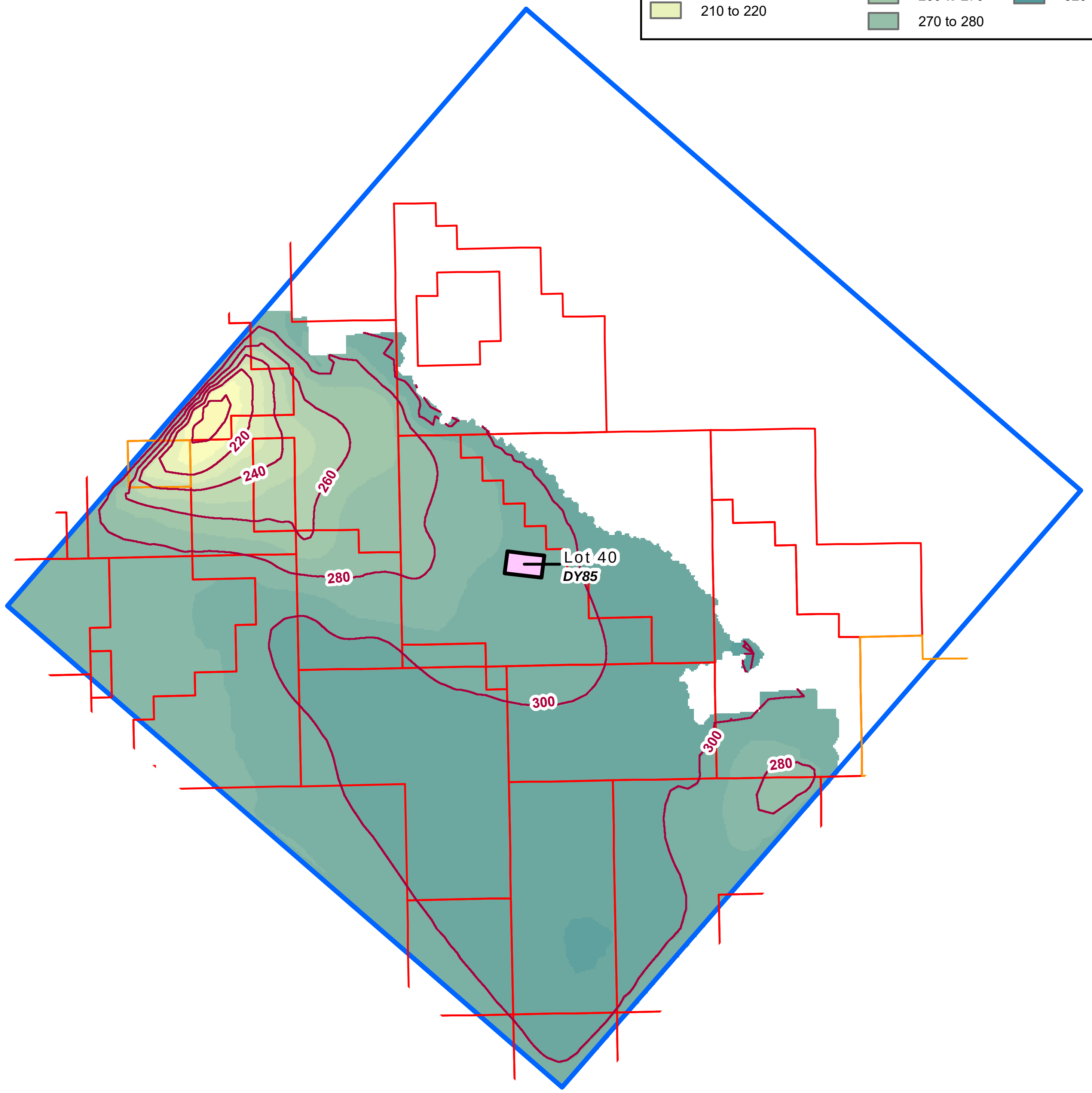
Groundwater Model

〜 Groundwater Contour (20 metre intervals)

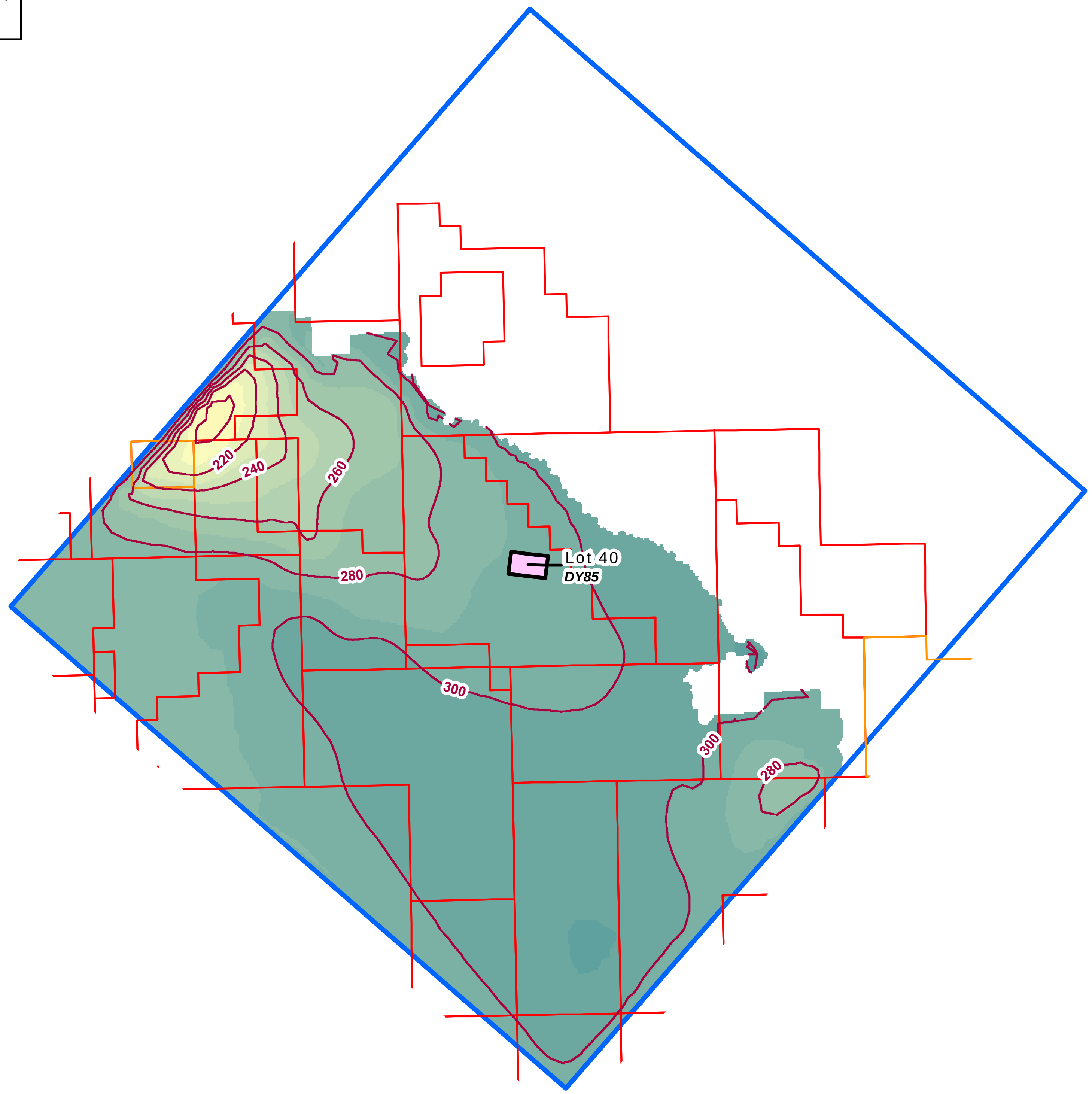
GW Model (metres AHD)

▭	190 to 200	▭	220 to 230	▭	280 to 290
▭	200 to 210	▭	230 to 240	▭	290 to 300
▭	210 to 220	▭	240 to 250	▭	300 to 310
		▭	250 to 260	▭	310 to 320
		▭	260 to 270	▭	320 to 330
		▭	270 to 280		

NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.



Base Case



10a Blue Case

Legend

- ▭ Hydrogeological Domain
- ▭ Boundary of Lot40 on DY85, Linc Energy UCG site
- ▭ Boundary Petroleum Lease Application
- ▭ Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

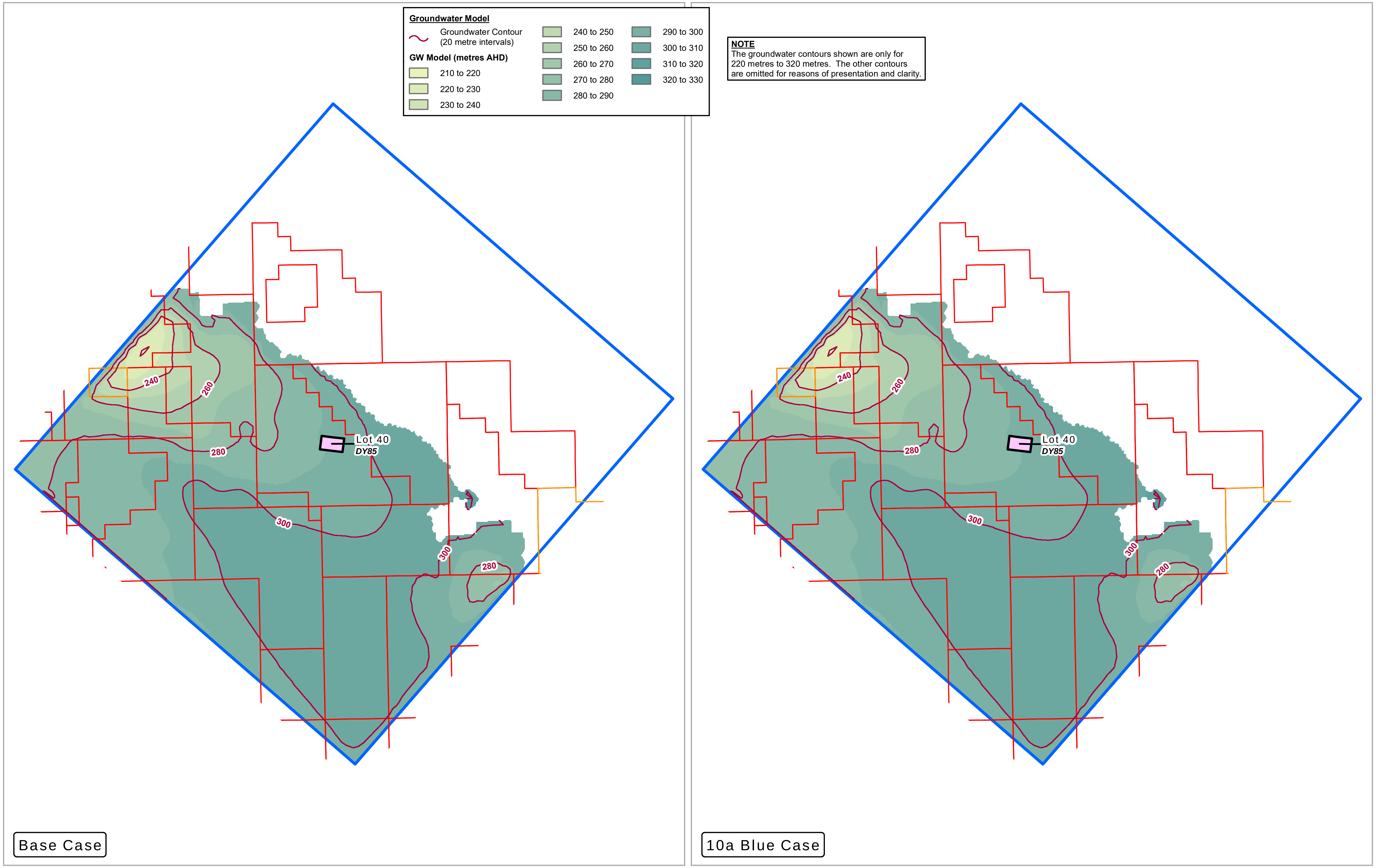
Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Springbok Sansdstone (Layer 3)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E2

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-22_piezoHeads_Base_vs_10aBlue_2035_Springbok_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

🟦	Hydrogeological Domain
🟪	Boundary of Lot40 on DY85, Linc Energy UCG site
🟧	Boundary Petroleum Lease Application
🟥	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

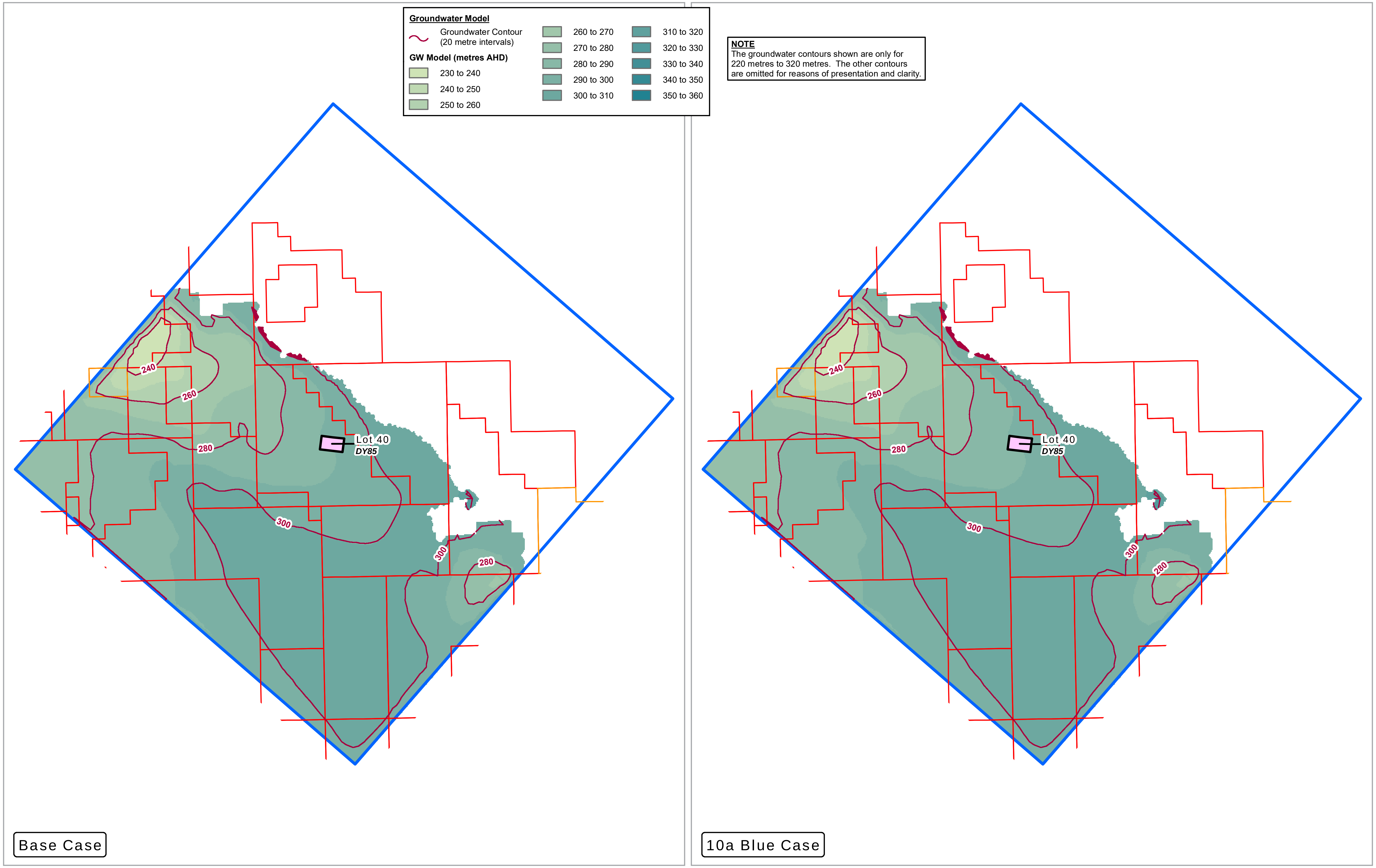
Piezometric heads
Base Case vs 10a Blue Case
Year 2045 : Springbok Sansdstone (Layer 3)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E3

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-23_piezoHeads_Base_vs_10aBlue_2045_Springbok_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Legend

🟦	Hydrogeological Domain
▨	Boundary of Lot40 on DY85, Linc Energy UCG site
🟧	Boundary Petroleum Lease Application
🟥	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

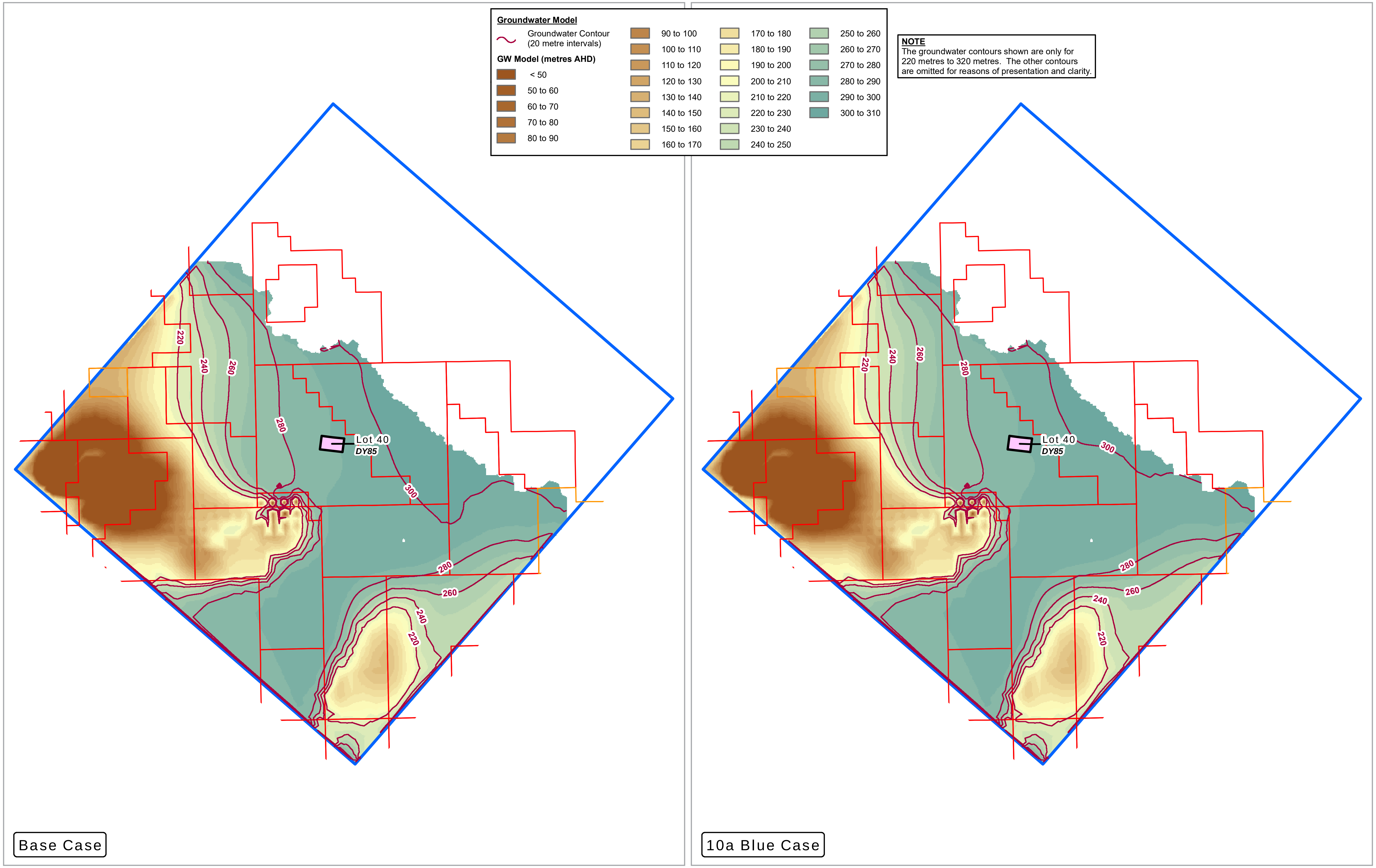
Piezometric heads
Base Case vs 10a Blue Case
Year 2055 : Springbok Sansdstone (Layer 3)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E4

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-24_piezoHeads_Base_vs_10aBlue_2055_Springbok_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Groundwater Model

Groundwater Contour (20 metre intervals)

GW Model (metres AHD)

▨	< 50	▨	90 to 100	▨	170 to 180	▨	250 to 260
▨	50 to 60	▨	100 to 110	▨	180 to 190	▨	260 to 270
▨	60 to 70	▨	110 to 120	▨	190 to 200	▨	270 to 280
▨	70 to 80	▨	120 to 130	▨	200 to 210	▨	280 to 290
▨	80 to 90	▨	130 to 140	▨	210 to 220	▨	290 to 300
		▨	140 to 150	▨	220 to 230	▨	300 to 310
		▨	150 to 160	▨	230 to 240		
		▨	160 to 170	▨	240 to 250		

NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

▢	Hydrogeological Domain	▢	Boundary Petroleum Lease Application
▢	Boundary of Lot40 on DY85, Linc Energy UCG site	▢	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

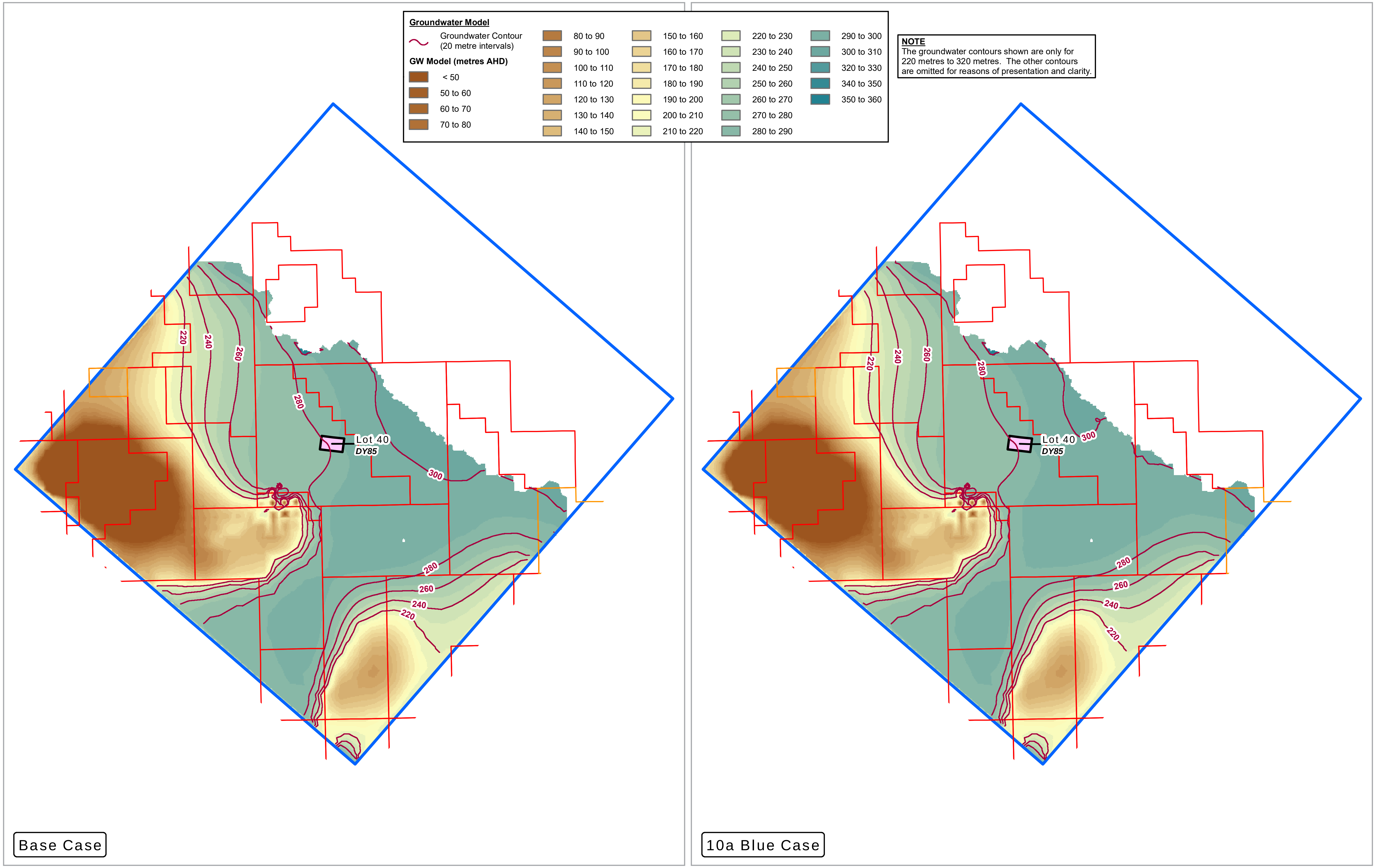
Project No. 41-32187
Revision No. A
Date 23/10/2019

Piezometric heads
Base Case vs 10a Blue Case
Year 2025 : Macalister Seam (Layer 5)

FIGURE E5

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-25_piezoHeads_Base_vs_10aBlue_2025_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Legend

Hydrogeological Domain	Boundary Petroleum Lease Application
Boundary of Lot40 on DY85, Linc Energy UCG site	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

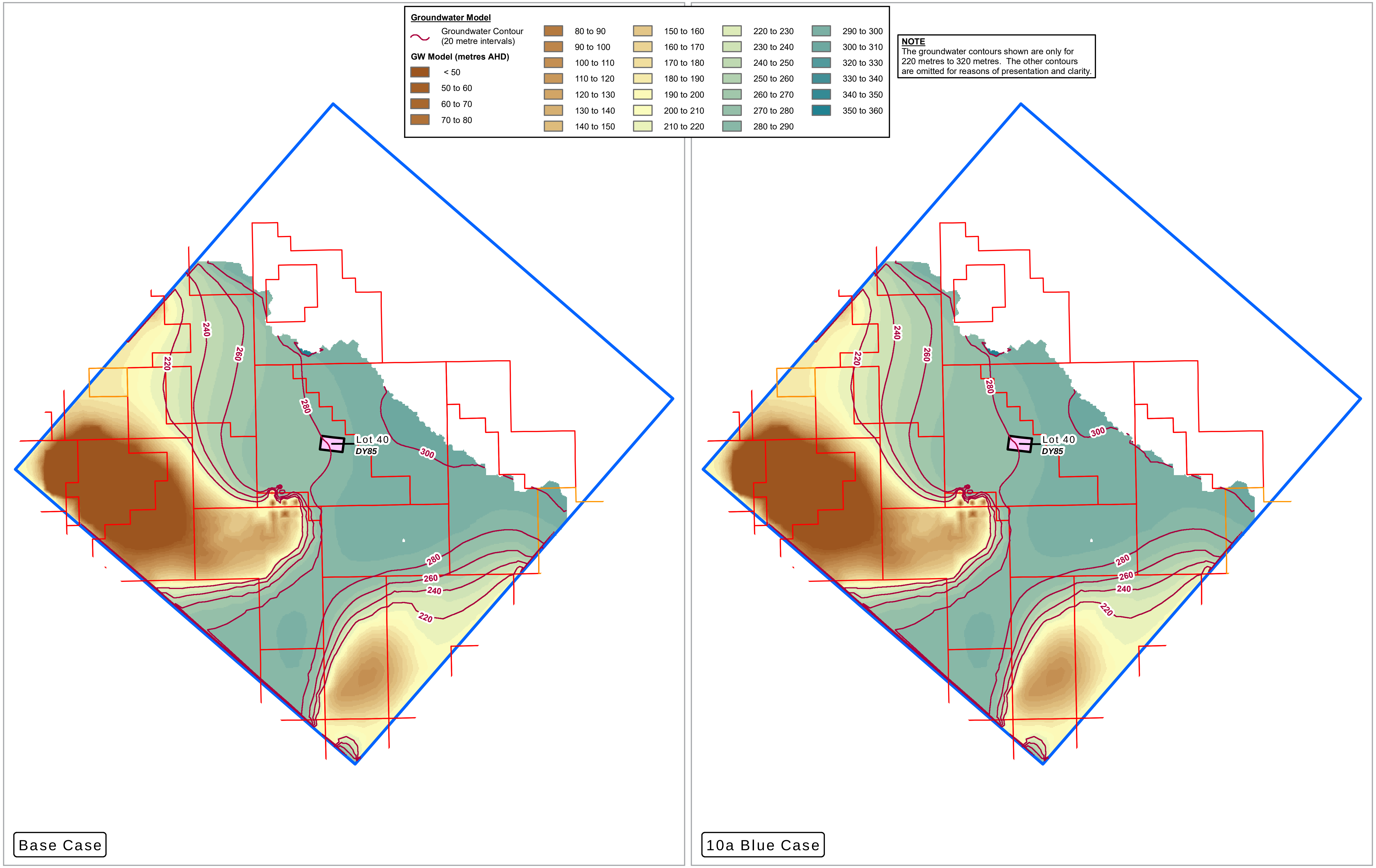
Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Macalister Seam (Layer 5)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E6

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-26_piezoHeads_Base_vs_10aBlue_2035_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

Hydrogeological Domain	Boundary Petroleum Lease Application
Boundary of Lot40 on DY85, Linc Energy UCG site	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Piezometric heads
Base Case vs 10a Blue Case
Year 2045 : Macalister Seam (Layer 5)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E7

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-27_piezoHeads_Base_vs_10aBlue_2045_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten

Groundwater Model

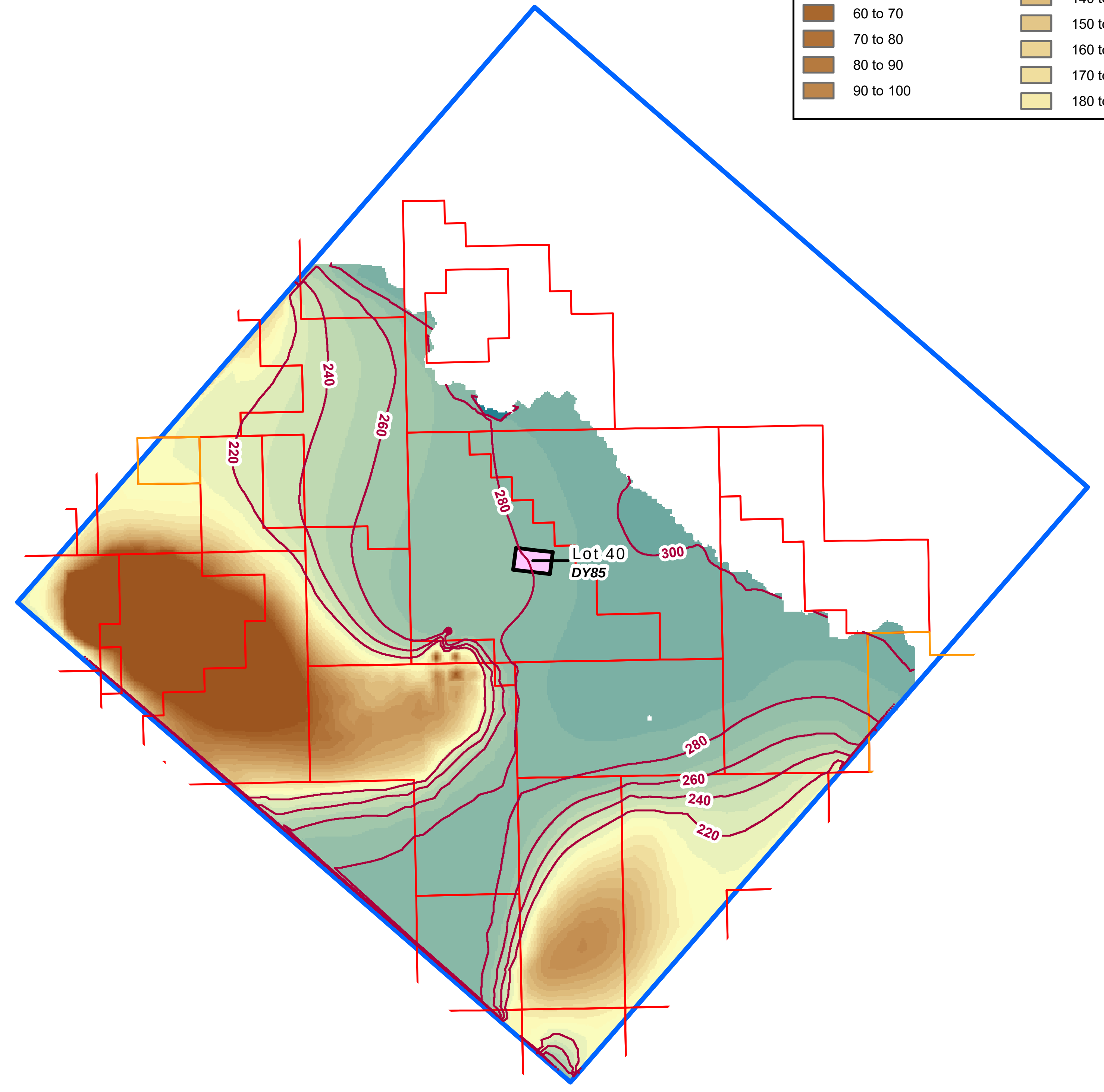
Groundwater Contour (20 metre intervals)

GW Model (metres AHD)

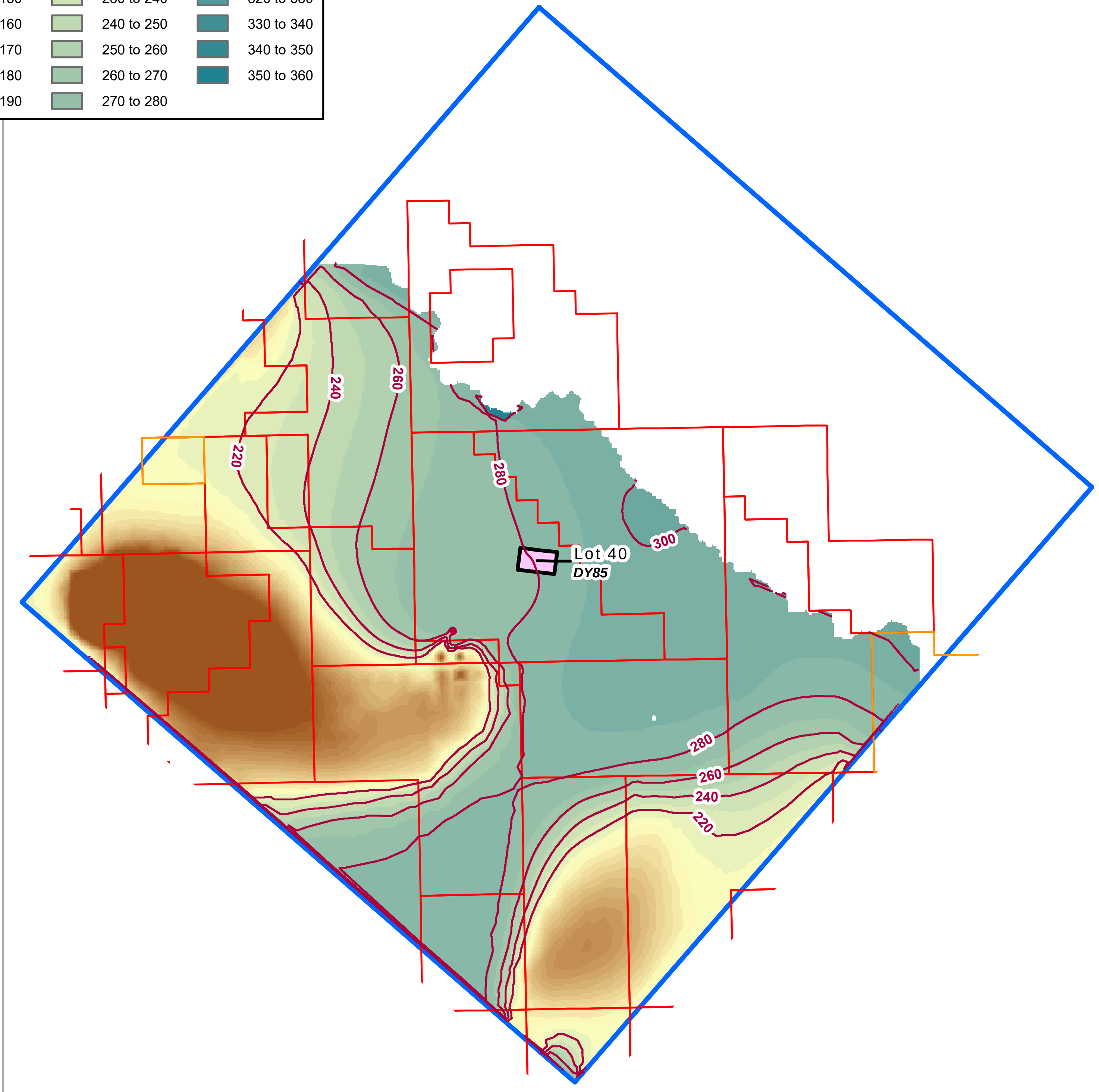
< 50	100 to 110	190 to 200
50 to 60	110 to 120	200 to 210
60 to 70	120 to 130	210 to 220
70 to 80	130 to 140	220 to 230
80 to 90	140 to 150	230 to 240
90 to 100	150 to 160	240 to 250
	160 to 170	250 to 260
	170 to 180	260 to 270
	180 to 190	270 to 280

280 to 290
290 to 300
300 to 310
310 to 320
320 to 330
330 to 340
340 to 350
350 to 360

NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.



Base Case



10a Blue Case

Legend

- Hydrogeological Domain
- Boundary of Lot40 on DY85, Linc Energy UCG site
- Boundary Petroleum Lease Application
- Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

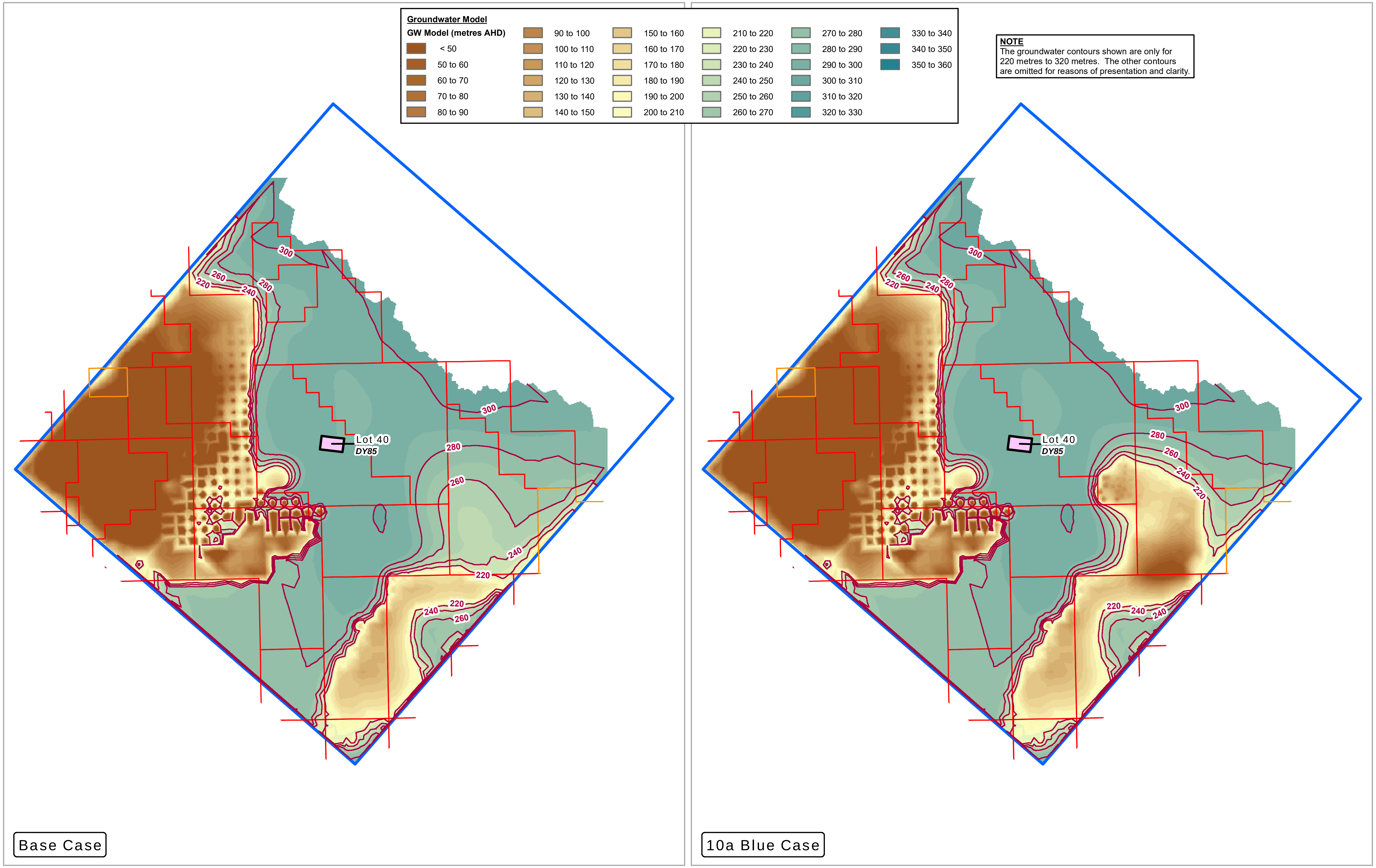
Piezometric heads
Base Case vs 10a Blue Case
Year 2055 : Macalister Seam (Layer 5)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E8

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-28_piezoHeads_Base_vs_10aBlue_2055_Macalister_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Groundwater Model

GW Model (metres AHD)

🟫 < 50
🟫 50 to 60
🟫 60 to 70
🟫 70 to 80
🟫 80 to 90
🟫 90 to 100
🟫 100 to 110
🟫 110 to 120
🟫 120 to 130
🟫 130 to 140
🟫 140 to 150
🟨 150 to 160
🟨 160 to 170
🟨 170 to 180
🟨 180 to 190
🟨 190 to 200
🟨 200 to 210
🟩 210 to 220
🟩 220 to 230
🟩 230 to 240
🟩 240 to 250
🟩 250 to 260
🟩 260 to 270
🟩 270 to 280
🟩 280 to 290
🟩 290 to 300
🟩 300 to 310
🟩 310 to 320
🟩 320 to 330
🟦 330 to 340
🟦 340 to 350
🟦 350 to 360

NOTE

The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

🟦 Hydrogeological Domain
🟪 Boundary of Lot40 on DY85, Linc Energy UCG site
🟧 Boundary Petroleum Lease Application
🟥 Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

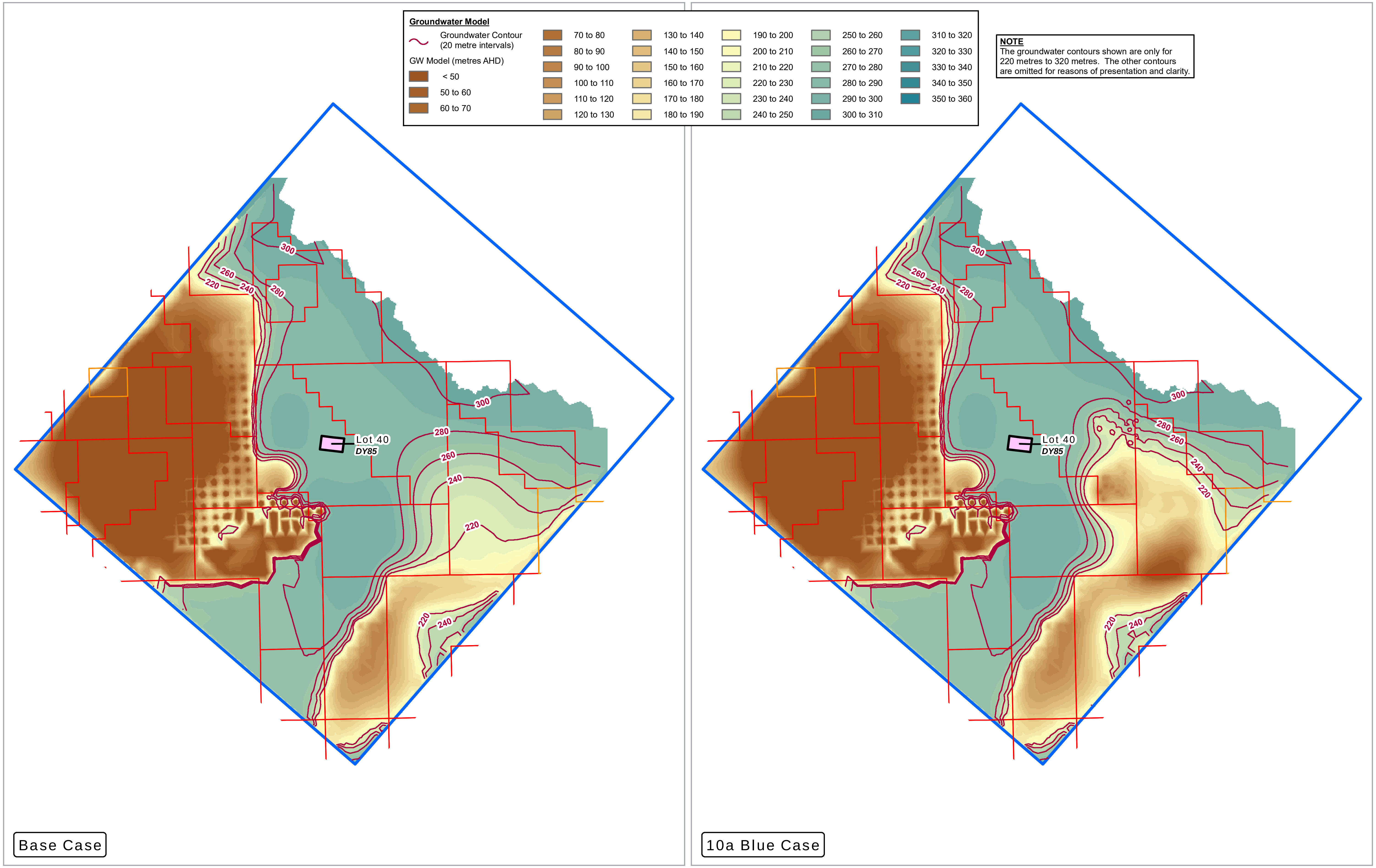
Piezometric heads
Base Case vs 10a Blue Case
Year 2025 : Argyle Seam (Layer 8)

Project No. 41-32187
Revision No. A
Date 23/10/2019

FIGURE E9

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-29_piezoHeads_Base_vs_10aBlue_2025_Argyle_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



NOTE
The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

🟦	Hydrogeological Domain
▭	Boundary of Lot40 on DY85, Linc Energy UCG site
🟧	Boundary Petroleum Lease Application
🟥	Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20
Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

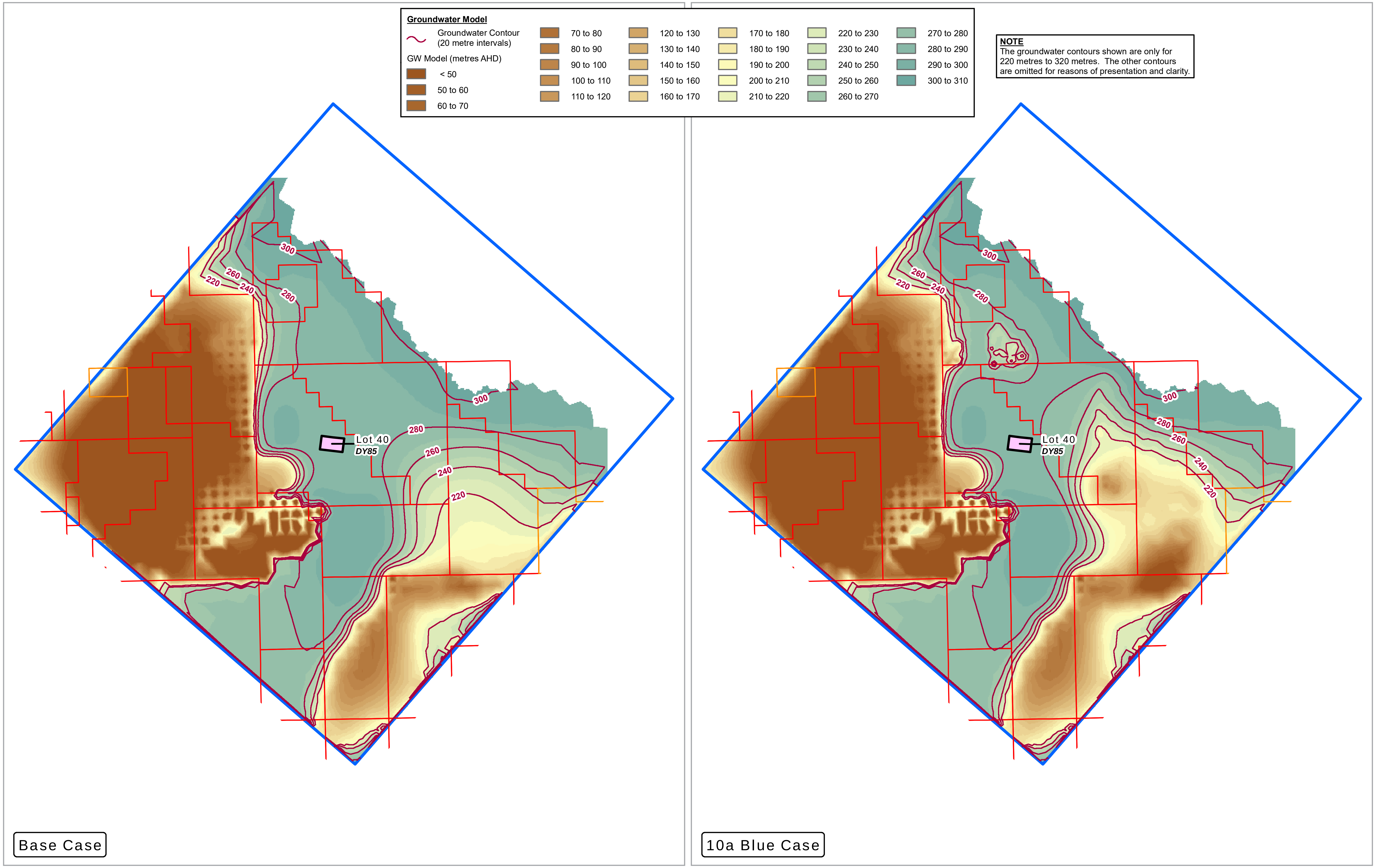
Piezometric heads
Base Case vs 10a Blue Case
Year 2035 : Argyle Seam (Layer 8)

Project No.	41-32187
Revision No.	A
Date	23/10/2019

FIGURE E10

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-30_piezoHeads_Base_vs_10aBlue_2035_Argyle_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Legend

- Hydrogeological Domain
- Boundary of Lot40 on DY85, Linc Energy UCG site
- Boundary Petroleum Lease Application
- Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

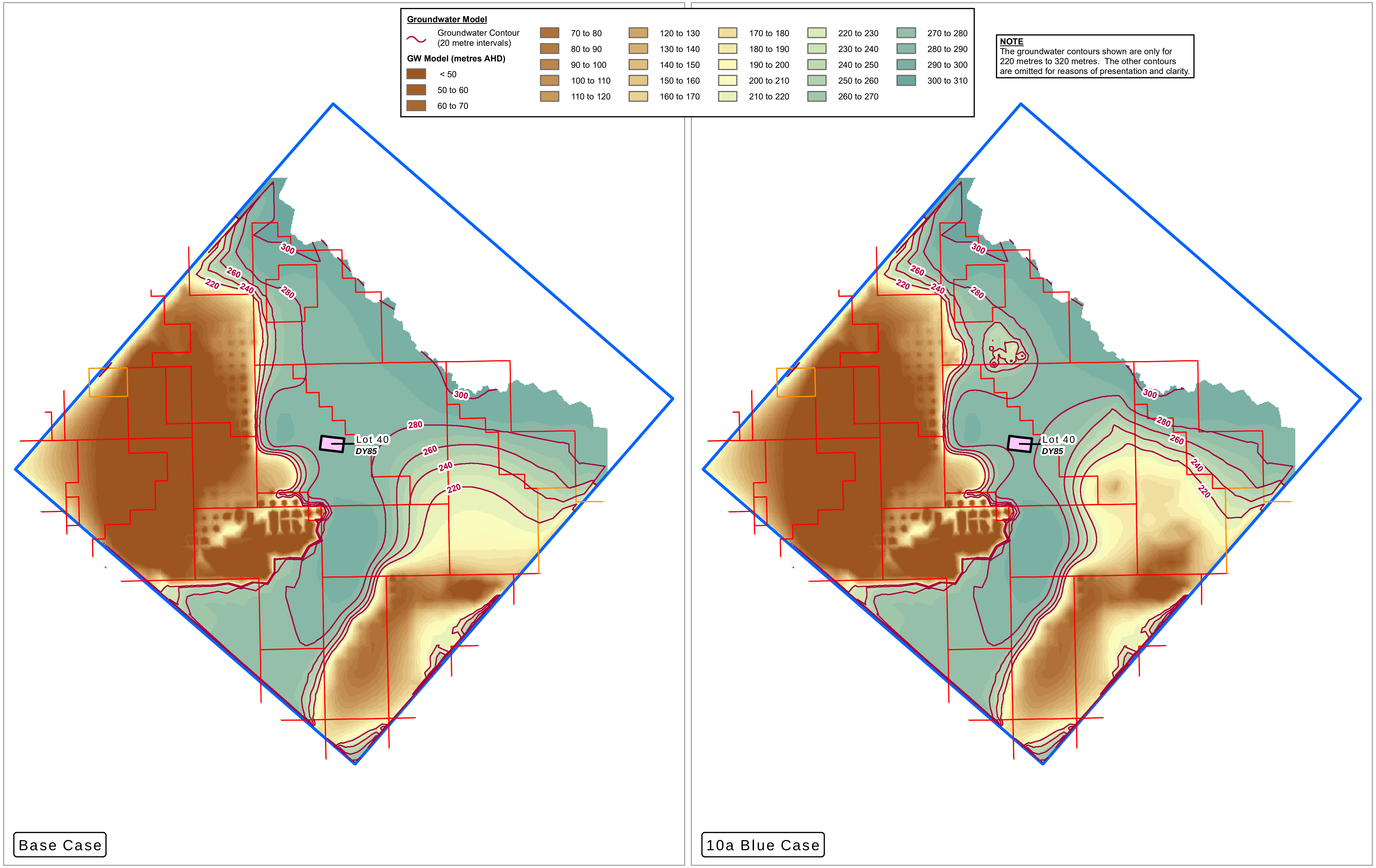
Piezometric heads
Base Case vs 10a Blue Case
Year 2045 : Argyle Seam (Layer 8)

Project No.	41-32187
Revision No.	A
Date	23/10/2019

FIGURE E11

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-31_piezoHeads_Base_vs_10aBlue_2045_Argyle_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten



Groundwater Model

〜 Groundwater Contour (20 metre intervals)

GW Model (metres AHD)

■ < 50	■ 70 to 80	■ 120 to 130	■ 170 to 180	■ 220 to 230	■ 270 to 280
■ 50 to 60	■ 80 to 90	■ 130 to 140	■ 180 to 190	■ 230 to 240	■ 280 to 290
■ 60 to 70	■ 90 to 100	■ 140 to 150	■ 190 to 200	■ 240 to 250	■ 290 to 300
	■ 100 to 110	■ 150 to 160	■ 200 to 210	■ 250 to 260	■ 300 to 310
	■ 110 to 120	■ 160 to 170	■ 210 to 220	■ 260 to 270	

NOTE

The groundwater contours shown are only for 220 metres to 320 metres. The other contours are omitted for reasons of presentation and clarity.

Legend

▭ Hydrogeological Domain	▭ Boundary Petroleum Lease Application
▭ Boundary of Lot40 on DY85, Linc Energy UCG site	▭ Boundary Petroleum Lease Granted

1:450,000 Paper Size A3

0 5 10 15 20

Kilometers

N

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

Arrow Energy Pty Ltd
Hopeland Environmental Authority
Groundwater Characteristics Monitoring Program

Project No. 41-32187
Revision No. A
Date 23/10/2019

Piezometric heads
Base Case vs 10a Blue Case
Year 2055 : Argyle Seam (Layer 8)

FIGURE E12

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-32187-32_piezoHeads_Base_vs_10aBlue_2055_Argyle_revA.mxd
Print date: 28 Oct 2019

Data source: DNRME: cadastre, imagery, roads, watercourses (2019); GHD: GW modelling (Oct 2019); Arrow: GWdata (2019). Created by: JVanCooten

Appendix F – Groundwater Seepage Assessment Results

Groundwater Gradient and Migration Calculations

Groundwater seepage velocity and specific discharge calculated from Darcys Equation

$v_s = k\ i\ n_e^{-1}$ (Equation 1) **$v_d = k\ i$** (Equation 2)

where:

v_d = Darcian velocity (m/d)

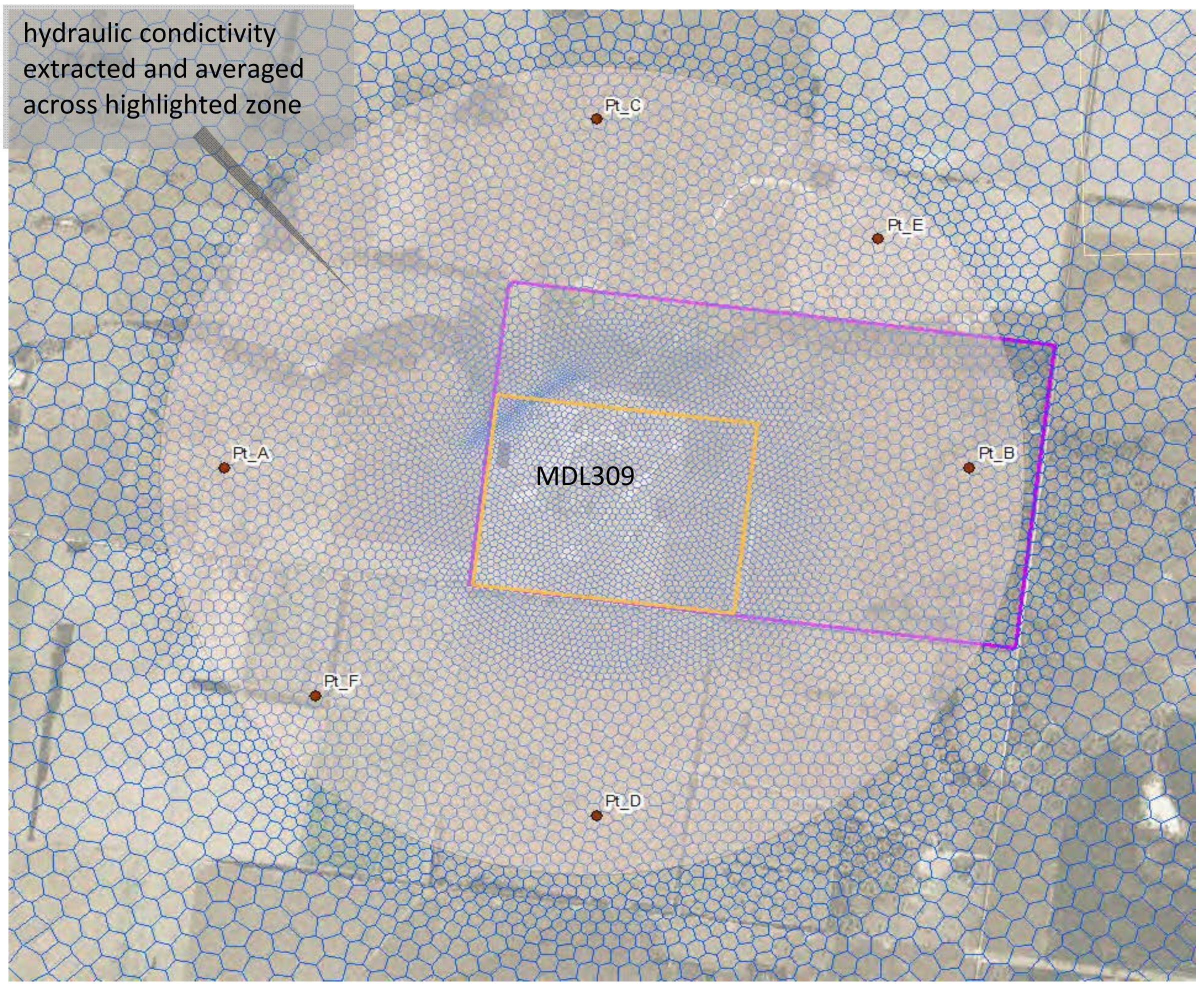
v_s = seepage velocity (m/d)

k - hydraulic condictivity (m/d)

i - hydraulic gradient (m/m)

n_e - effective porosity

Hydraulic condictivity averaged across the area displayed in the figure below



Hydraulic conductivity (kx)

Layer 3	Springbok Sst	0.52	m/d
Layer 5	Macalister Seam	0.36	m/d
Layer 8	Argyle Seam	0.0015	m/d

Table F1: Seepage over Hopland pilot operation period

Scenario: 1 - Hopeland pilot (PL253) assessment
Calculation period: 1/3/2014 - 30/9/2018

		Average Hydraulic Gradient (m/m)		Darcian Velocity (m/d)			Darcian Velocity (m over 4.6 years)				
Assessment Location	**Unit**	**Base Case**	**No Hopeland**	**Base Case**	**No Hopeland**	**Hopeland contribution**	**Base Case**	**No Hopeland**	**Hopeland contribution**	**Direction**	**Arrow impact as % of total**
Pt_A / Pt_B	Springbok Sst	0.00048	0.00047	0.00025	0.00024	0.00001	0.42	0.41	0.011	W → E	2.6%
	Macalister Seam	0.0020	0.0020	0.00073	0.00072	0.00001	1.2	1.2	0.023	W → E	1.9%
	Argyle Seam	0.00025	0.00025	0.00000	0.00000	0.00000	0.00064	0.00064	0.00000	W → E	0.0%
Pt_C / Pt_D	Springbok Sst	0.00019	0.00017	0.00010	0.00009	0.00001	0.16	0.15	0.013	S → N	8.4%
	Macalister Seam	0.0010	0.0010	0.00038	0.00036	0.00001	0.63	0.61	0.019	S → N	3.0%
	Argyle Seam	0.00005	0.00005	0.00000	0.00000	0.00000	0.00014	0.00014	0.00000	N → S	0.1%
Pt_E / Pt_F	Springbok Sst	0.00051	0.00050	0.00027	0.00026	0.00001	0.45	0.43	0.014	SW → NE	3.3%
	Macalister Seam	0.0020	0.0020	0.00072	0.00070	0.00002	1.2	1.2	0.026	SW → NE	2.2%
	Argyle Seam	0.00020	0.00020	0.00000	0.00000	0.00000	0.00051	0.00051	0.00000	NE → SW	0.0%

Highlighted row: highest Arrow impact per HSU. If a HSU is not highlighted, the Arrow contribution is effectivly nill or beneficial (i.e. reduction in predicted GW migration)

Darcian velocity has been calculated using Equation 2 and does not include the effects of porosity on groundwater flow

Table F2: Seepage over Hopeland operational phase

Scenario: 1 - Hopeland pilot (PL253) assessment
Calculation period: 2019 - 2038 (20 years)

		Average Hydraulic Gradient (m/m)		Darcian Velocity (m/d)			Darcian Velocity (m over 20 years)				
Assessment Location	**Unit**	**Base Case**	**No Hopeland**	**Base Case**	**No Hopeland**	**Hopeland contribution**	**Base Case**	**No Hopeland**	**Hopeland contribution**	**Direction**	**Arrow impact as % of total**
Pt_A / Pt_B	Springbok Sst	0.00093	0.00089	0.00048	0.00047	0.00002	3.5	3.4	0.14	W → E	4.1%
	Macalister Seam	0.0029	0.0028	0.0010	0.0010	0.00003	7.6	7.4	0.21	W → E	2.9%
	Argyle Seam	0.00075	0.00077	0.00000	0.00000	0.00000	0.0083	0.0086	-0.00029	W → E	-3.3%
Pt_C / Pt_D	Springbok Sst	0.00058	0.00053	0.00030	0.00028	0.00003	2.2	2.0	0.19	N → S	9.6%
	Macalister Seam	0.0015	0.0014	0.00053	0.00051	0.00002	3.9	3.7	0.18	N → S	4.8%
	Argyle Seam	0.00016	0.00018	0.00000	0.00000	0.00000	0.0017	0.0019	-0.00022	N → S	-11.2%
Pt_E / Pt_F	Springbok Sst	0.0011	0.0011	0.00060	0.00057	0.00003	4.4	4.2	0.22	NE → SW	5.4%
	Macalister Seam	0.0029	0.0028	0.0010	0.00099	0.00003	7.5	7.2	0.25	NE → SW	3.4%
	Argyle Seam	0.00057	0.00065	0.00000	0.00000	0.00000	0.0063	0.0072	-0.00085	NE → SW	-11.9%

Highlighted row: highest Arrow impact per HSU. If a HSU is not highlighted, the Arrow contribution is beneficial (i.e. reduction in predicted GW migration)

Darcian velocity has been calculated using Equation 2 and does not include the effects of porosity on groundwater flow

Table F3: Seepage over Arrow 10a Blue operational phase

Scenario: 2 - Arrow 10a Blue (PL185 & PL493) assessment
Calculation period: 2019 - 2058 (40 years)

		Average Hydraulic Gradient (m/m)		Darcian Velocity (m/d)			Darcian Velocity (m over 40 years)				
Assessment Location	**Unit**	**Base Case**	**Arrow 10a Blue**	**Base Case**	**Arrow 10a Blue**	**Arrow contribution**	**Base Case**	**Arrow 10a Blue**	**Arrow contribution**	**Direction**	**Arrow impact as % of total**
Pt_A / Pt_B	Springbok Sst	0.00099	0.0010	0.00052	0.00052	0.00001	7.6	7.7	0.084	W → E	1.1%
	Macalister Seam	0.0029	0.0029	0.0010	0.0010	-0.00001	15	15	-0.098	W → E	-0.7%
	Argyle Seam	0.00044	0.00060	0.00000	0.00000	0.00000	0.0097	0.013	0.0036	W → E	27.0%
Pt_C / Pt_D	Springbok Sst	0.00060	0.00063	0.00031	0.00033	0.00002	4.6	4.8	0.25	N → S	5.1%
	Macalister Seam	0.0014	0.0014	0.00051	0.00052	0.00001	7.4	7.5	0.13	N → S	1.7%
	Argyle Seam	0.00006	0.00005	0.00000	0.00000	0.00000	0.0014	0.0010	-0.00034	N → S	-32.6%
Pt_E / Pt_F	Springbok Sst	0.0012	0.0012	0.00063	0.00065	0.00002	9.2	9.4	0.22	NE → SW	2.4%
	Macalister Seam	0.0028	0.0028	0.0010	0.0010	0.00000	15	15	0.064	NE → SW	0.4%
	Argyle Seam	0.00014	0.00025	0.00000	0.00000	0.00000	0.0032	0.0055	0.0023	NE → SW	41.3%

Highlighted row: highest Arrow impact per HSU. If a HSU is not highlighted, the Arrow contribution is beneficial (i.e. reduction in predicted GW migration)

Darcian velocity has been calculated using Equation 2 and does not include the effects of porosity on groundwater flow

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4132187-38249/https://projects.ghd.com/oc/sqoc2/arrowgroundwaterstud/Delivery/Documents/4132187-REP GW Modelling Report_Oct2019.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	R Gresswell J Dowdeswell	J Dowdeswell		J Dowdeswell		28/10/19
1	R Gresswell J Dowdeswell	J Dowdeswell		J Dowdeswell		29/10/19

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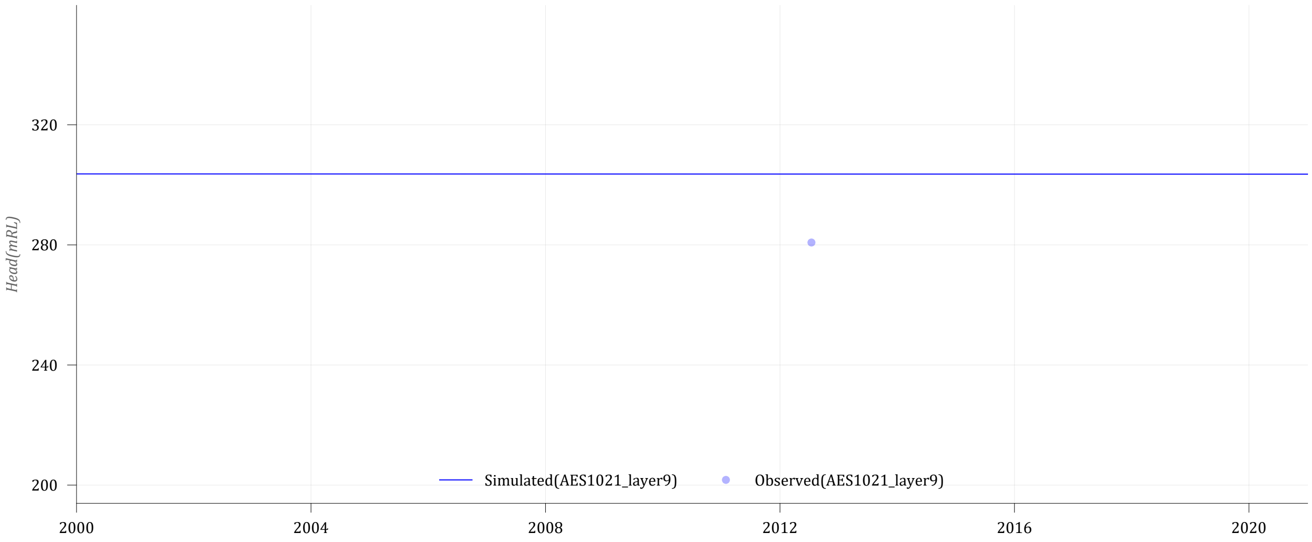
Appendix B Phase 1 groundwater flow model calibration

AES1021



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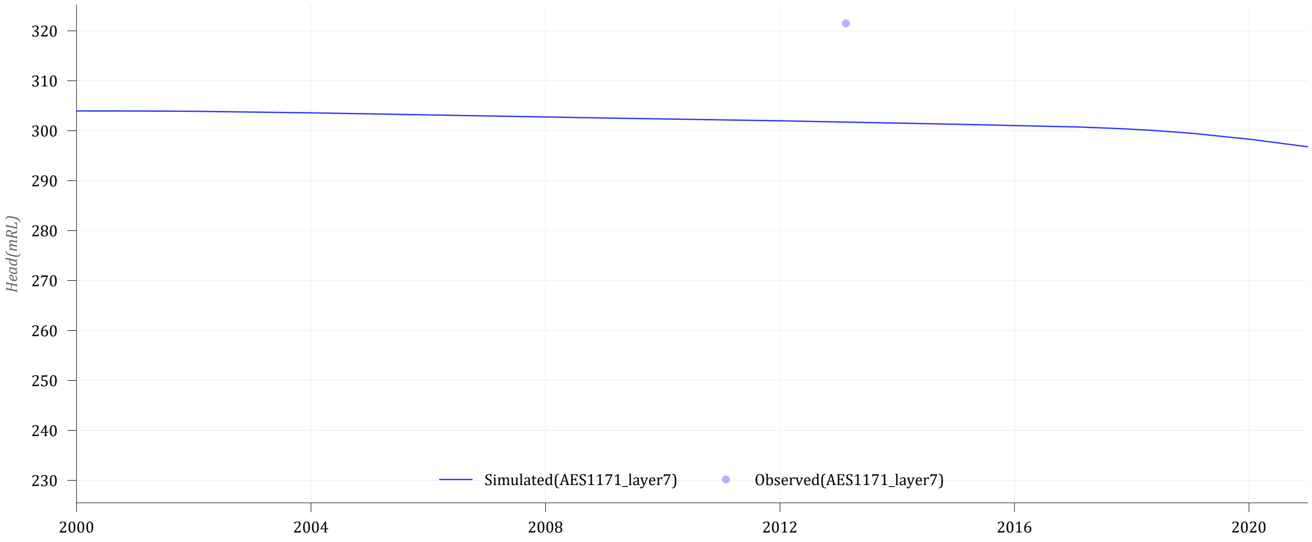
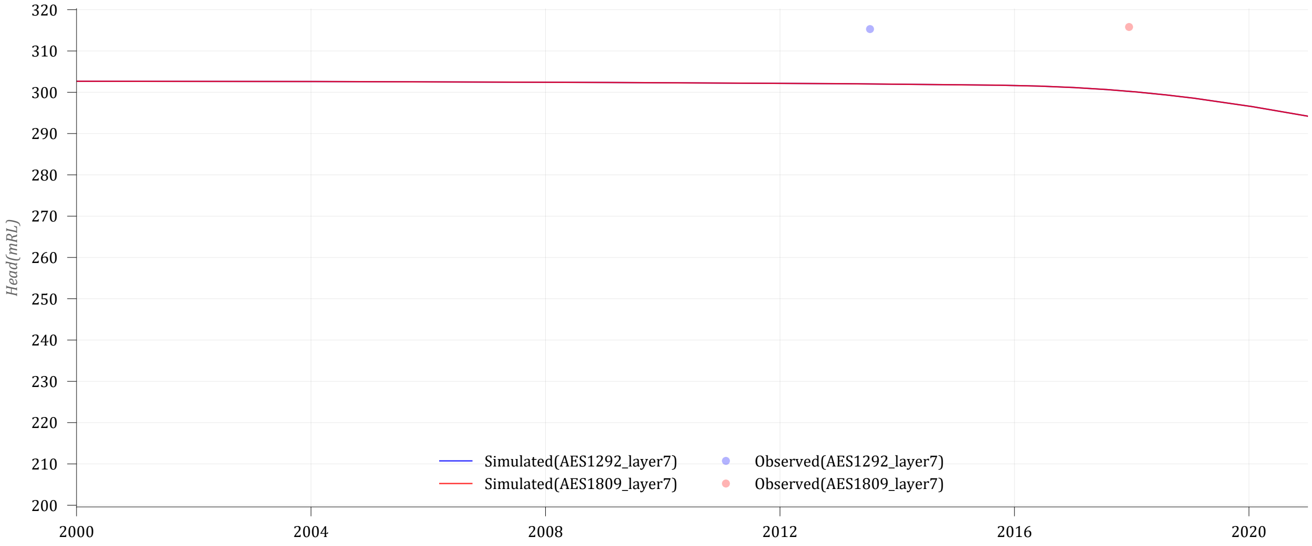
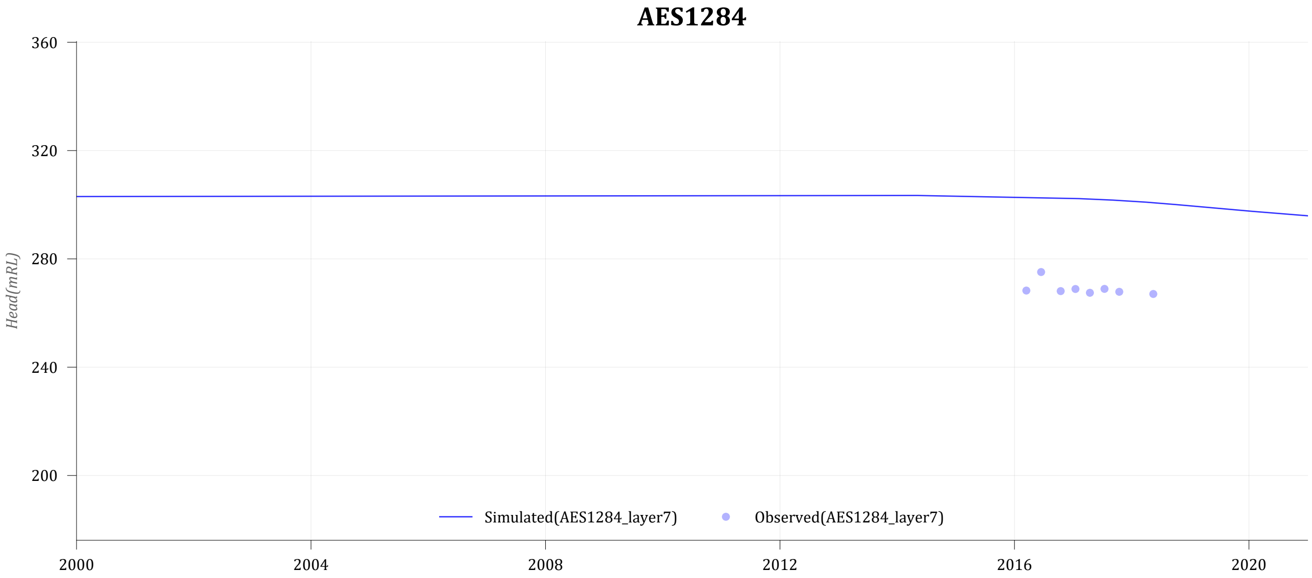


AES12

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Head(mRL)
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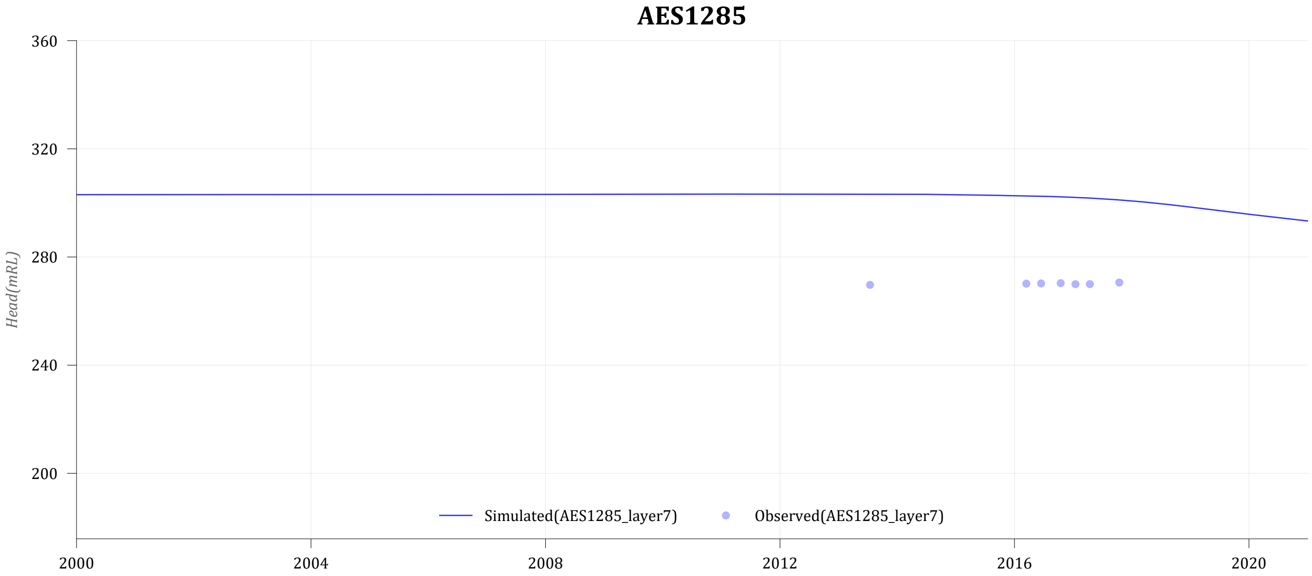
320
280
240
200
2000
2004
2008
2012
2016
2020
Simulated(AES1284_layer7)
Observed(AES1284_layer7)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200
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2008
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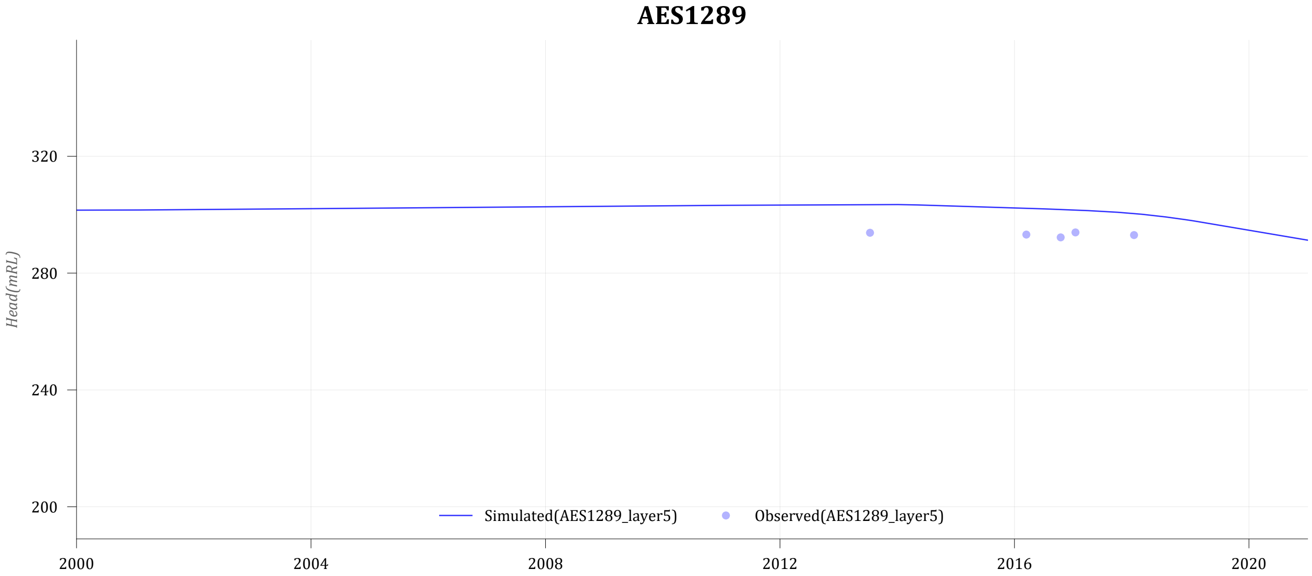
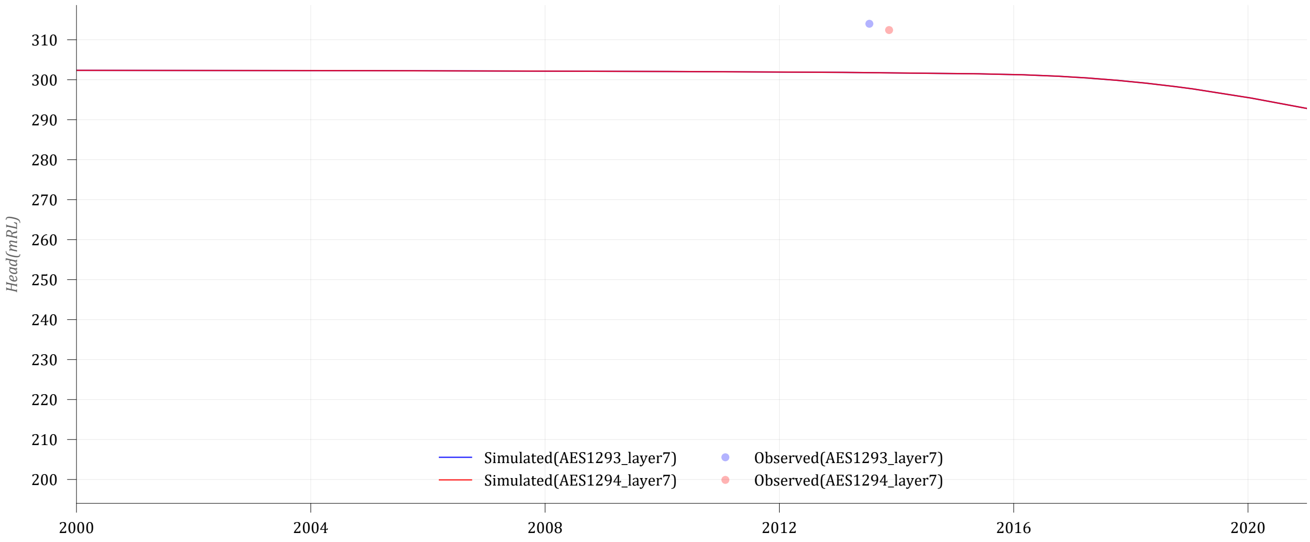

AES1289
Head(mRL)
320
280
240
200
2000
2004
2008
2012
2016
2020
Simulated(AES1289_layer5)
Observed(AES1289_layer5)

AES129



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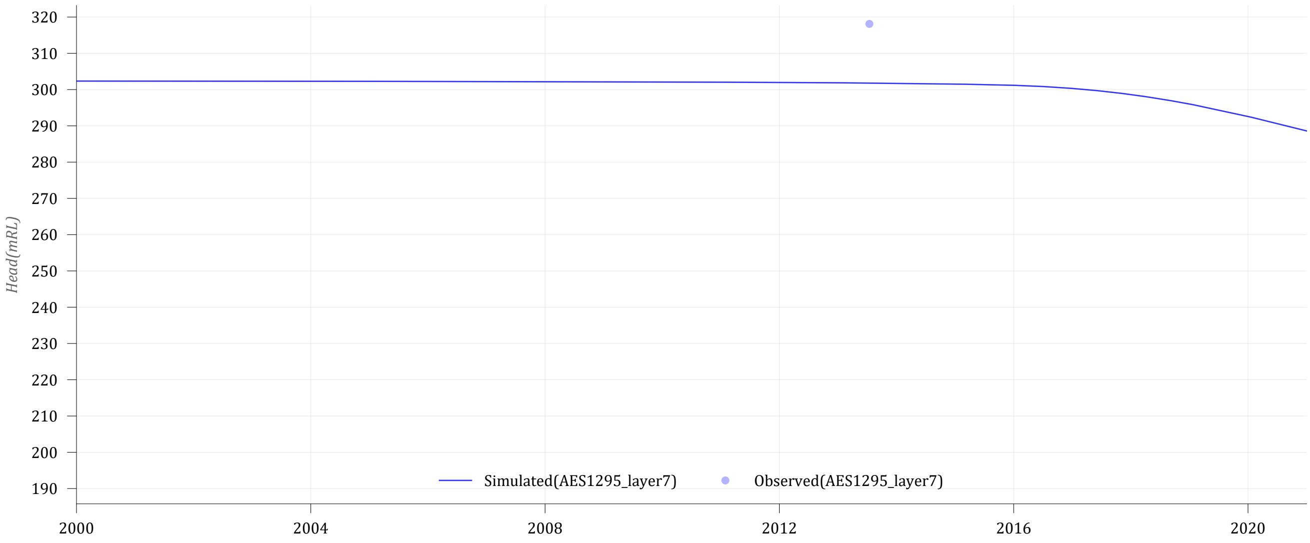
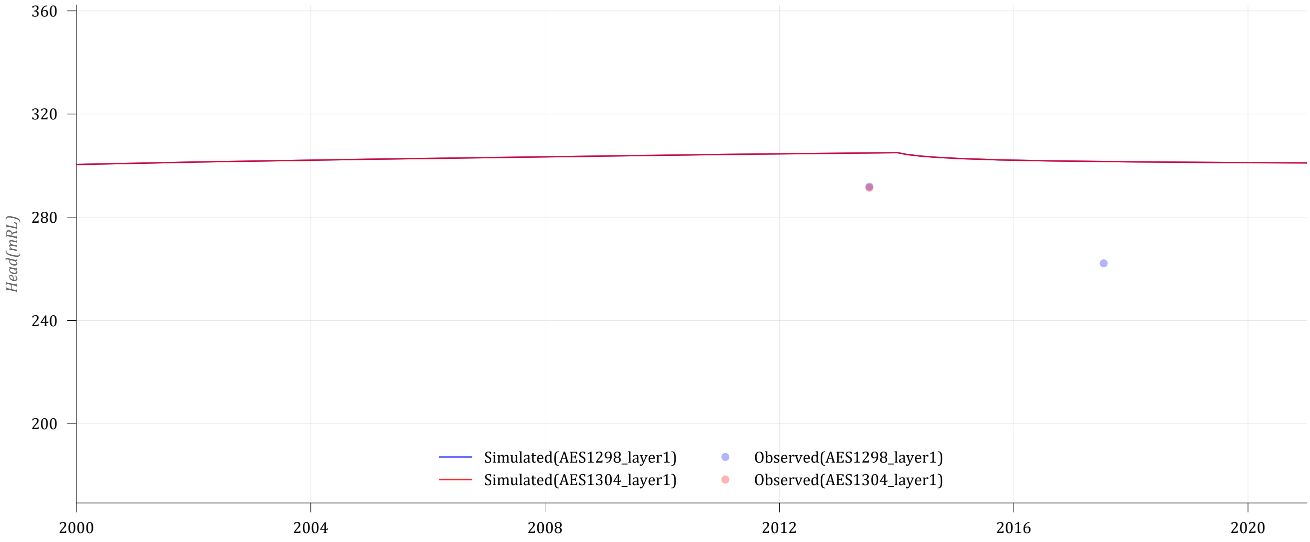
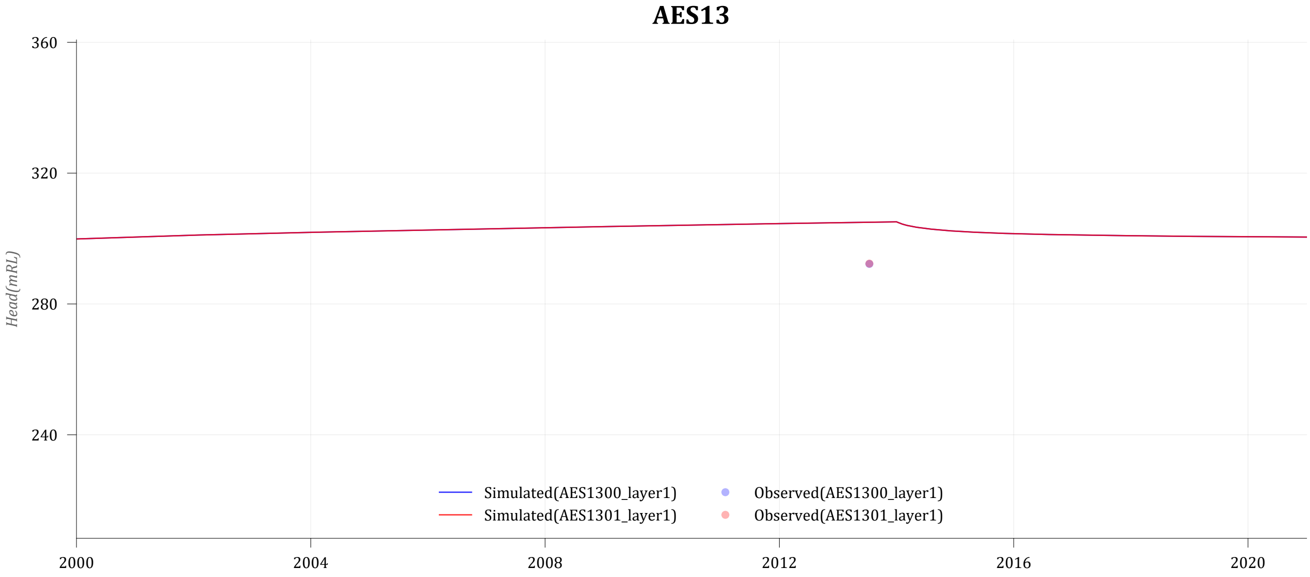


AES129_2

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240
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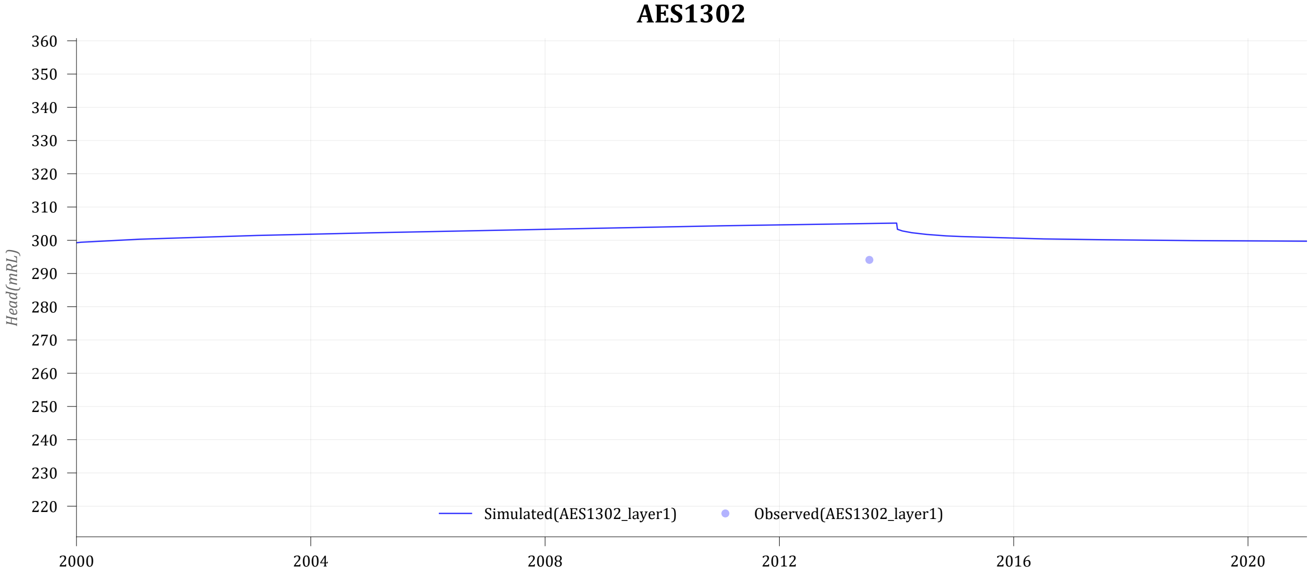
Observed(AES1301_layer1)
2000
2004
2008
2012
2016
2020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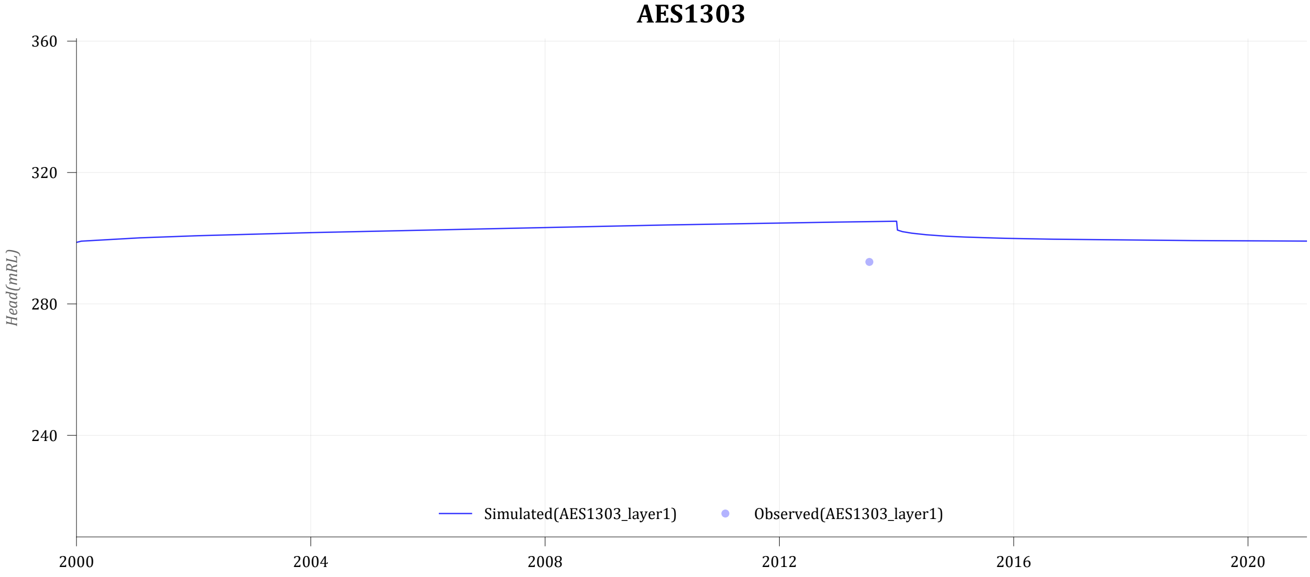
350
340
330
320
310
300
290
280
270
260
250
240
230
220
Head(mRL)
Simulated(AES1302_layer1)
Observed(AES1302_layer1)
2000
2004
2008
2012
2016
2020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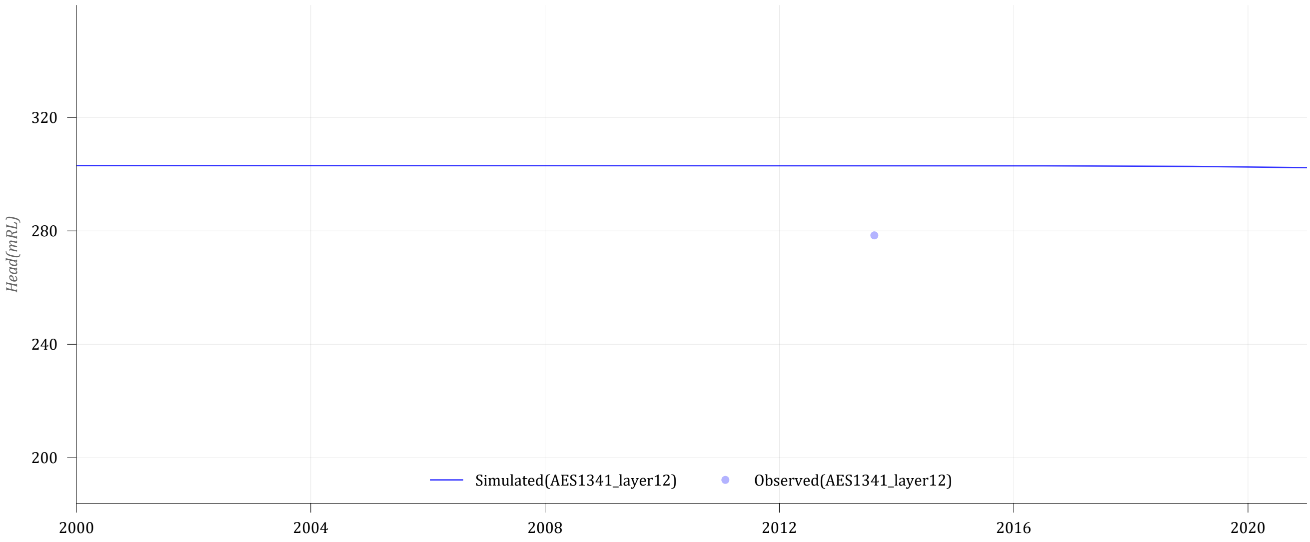
2016
2020

AES1341



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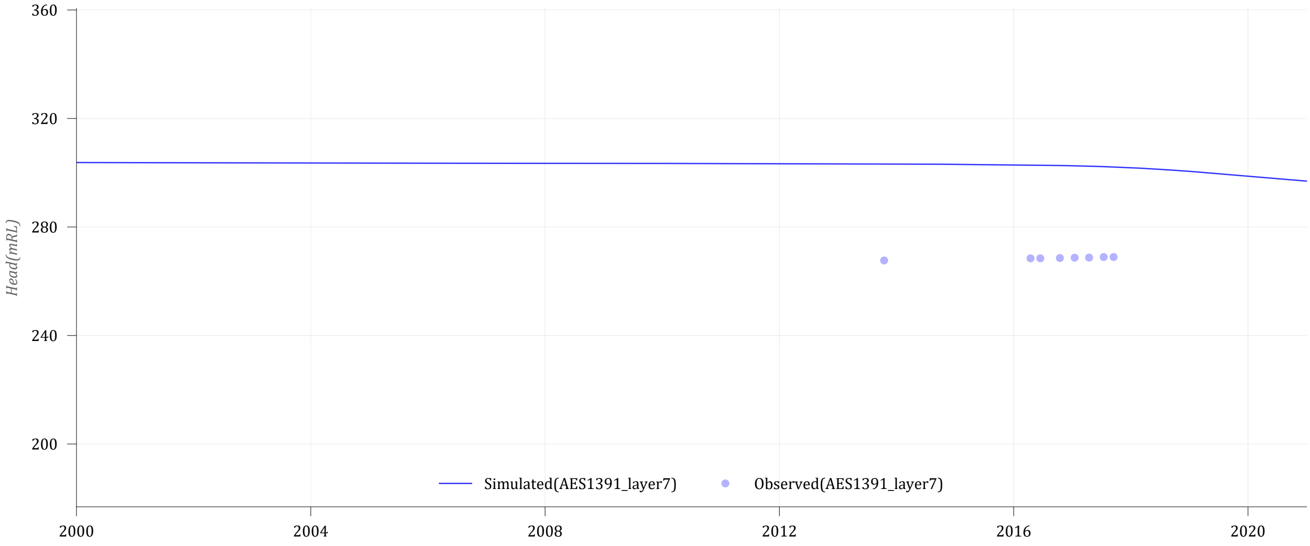

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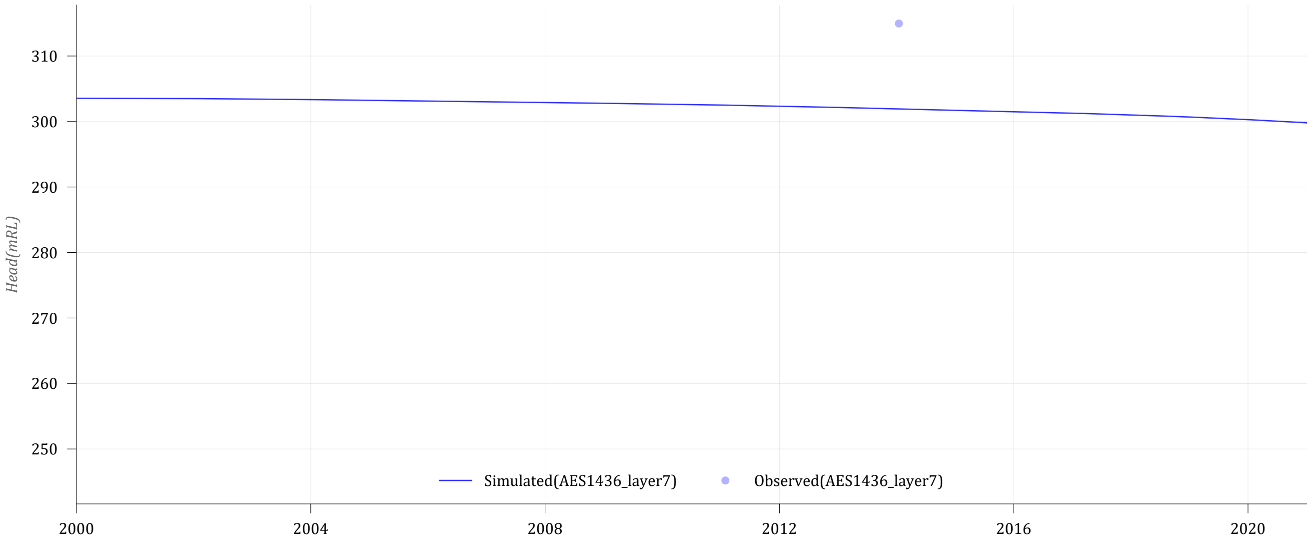

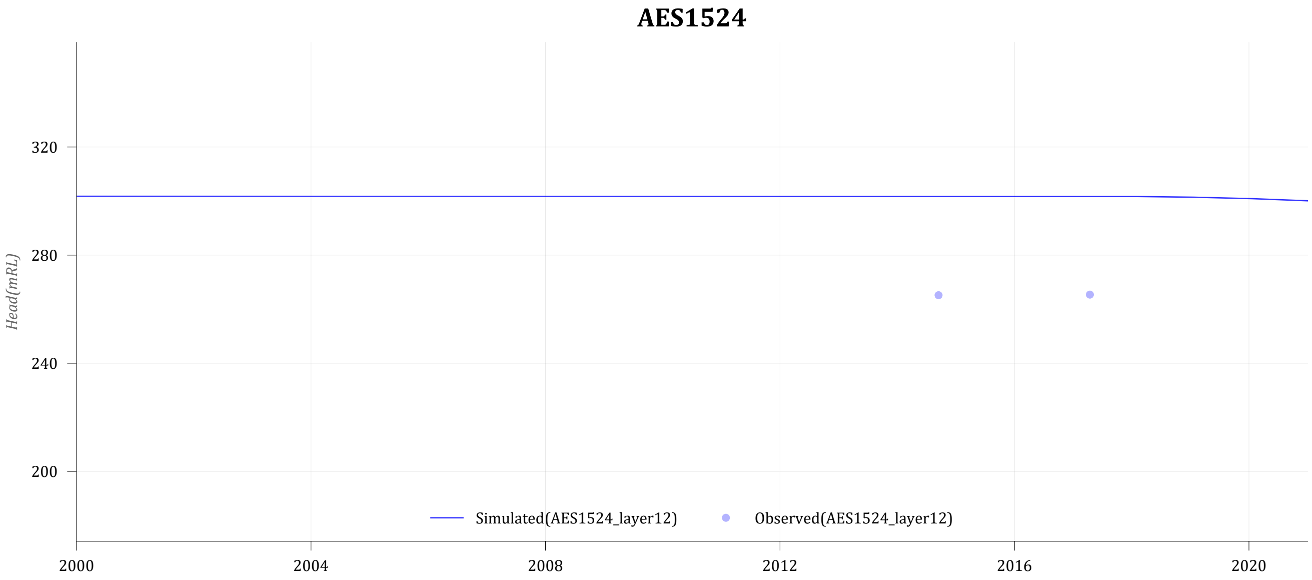
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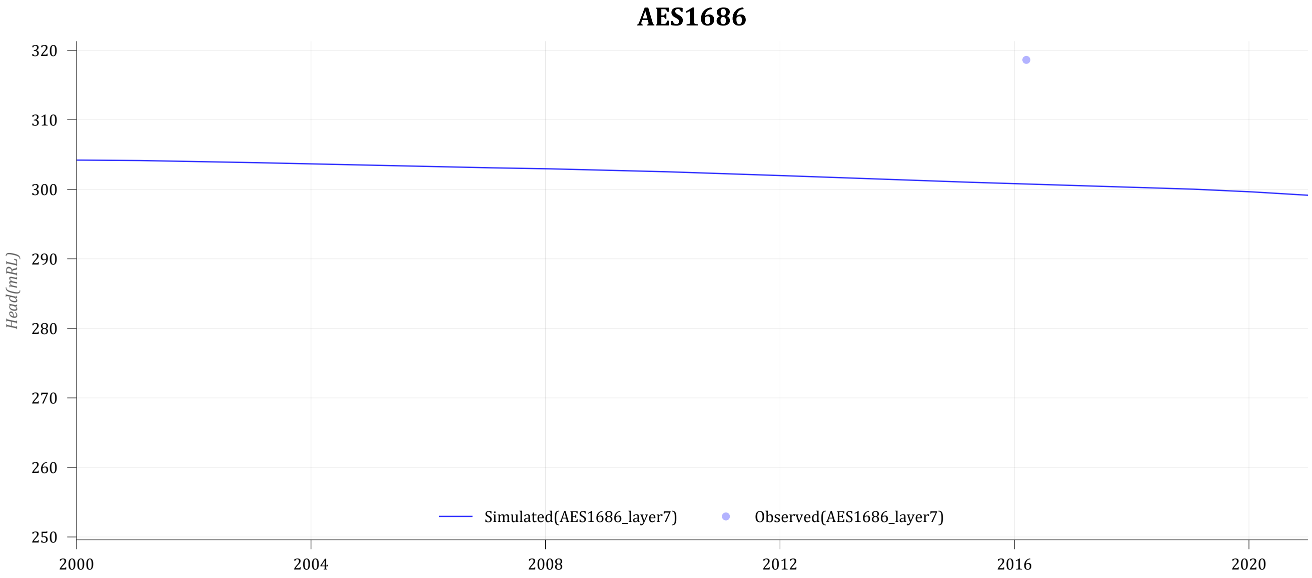
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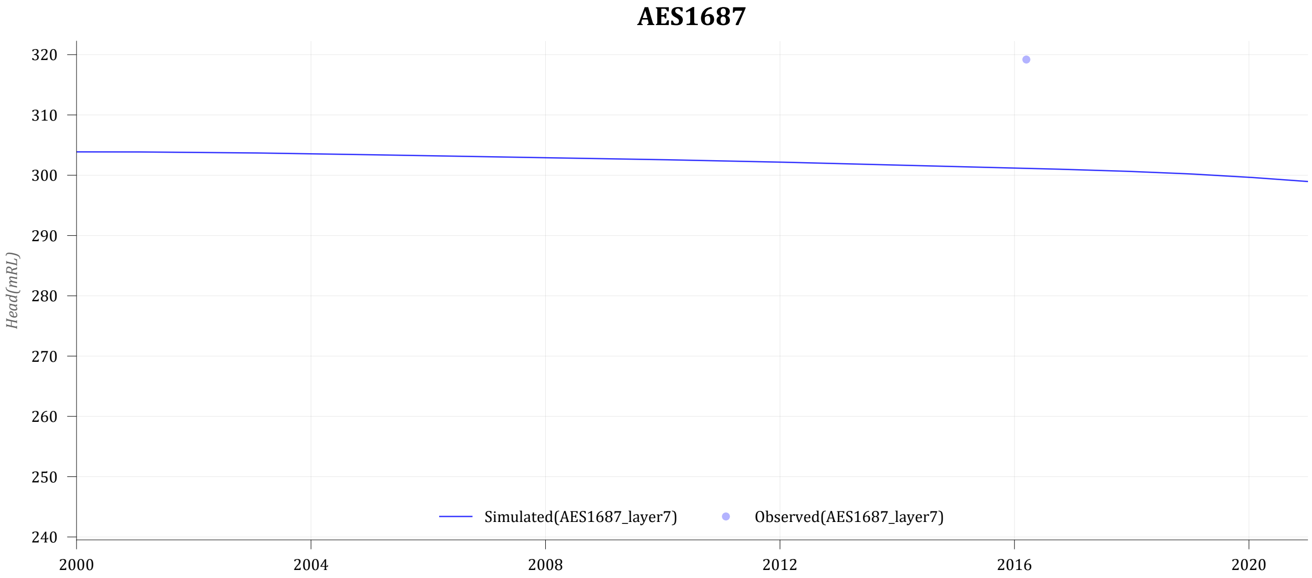
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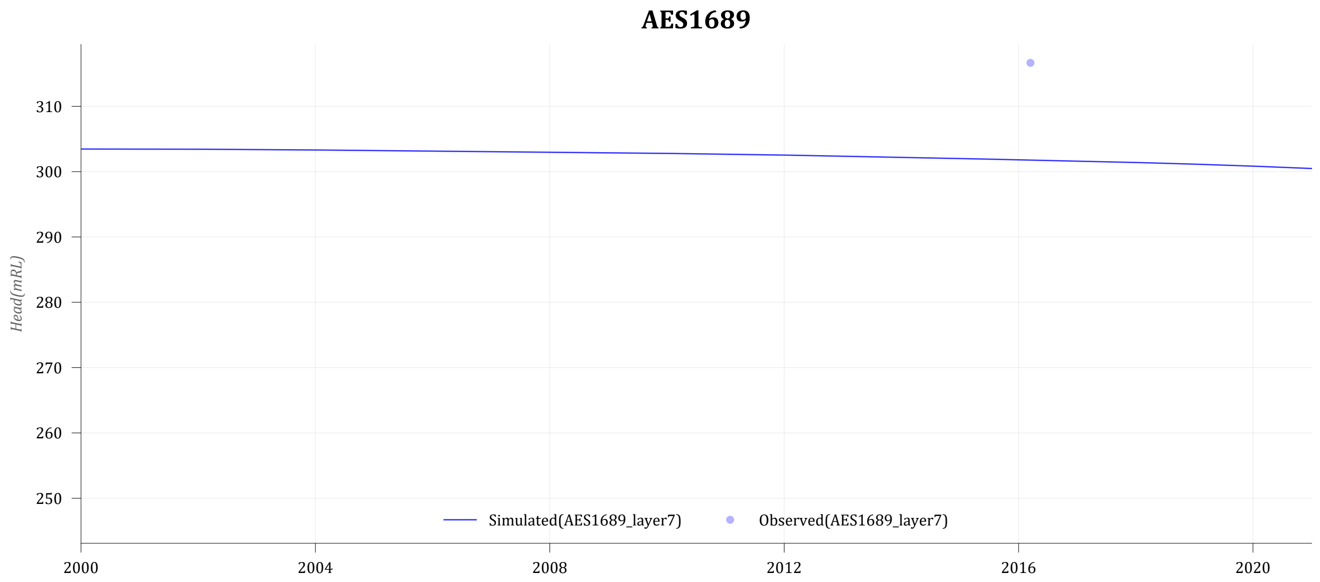
AES1689
Head(mRL)
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290
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250
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2004
2008
2012
2016
2020
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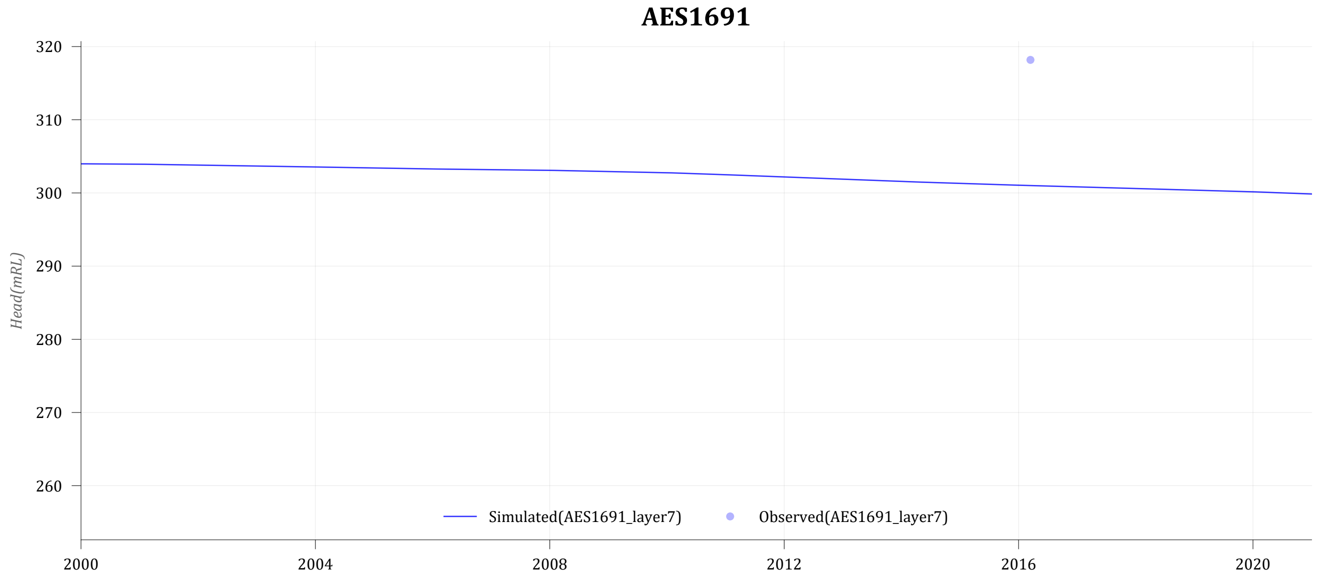
Observed(AES1689_layer7)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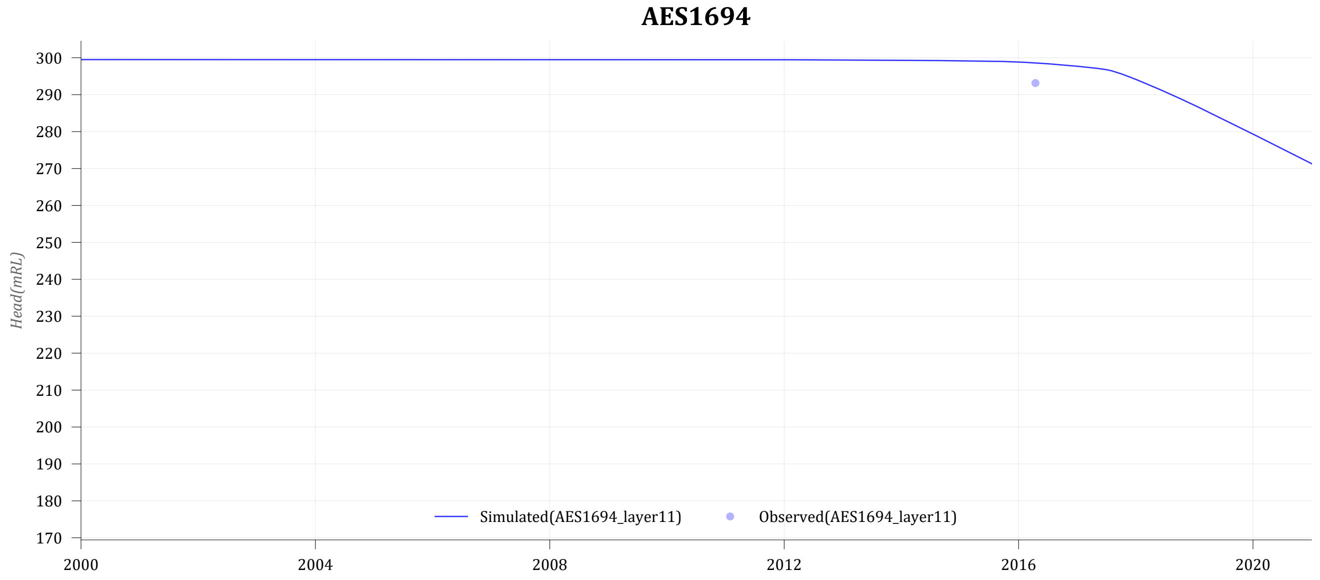
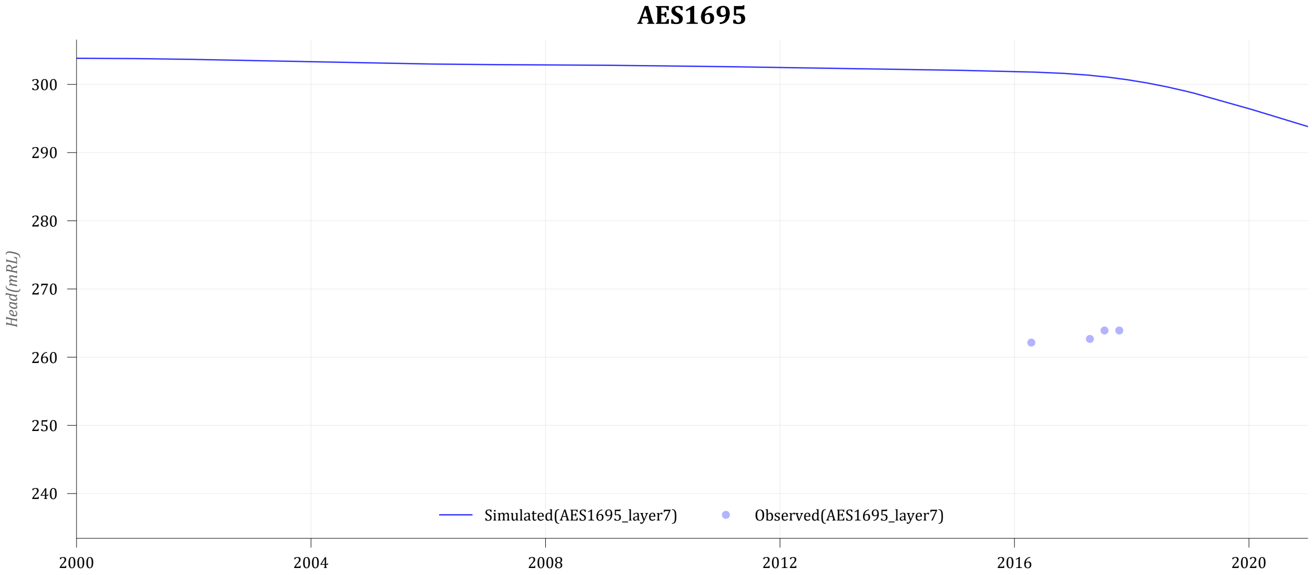
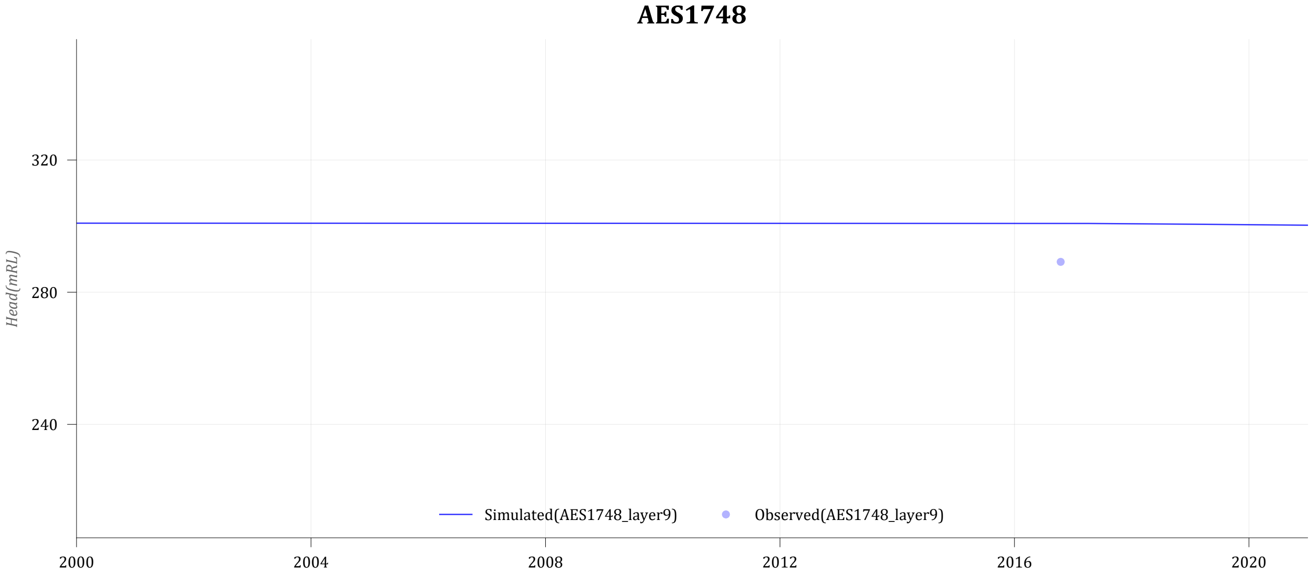
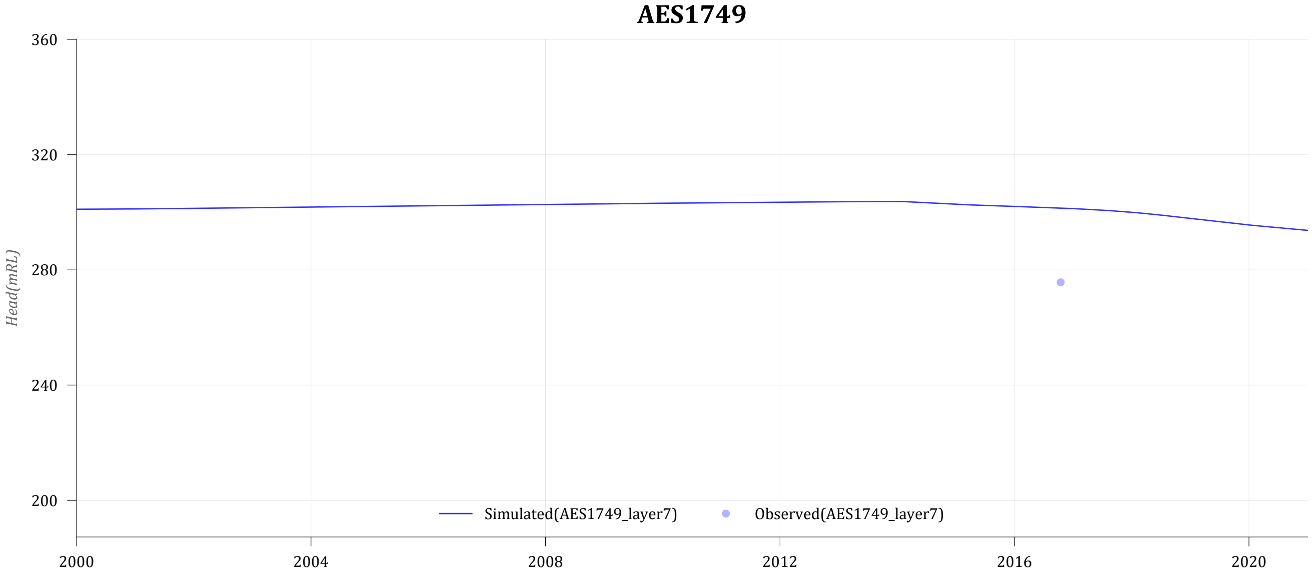
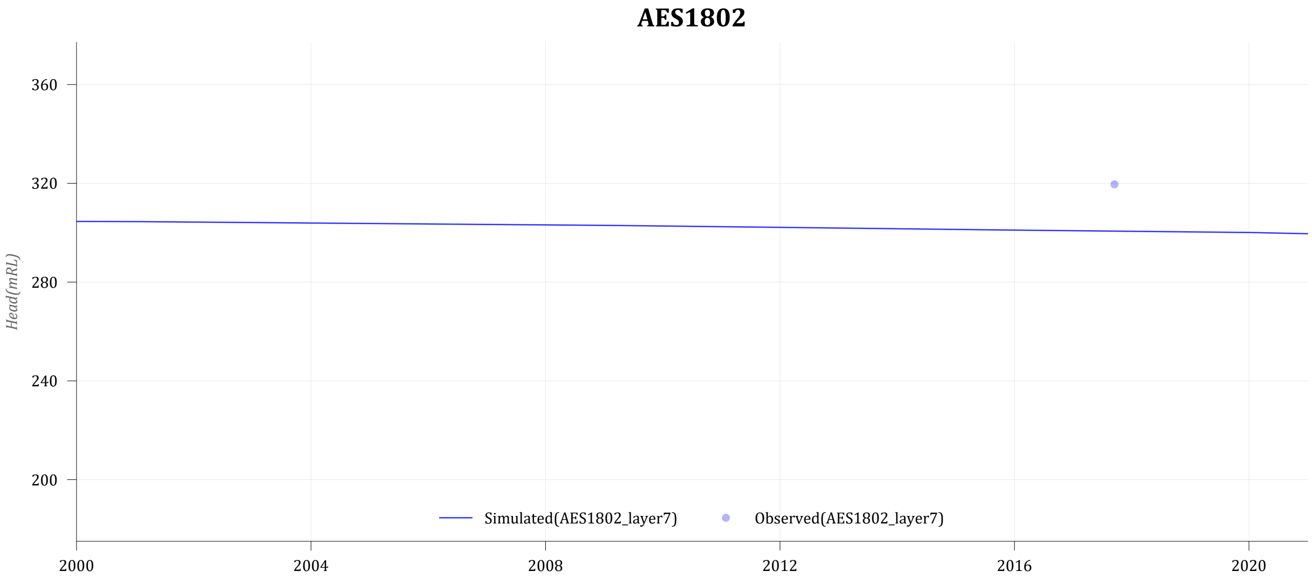
320
310
300
290
280
270
260
2000
2004
2008
2012
2016
2020
Simulated(AES1691_layer7)
Observed(AES1691_layer7)

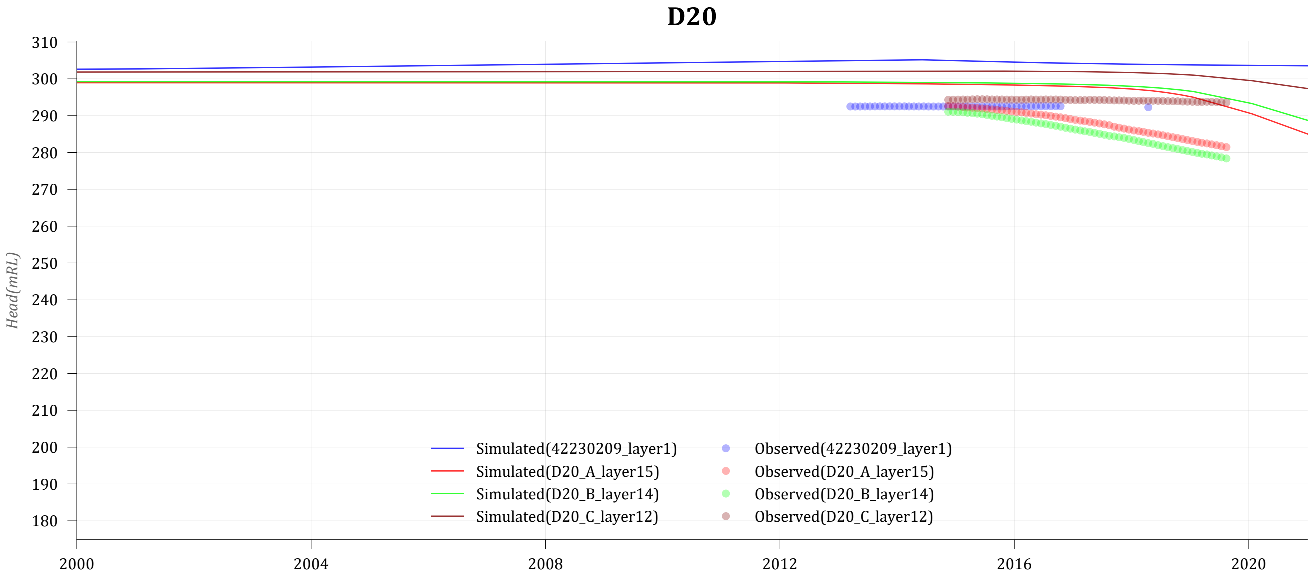

AES1694
Head(mRL)
300
290
280
270
260
250
240
230
220
210
200
190
180
170
2000
2004
2008
2012
2016
2020
Simulated(AES1694_layer11)
Observed(AES1694_layer11)

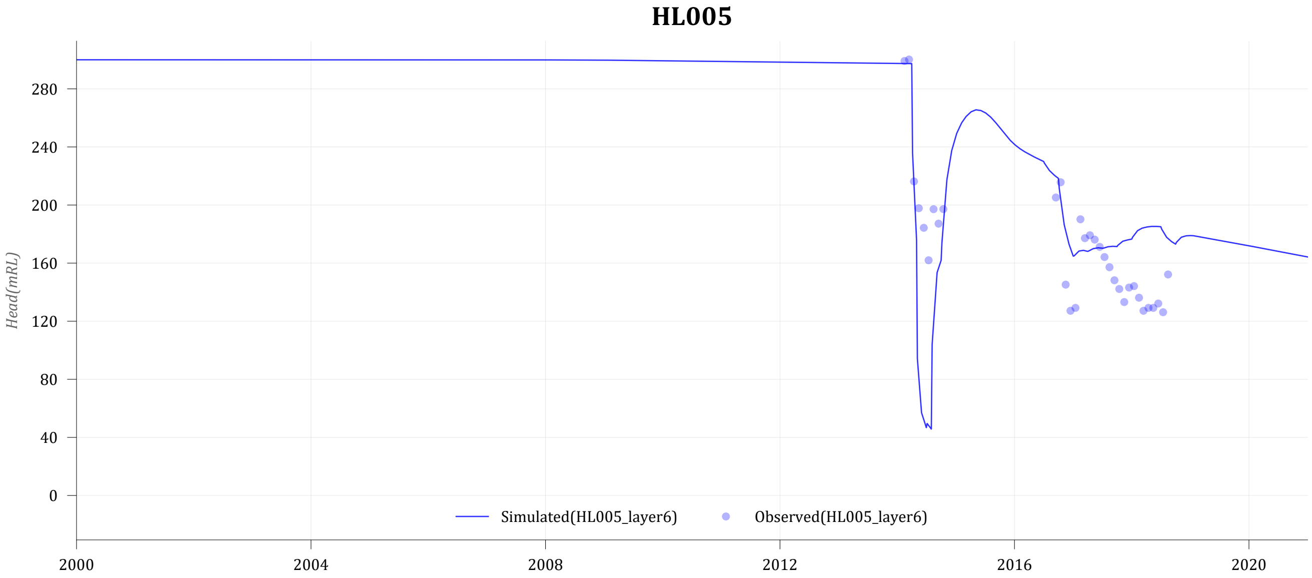

AES1695
Head(mRL)
300
290
280
270
260
250
240
Simulated(AES1695_layer7)
Observed(AES1695_layer7)
2000
2004
2008
2012
2016
2020


AES1748
Head(mRL)
320
280
240
Simulated(AES1748_layer9)
Observed(AES1748_layer9)
2000
2004
2008
2012
2016
2020

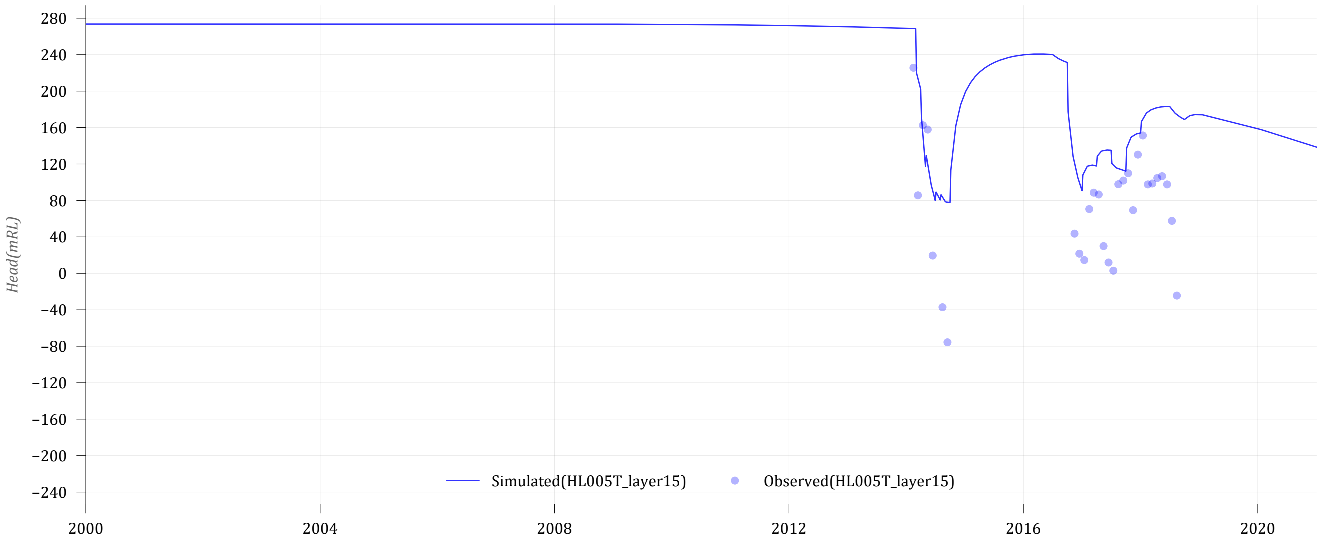

AES1749
Head(mRL)
360
320
280
240
200
Simulated(AES1749_layer7)
Observed(AES1749_layer7)
2000
2004
2008
2012
2016
2020


AES1802
Head(mRL)
360
320
280
240
200
Simulated(AES1802_layer7)
Observed(AES1802_layer7)
2000
2004
2008
2012
2016
2020

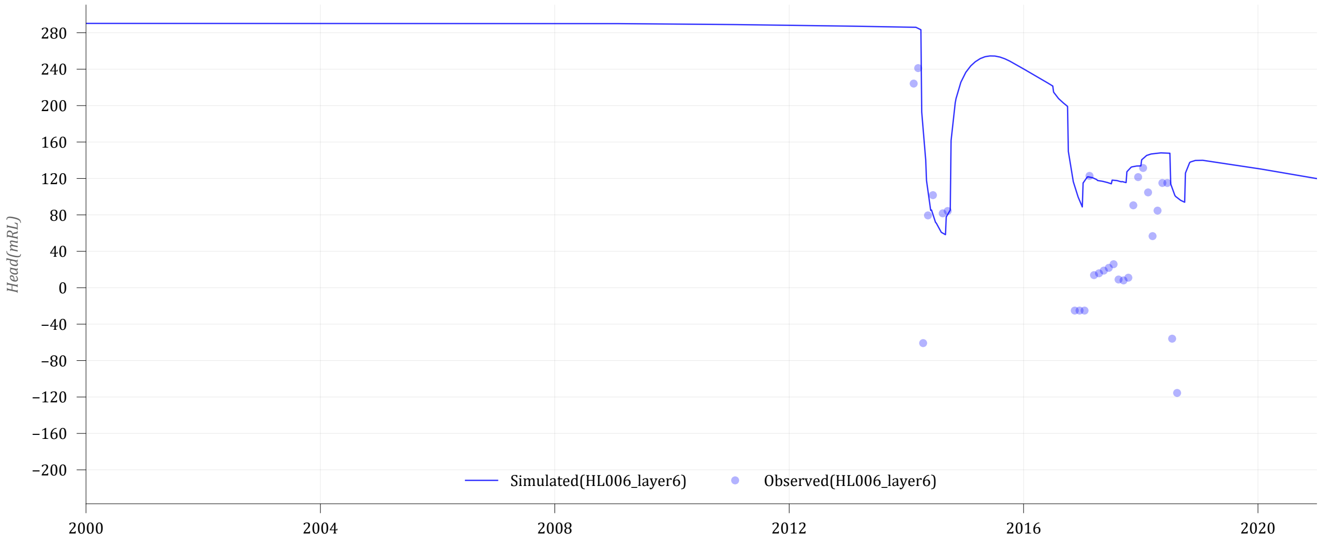

D20
Head(mRL)
310
300
290
280
270
260
250
240
230
220
210
200
190
180
Simulated(42230209_layer1)
Simulated(D20_A_layer15)
Simulated(D20_B_layer14)
Simulated(D20_C_layer12)
Observed(42230209_layer1)
Observed(D20_A_layer15)
Observed(D20_B_layer14)
Observed(D20_C_layer12)
2000
2004
2008
2012
2016
2020


HL005
Head(mRL)
280
240
200
160
120
80
40
0
Simulated(HL005_layer6)
Observed(HL005_layer6)
2000
2004
2008
2012
2016
2020

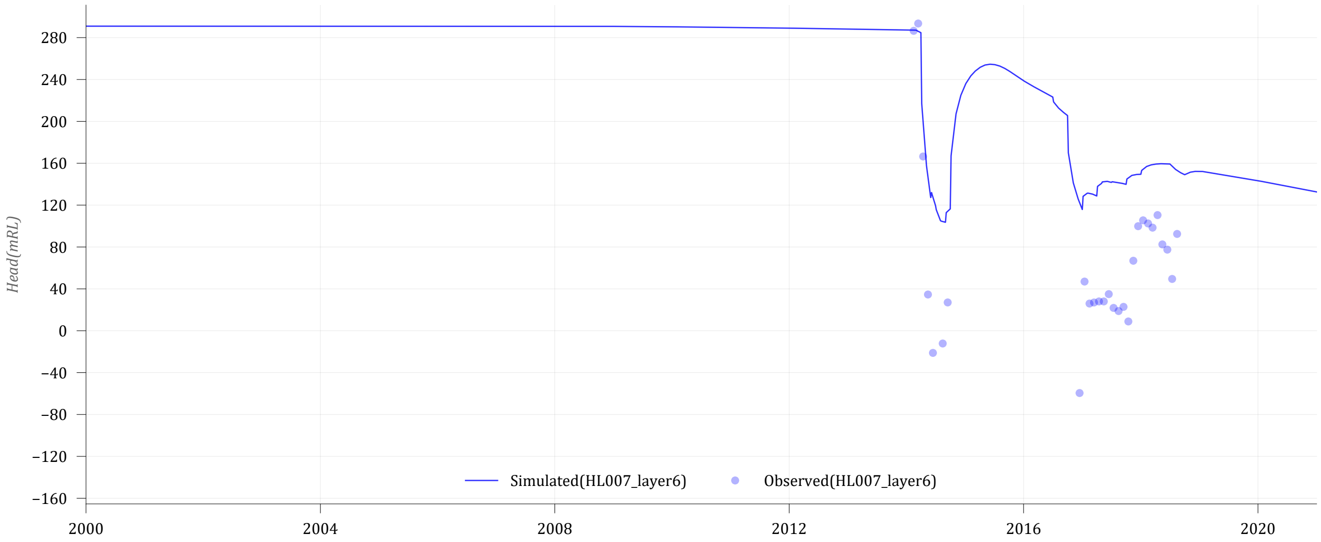
HL005T

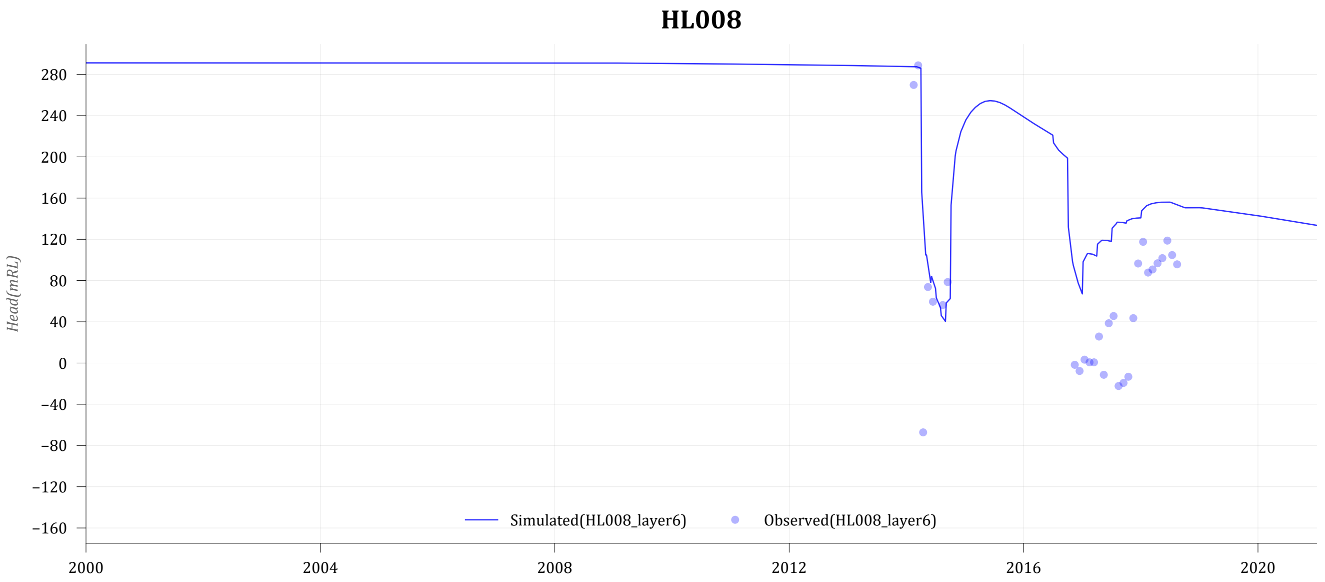


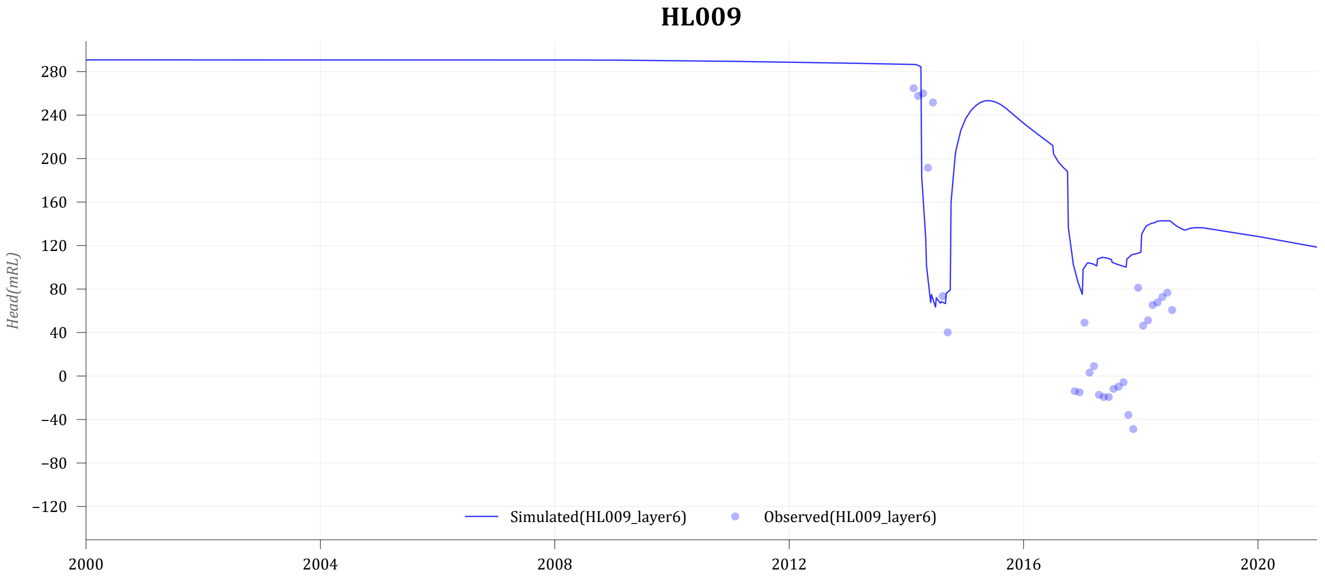
HL006

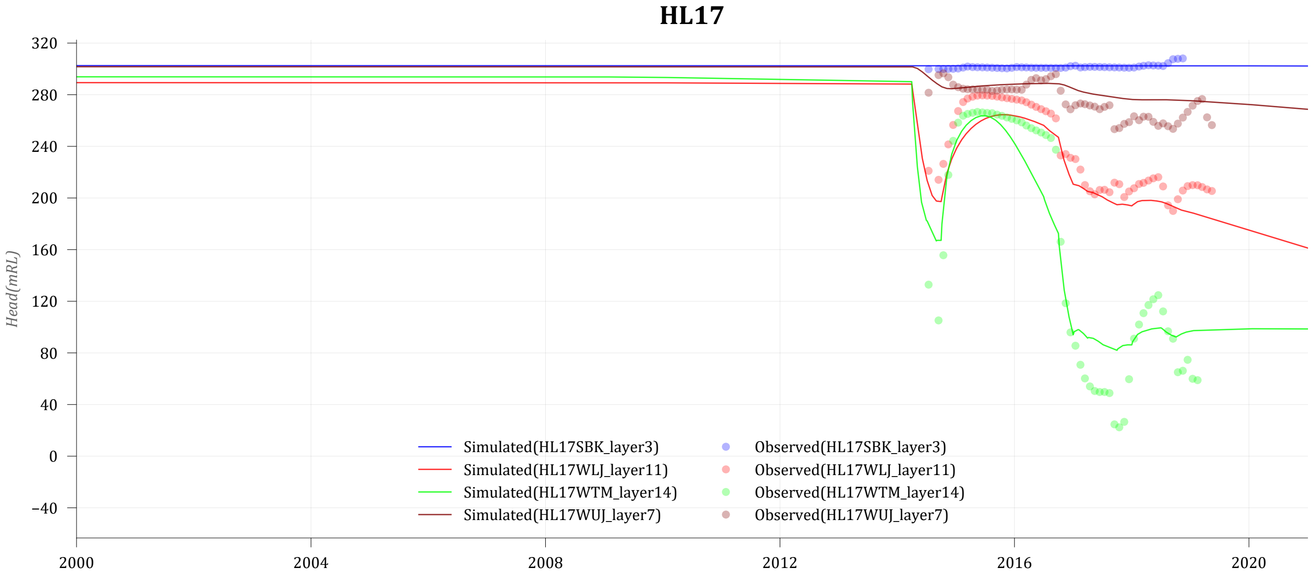


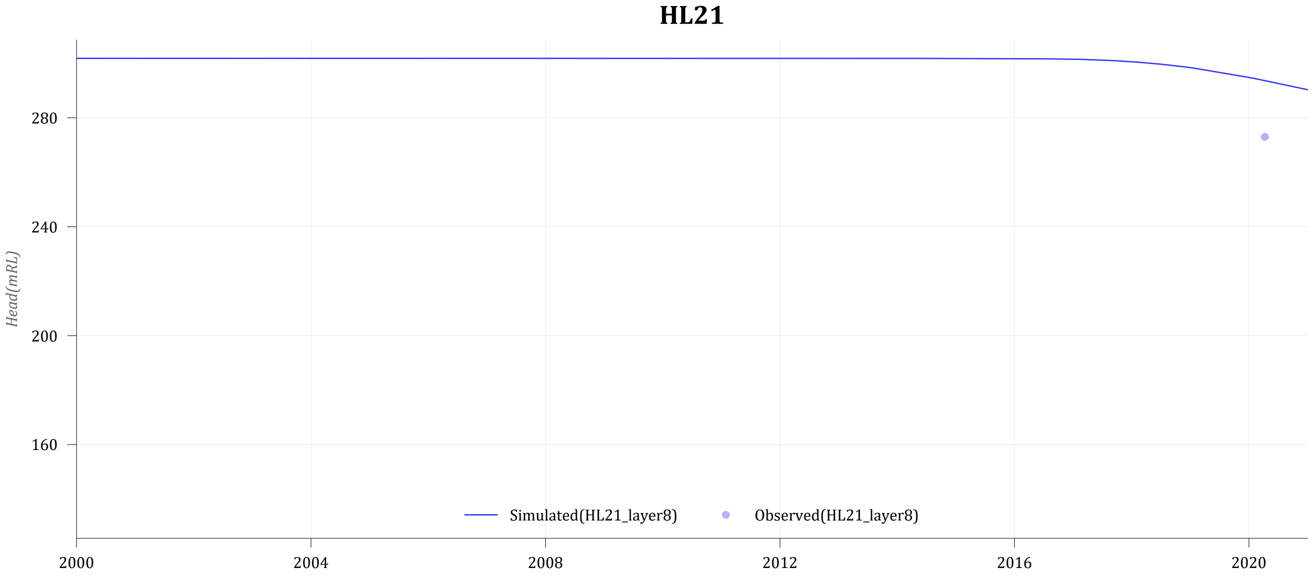
HL007

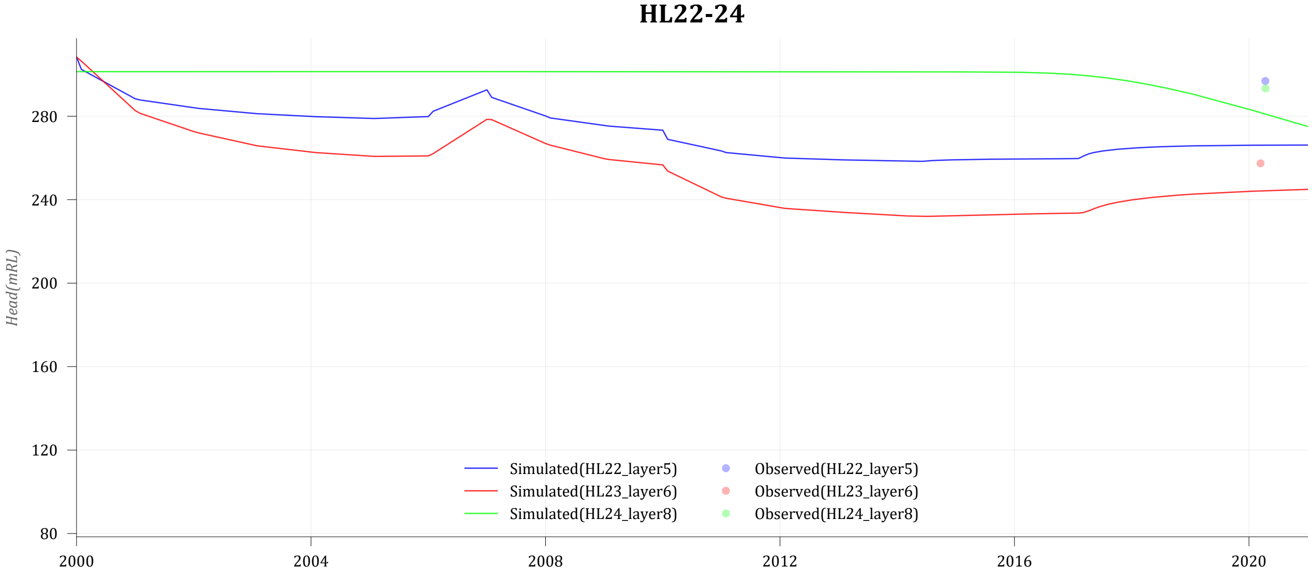


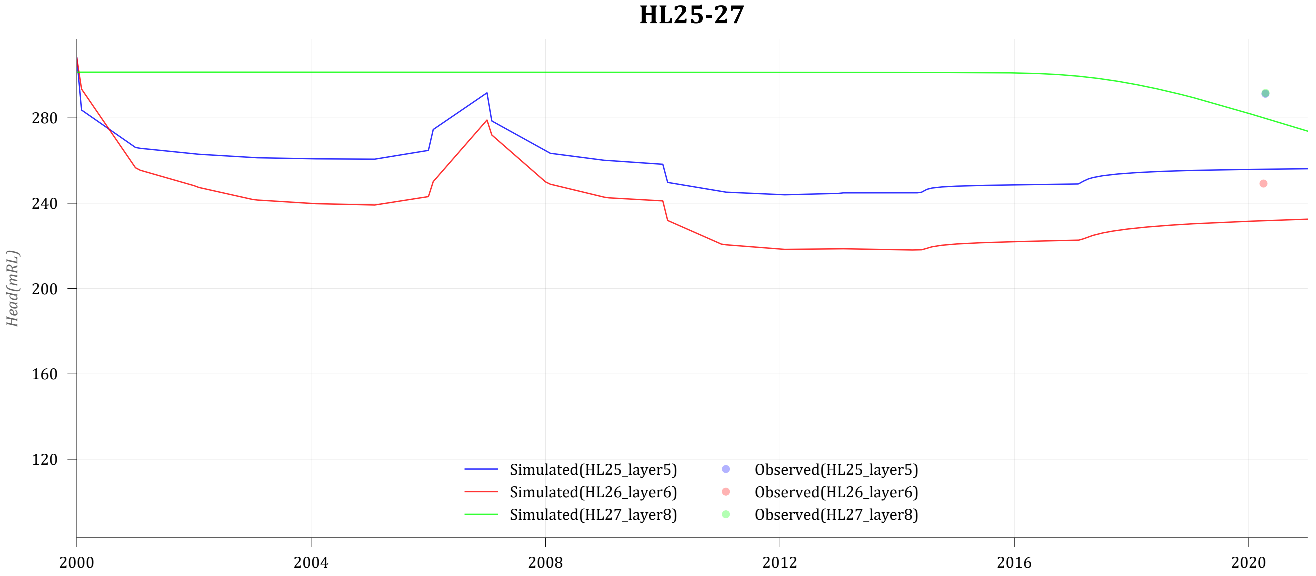

HL008
Head(mRL)
280
240
200
160
120
80
40
0
−40
−80
−120
−160
2000
2004
2008
2012
2016
2020
Simulated(HL008_layer6)
Observed(HL008_layer6)

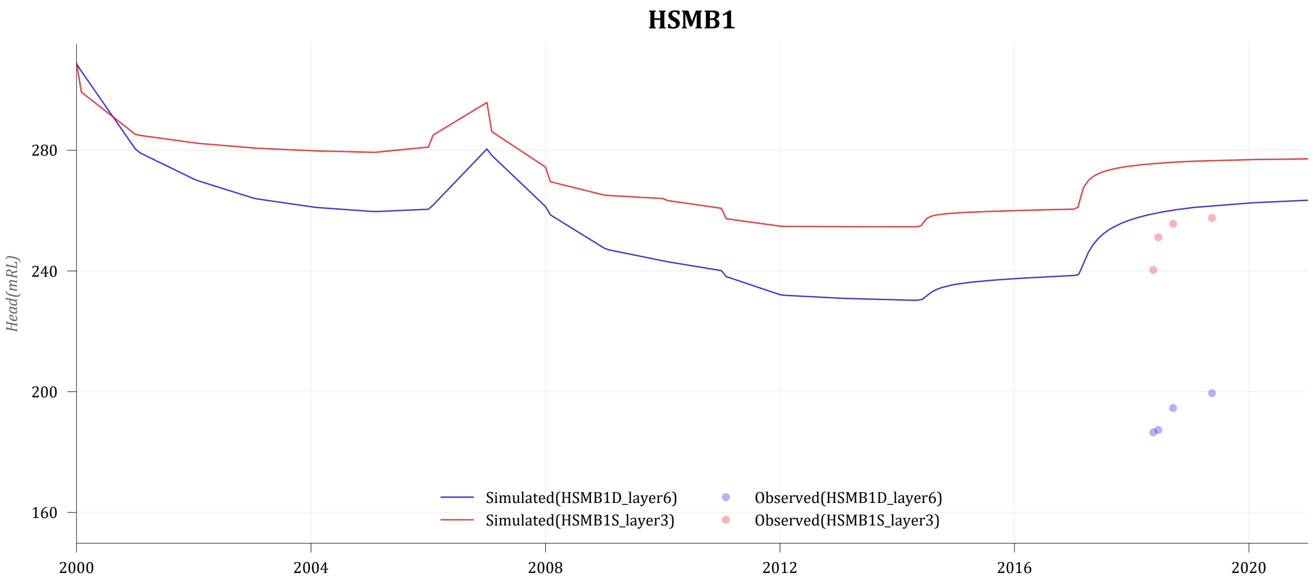

HL009
Head(mRL)
280
240
200
160
120
80
40
0
−40
−80
−120
2000
2004
2008
2012
2016
2020
Simulated(HL009_layer6)
Observed(HL009_layer6)

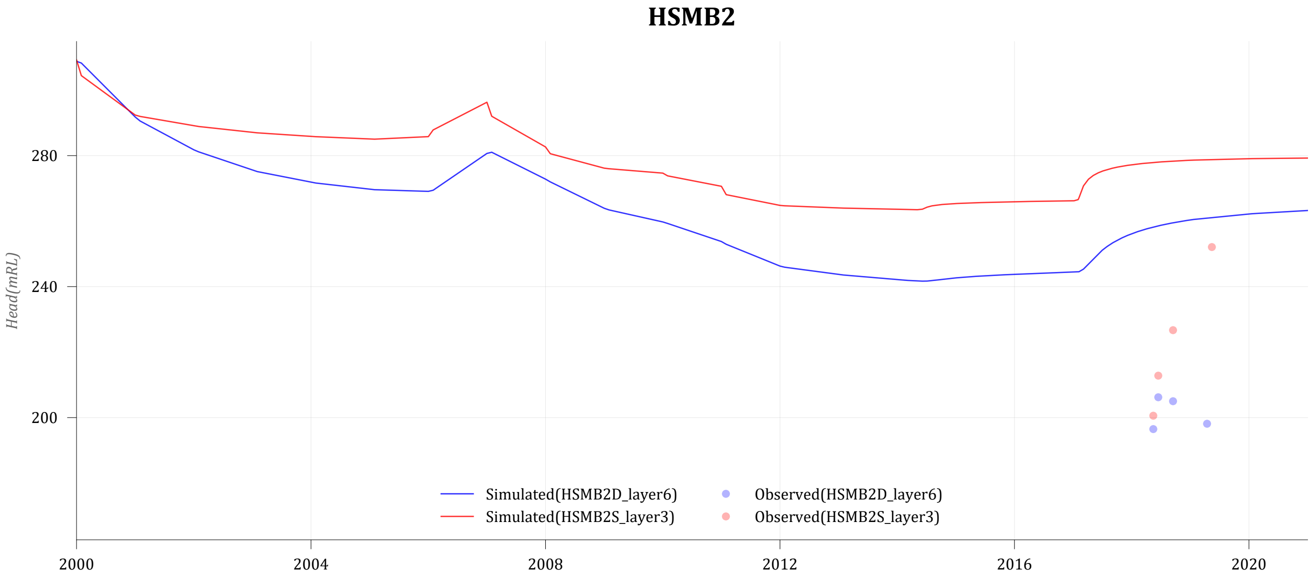

HL17
Head(mRL)
320
280
240
200
160
120
80
40
0
−40
2000
2004
2008
2012
2016
2020
Simulated(HL17SBK_layer3)
Simulated(HL17WLJ_layer11)
Simulated(HL17WTM_layer14)
Simulated(HL17WUJ_layer7)
Observed(HL17SBK_layer3)
Observed(HL17WLJ_layer11)
Observed(HL17WTM_layer14)
Observed(HL17WUJ_layer7)

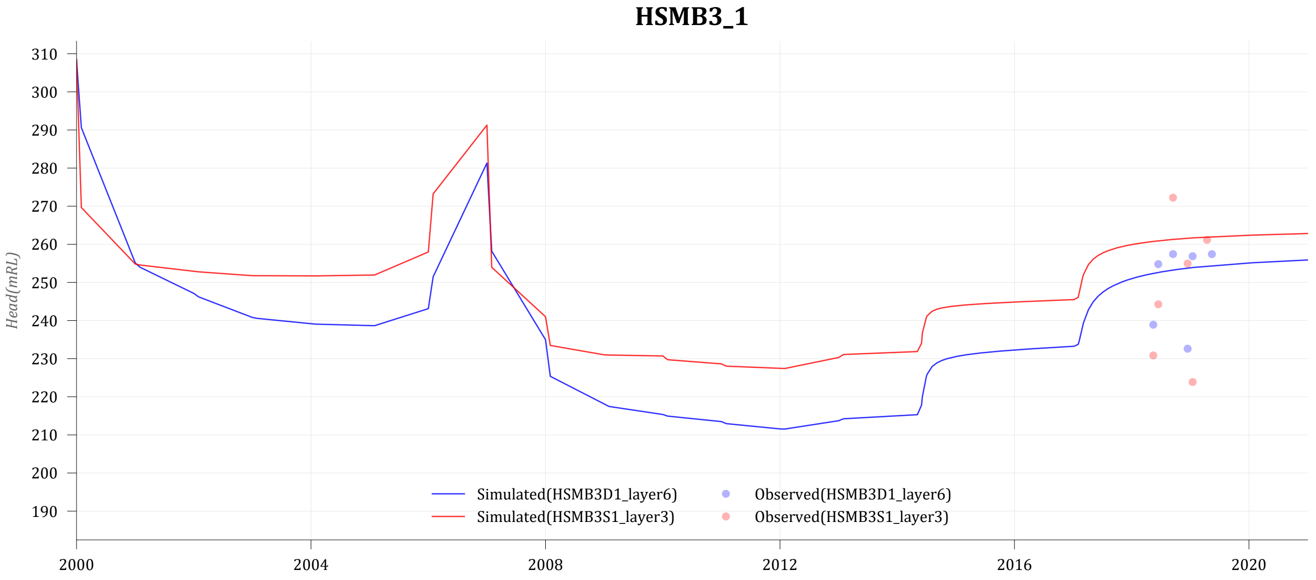

HL21


HL22-24

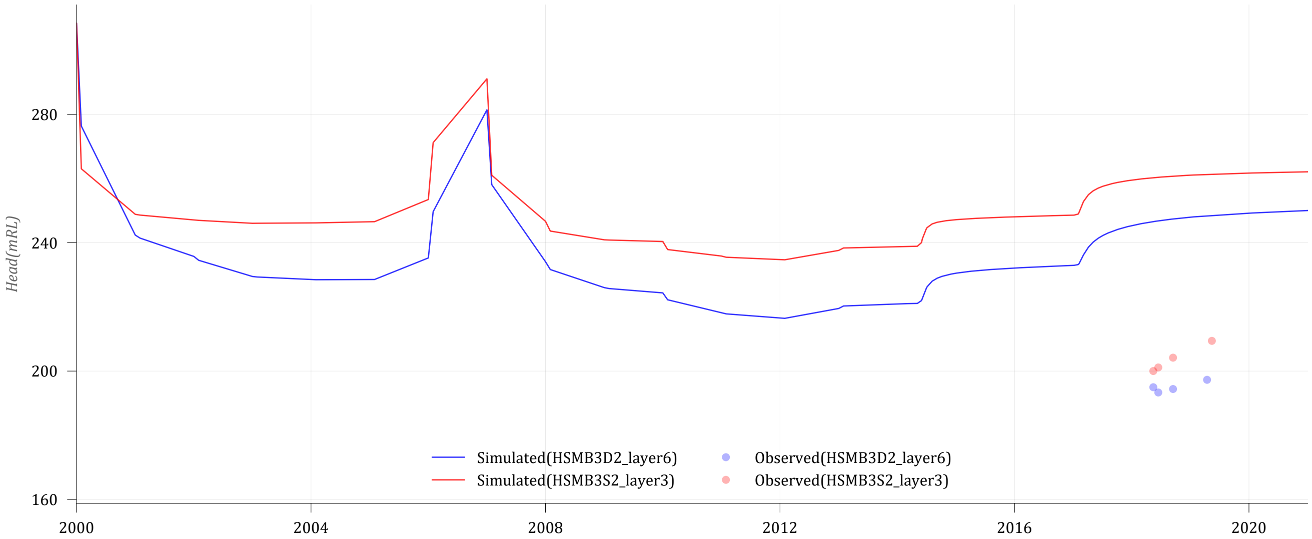

HL25-27


HSMB1
Head(mRL)
280
240
200
160
2000
2004
2008
2012
2016
2020
Simulated(HSMB1D_layer6)
Simulated(HSMB1S_layer3)
Observed(HSMB1D_layer6)
Observed(HSMB1S_layer3)

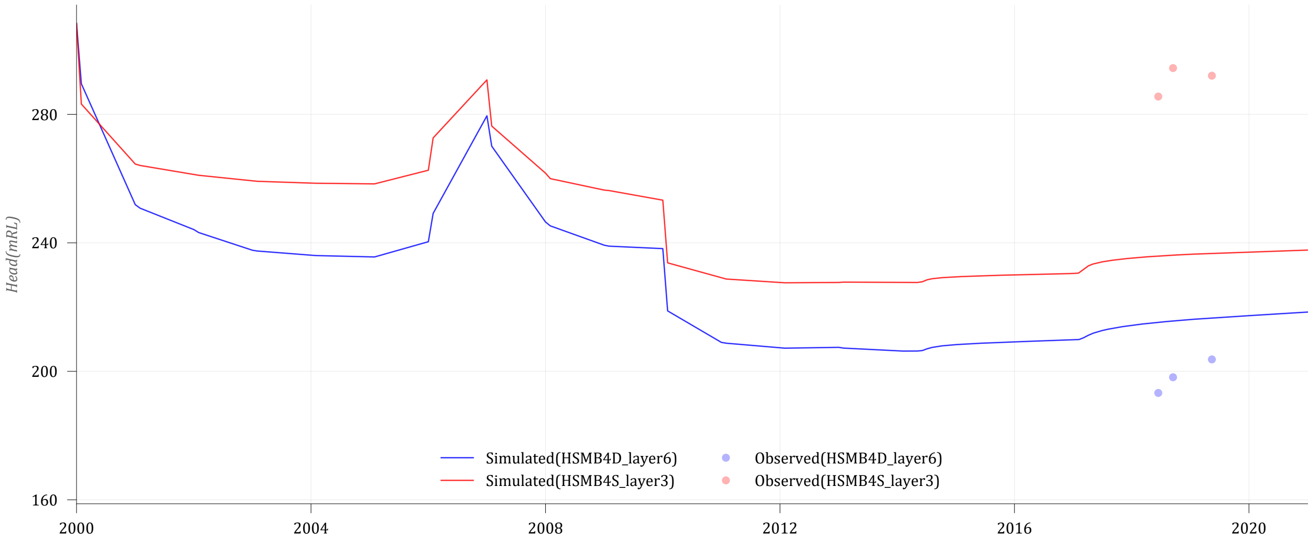

HSMB2
Head(mRL)
280
240
200
2000
2004
2008
2012
2016
2020
Simulated(HSMB2D_layer6)
Simulated(HSMB2S_layer3)
Observed(HSMB2D_layer6)
Observed(HSMB2S_layer3)


HSMB3_1
Head(mRL)
310
300
290
280
270
260
250
240
230
220
210
200
190
2000
2004
2008
2012
2016
2020
Simulated(HSMB3D1_layer6)
Simulated(HSMB3S1_layer3)
Observed(HSMB3D1_layer6)
Observed(HSMB3S1_layer3)

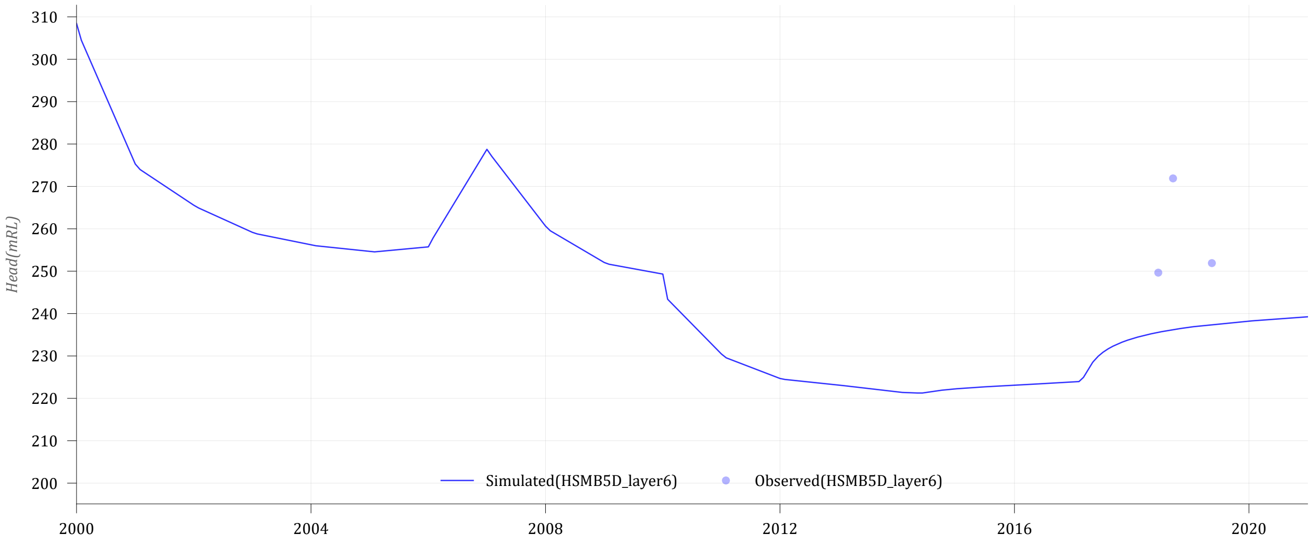
HSMB3_2

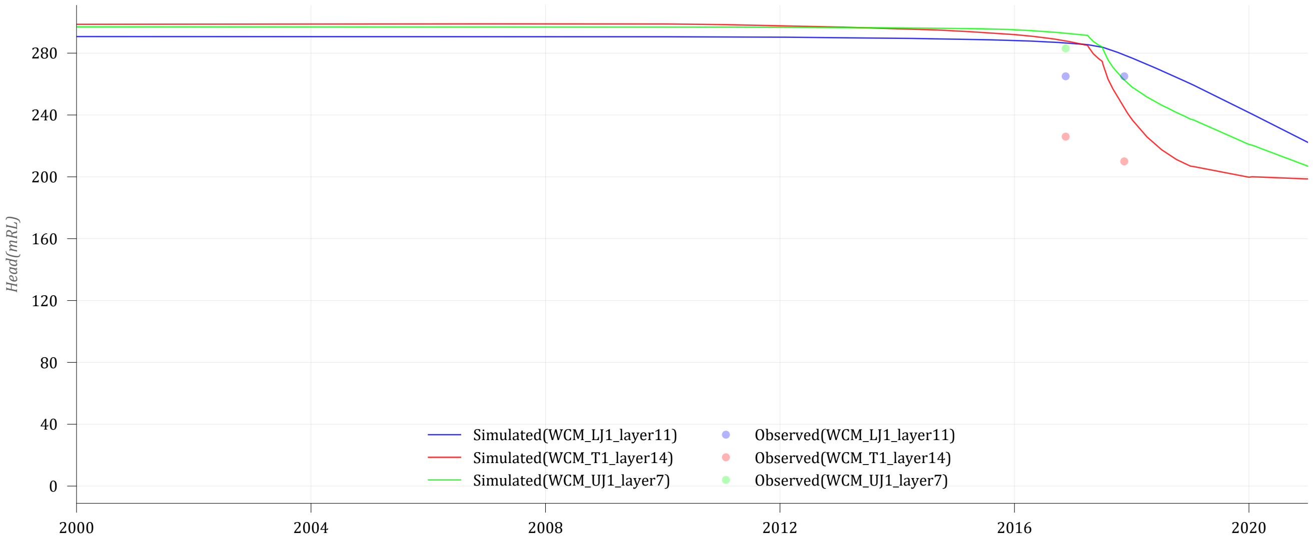


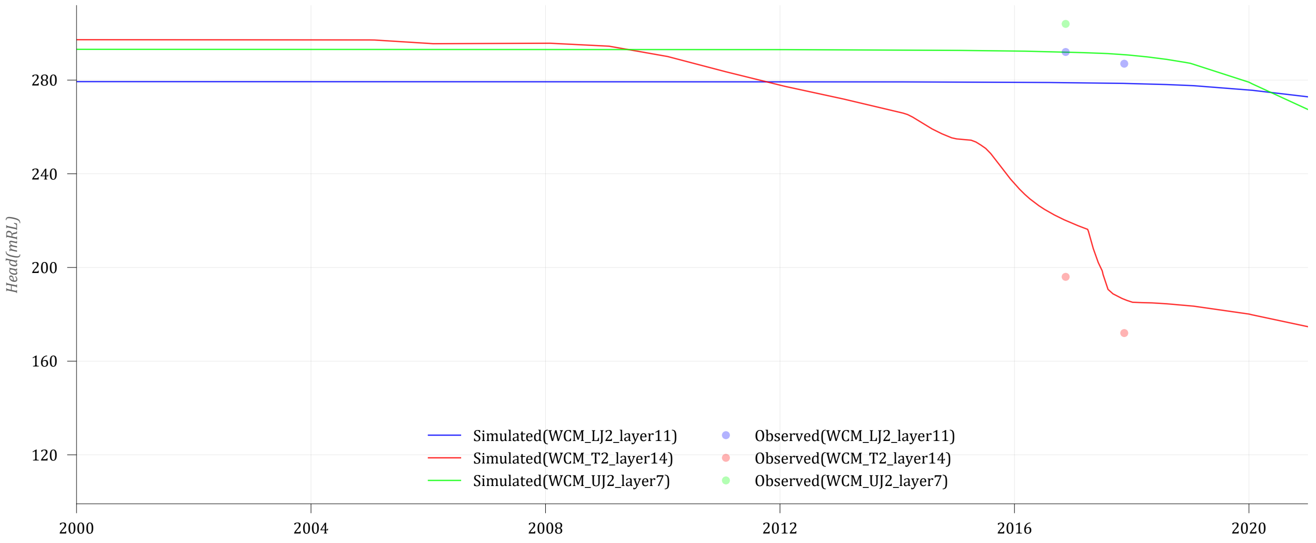
HSMB4

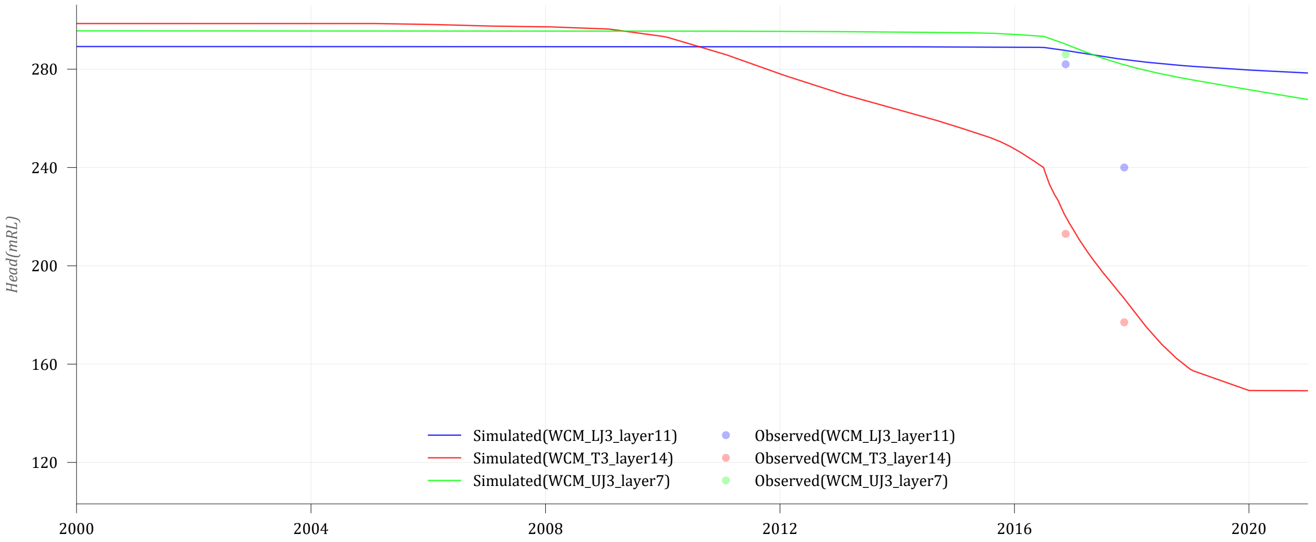


HSMB5D

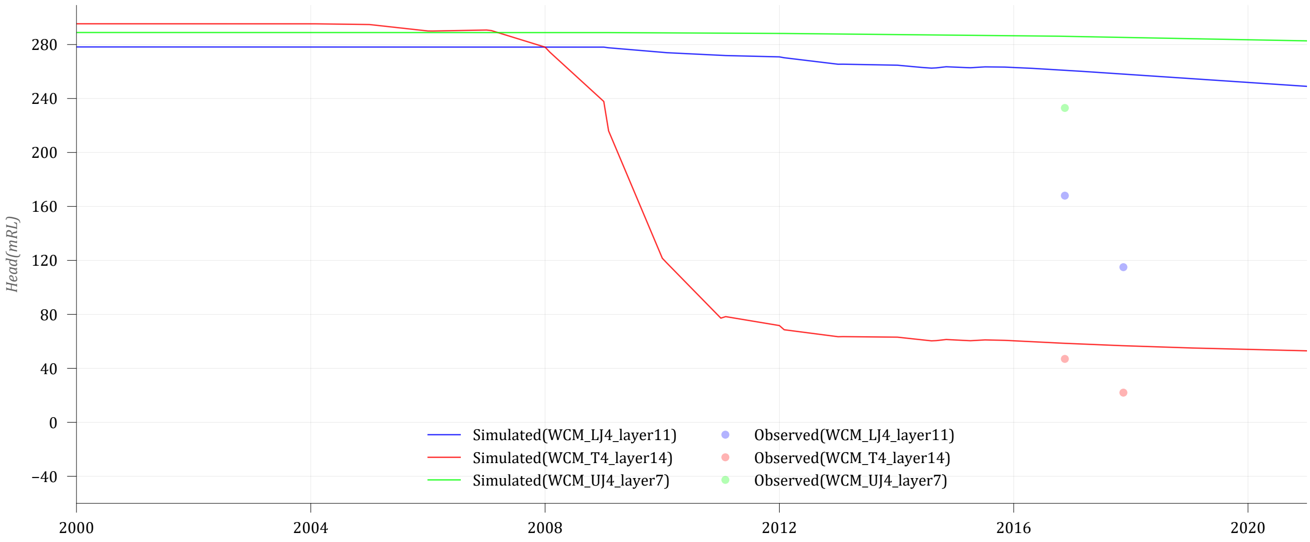



WCM1

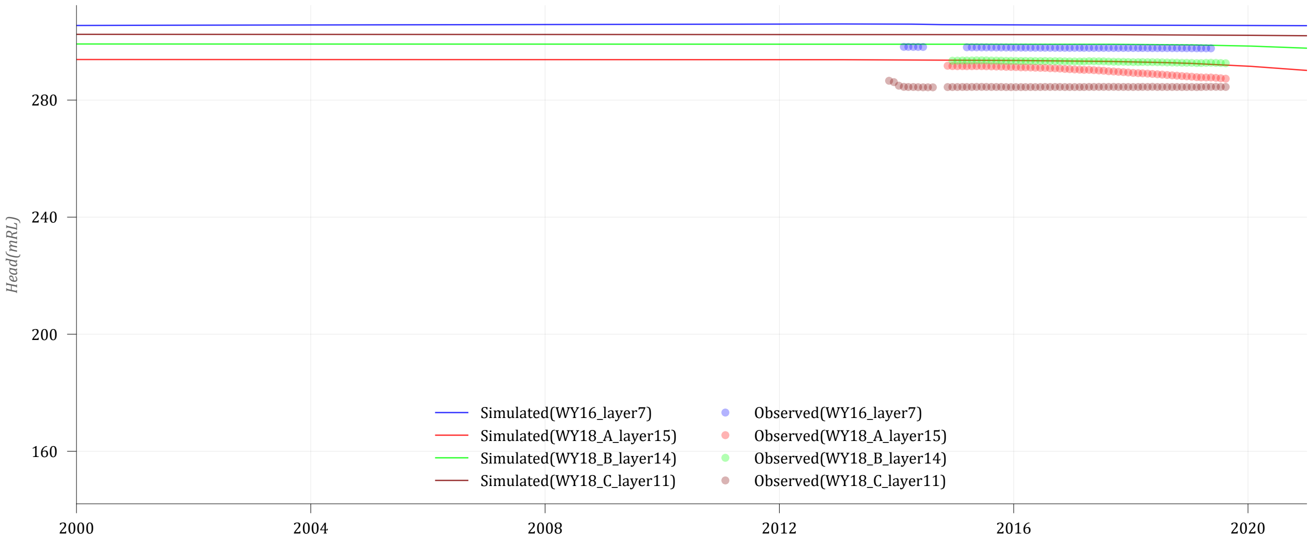

WCM2


WCM3

WCM4


Head(mRL)
280
240
200
160
120
80
40
0
−40
2000
2004
2008
2012
2016
2020
Simulated(WCM_LJ4_layer11)
Simulated(WCM_T4_layer14)
Simulated(WCM_UJ4_layer7)
Observed(WCM_LJ4_layer11)
Observed(WCM_T4_layer14)
Observed(WCM_UJ4_layer7)

WYALLA


Head(mRL)
280
240
200
160
2000
2004
2008
2012
2016
2020
Simulated(WY16_layer7)
Simulated(WY18_A_layer15)
Simulated(WY18_B_layer14)
Simulated(WY18_C_layer11)
Observed(WY16_layer7)
Observed(WY18_A_layer15)
Observed(WY18_B_layer14)
Observed(WY18_C_layer11)

Appendix C Phase 2 contaminant transport model calibration

Initial Concentrations in June 2018

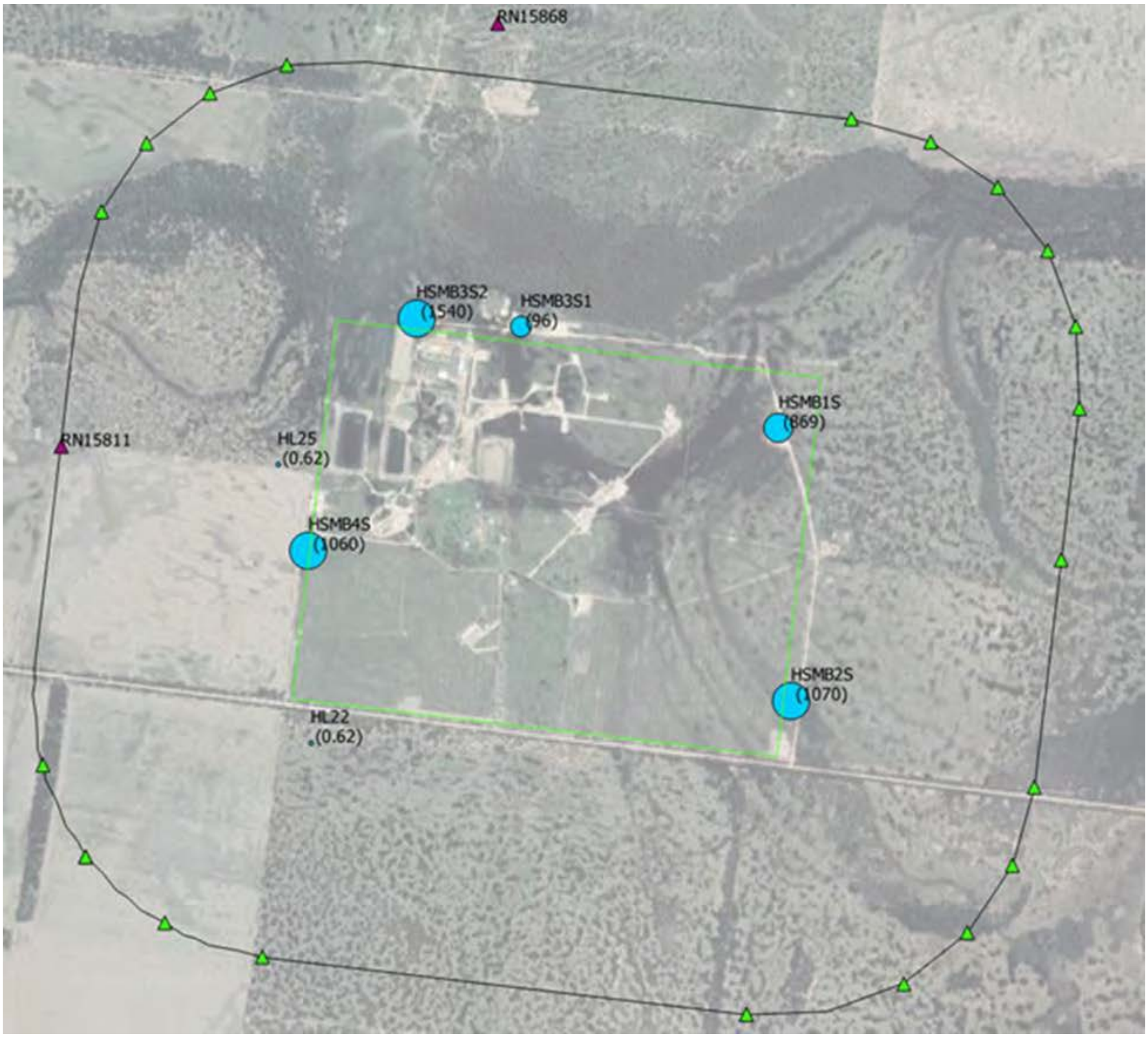


Figure C 1 Initial Benzene concentrations in Springbok

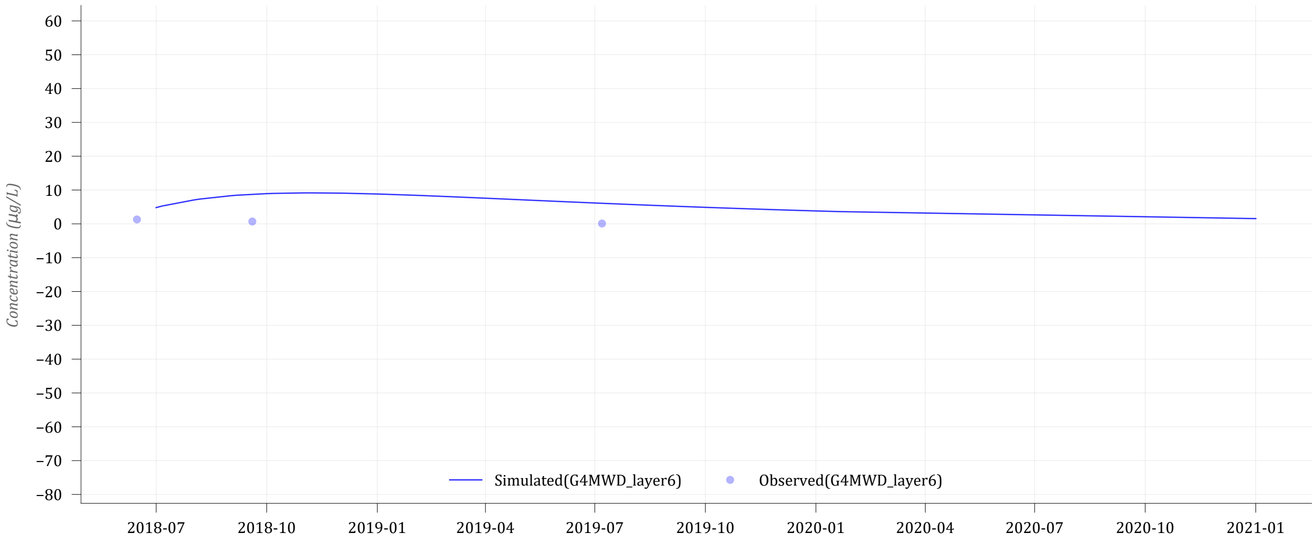
Figure C 2 Initial Benzene concentrations in Macalister

Figure C 3 Initial Naphthalene concentrations in Springbok

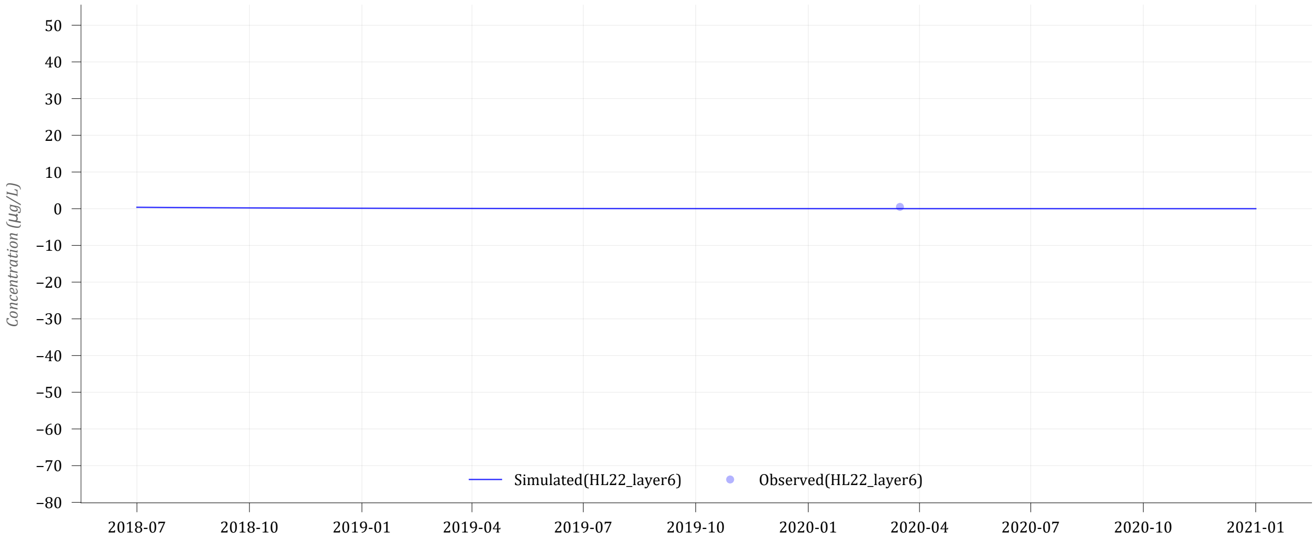
Figure C 4 Initial Naphthalene concentrations in Macalister

Appendix C 1 Modelled versus observed concentration time series plots - Naphthlene

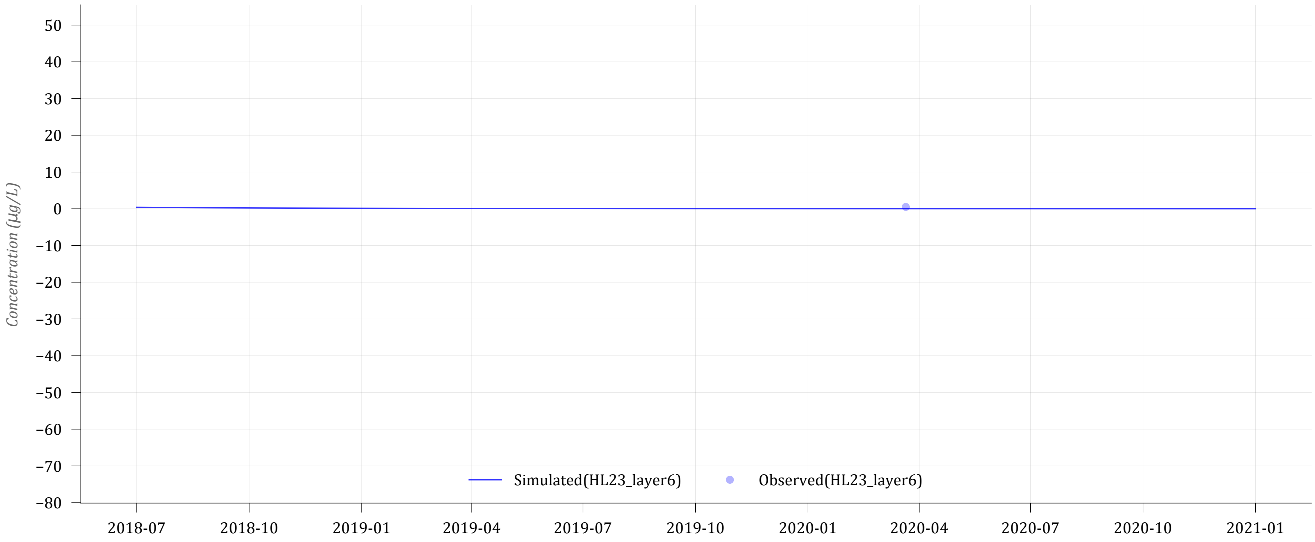
G4MWD



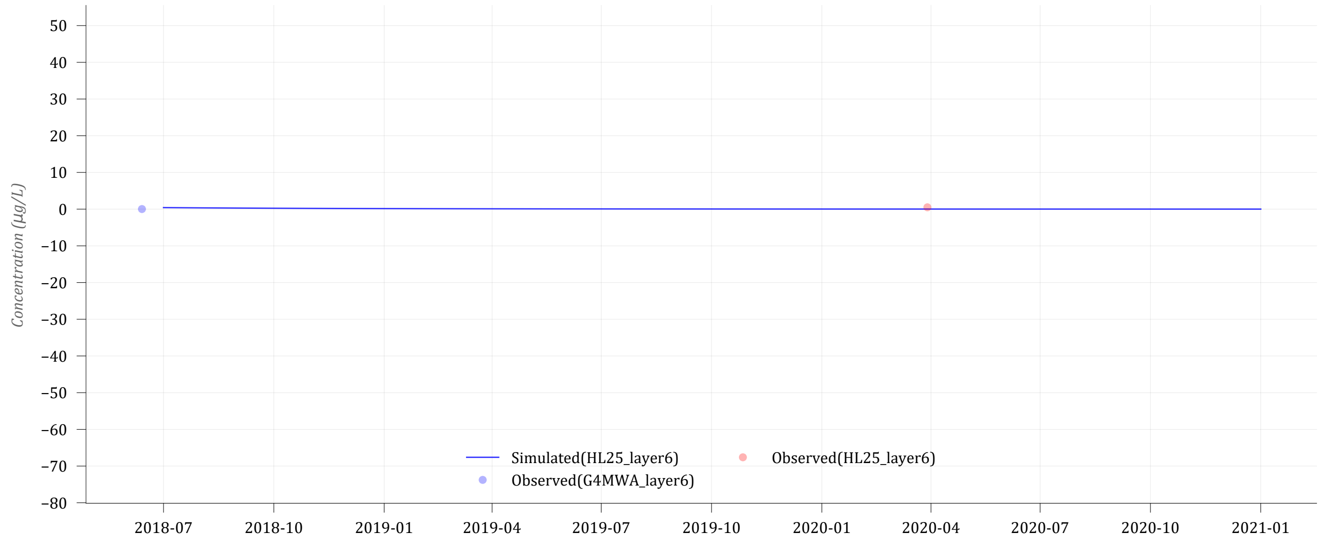
HL22



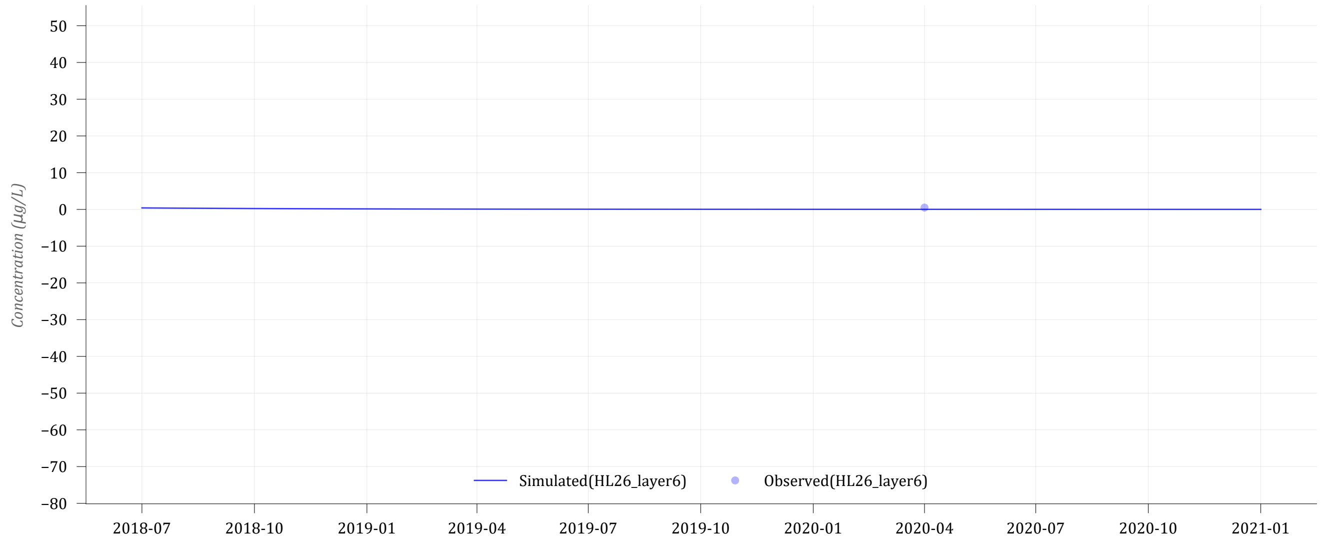
HL23



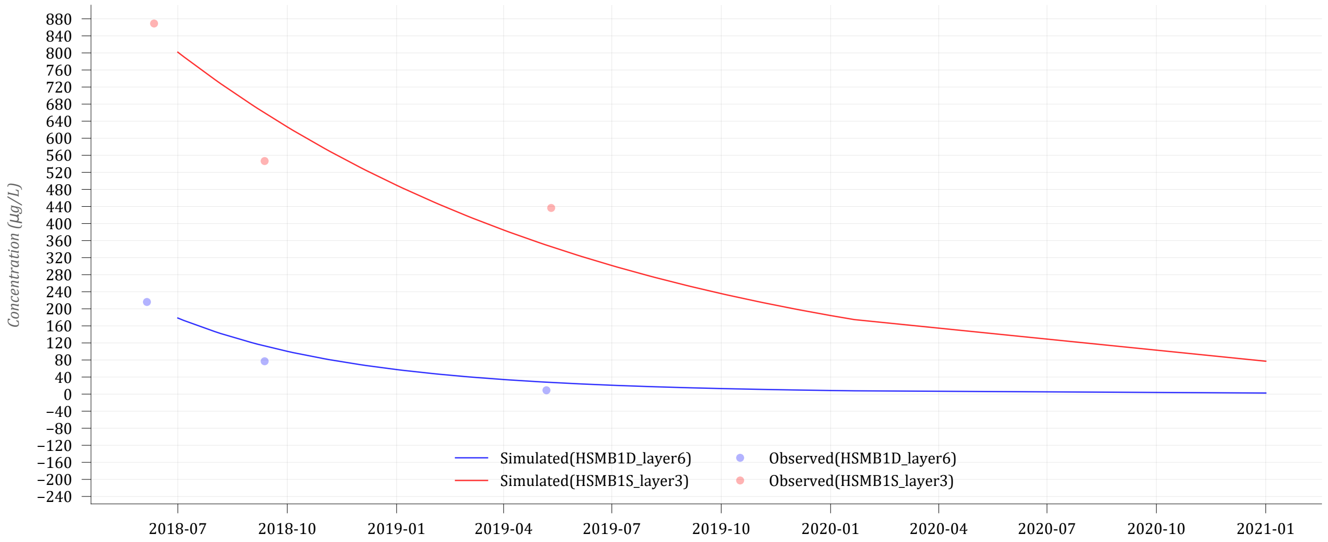
HL25

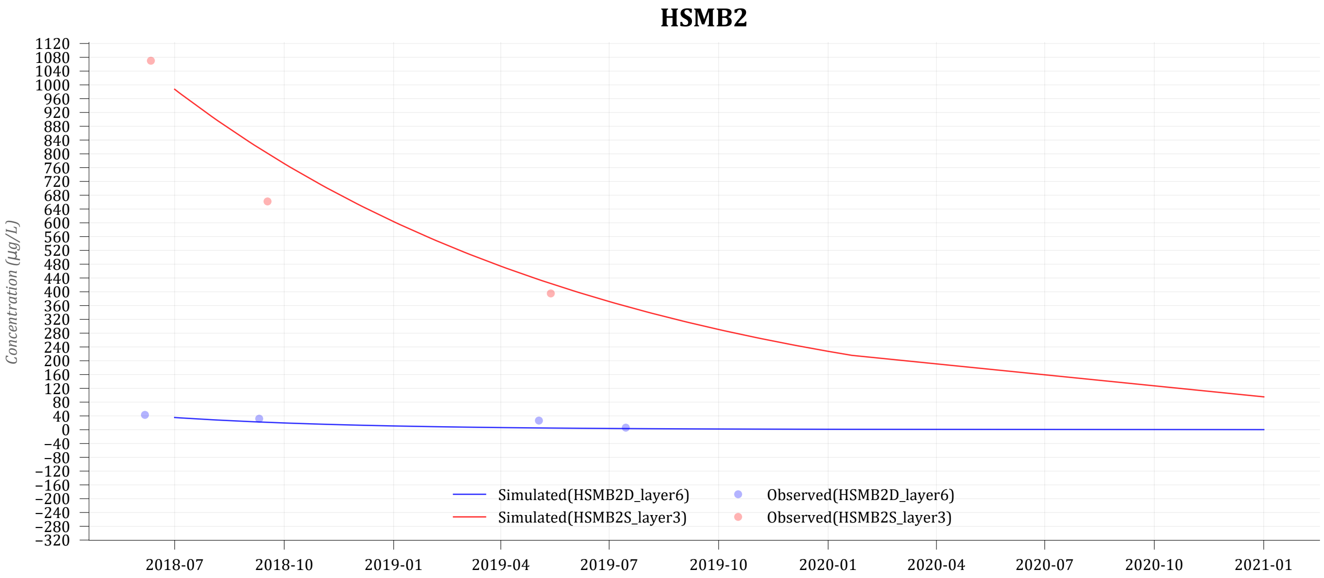


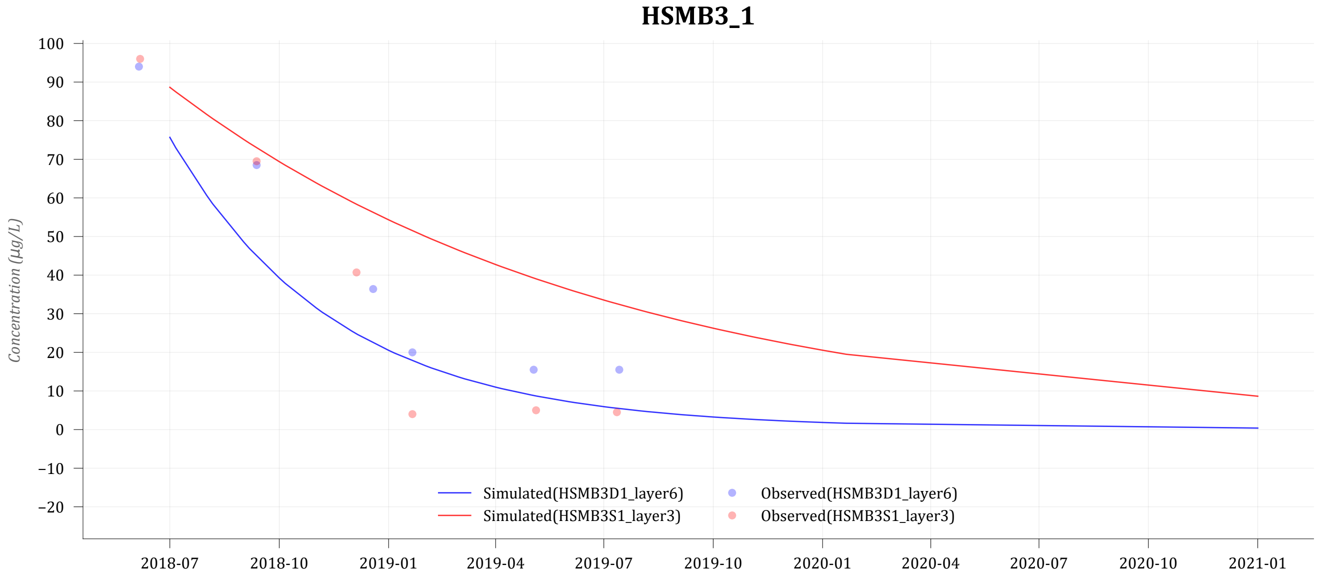
HL26

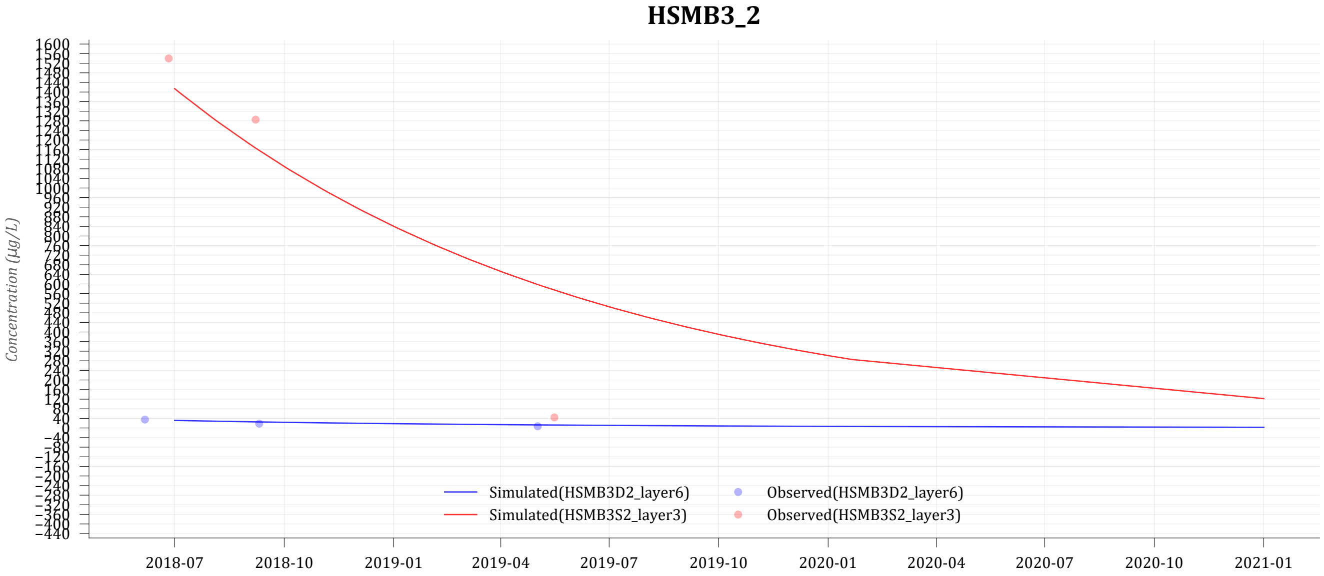


HSMB1

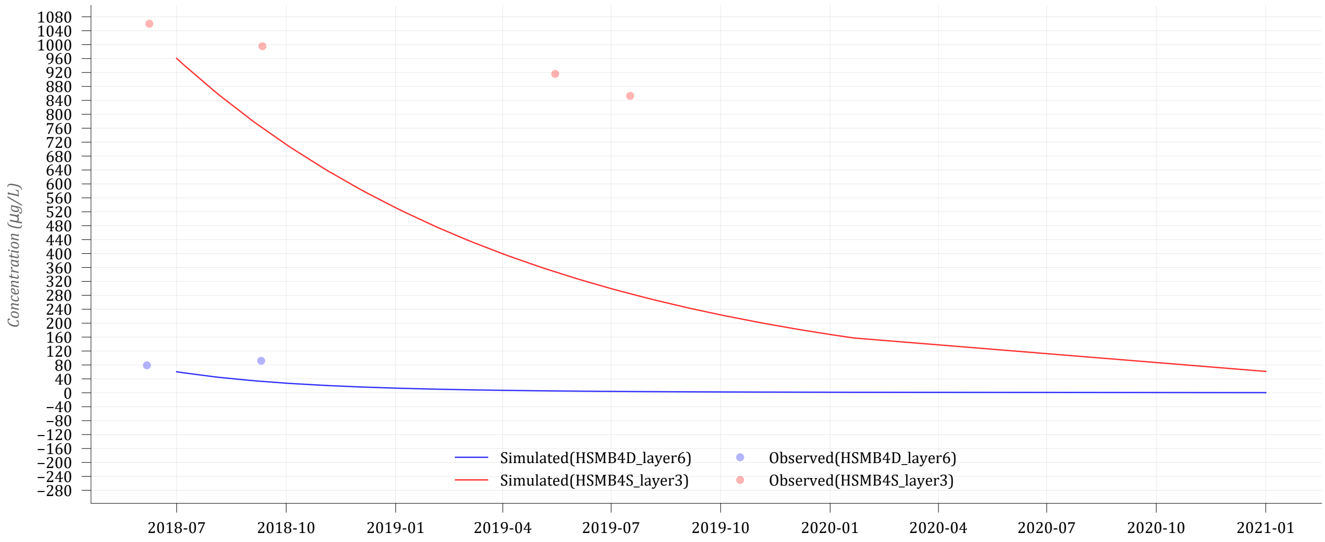



HSMB2
Concentration (µg/L)
1120
1080
1040
1000
960
920
880
840
800
760
720
680
640
600
560
520
480
440
400
360
320
280
240
200
160
120
80
40
0
−40
−80
−120
−160
−200
−240
−280
−320
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB2D_layer6)
Simulated(HSMB2S_layer3)
Observed(HSMB2D_layer6)
Observed(HSMB2S_layer3)

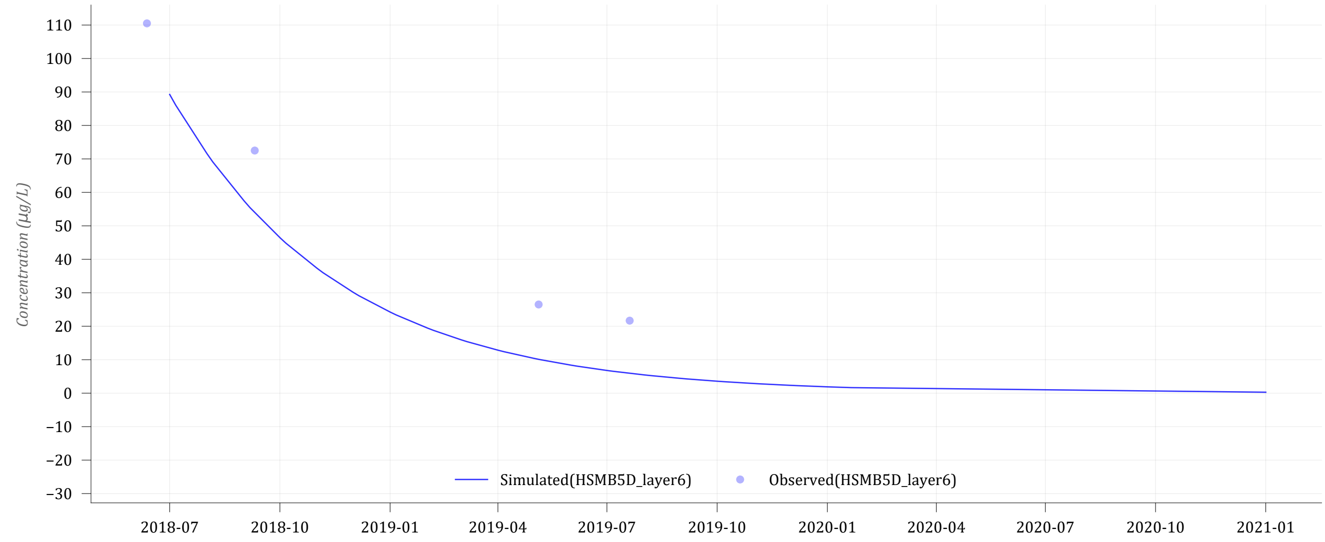

HSMB3_1
Concentration (µg/L)
100
90
80
70
60
50
40
30
20
10
0
−10
−20
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB3D1_layer6)
Simulated(HSMB3S1_layer3)
Observed(HSMB3D1_layer6)
Observed(HSMB3S1_layer3)


HSMB3_2
Concentration (µg/L)
1600
1560
1520
1480
1440
1400
1360
1320
1280
1240
1200
1160
1120
1080
1040
1000
960
920
880
840
800
760
720
680
640
600
560
520
480
440
400
360
320
280
240
200
160
120
80
40
0
−40
−80
−120
−160
−200
−240
−280
−320
−360
−400
−440
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB3D2_layer6)
Simulated(HSMB3S2_layer3)
Observed(HSMB3D2_layer6)
Observed(HSMB3S2_layer3)

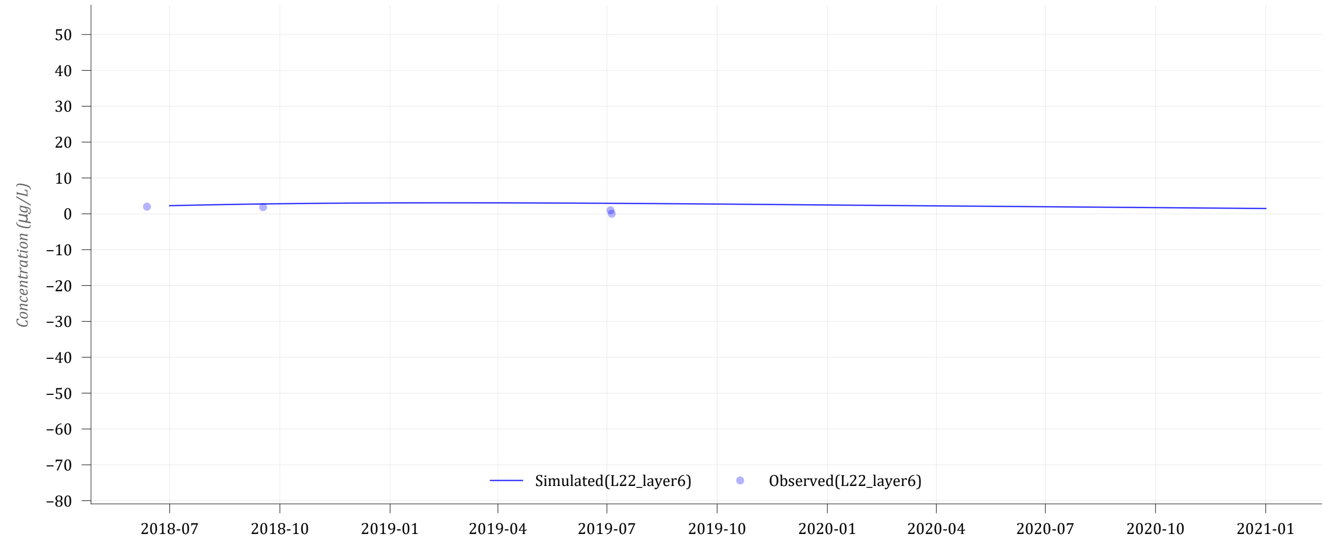
HSMB4



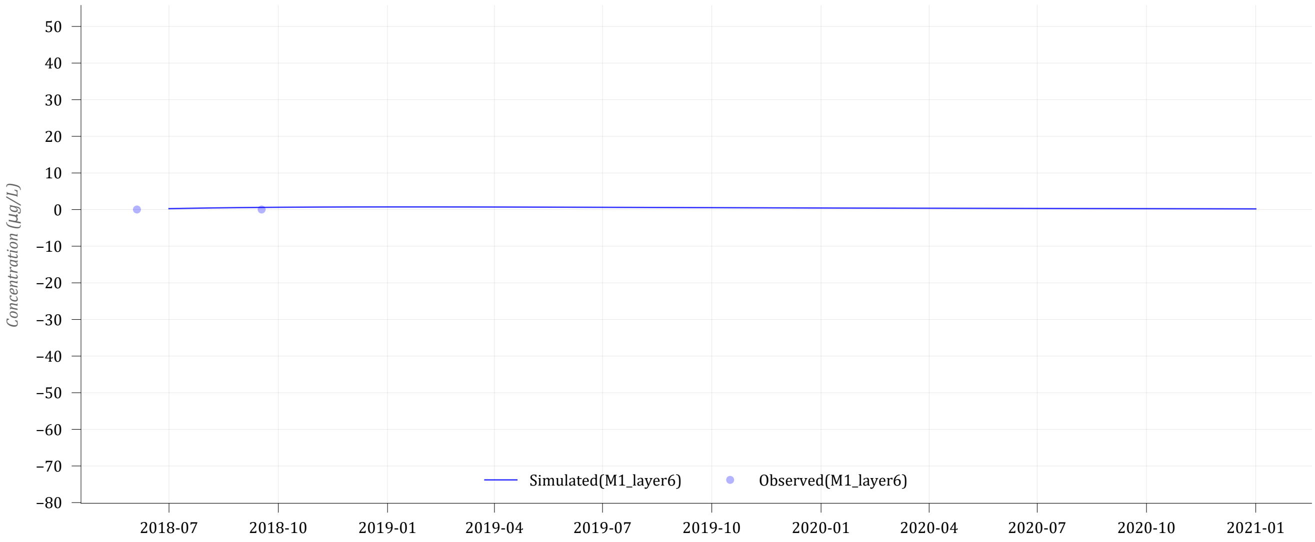
HSMB5D



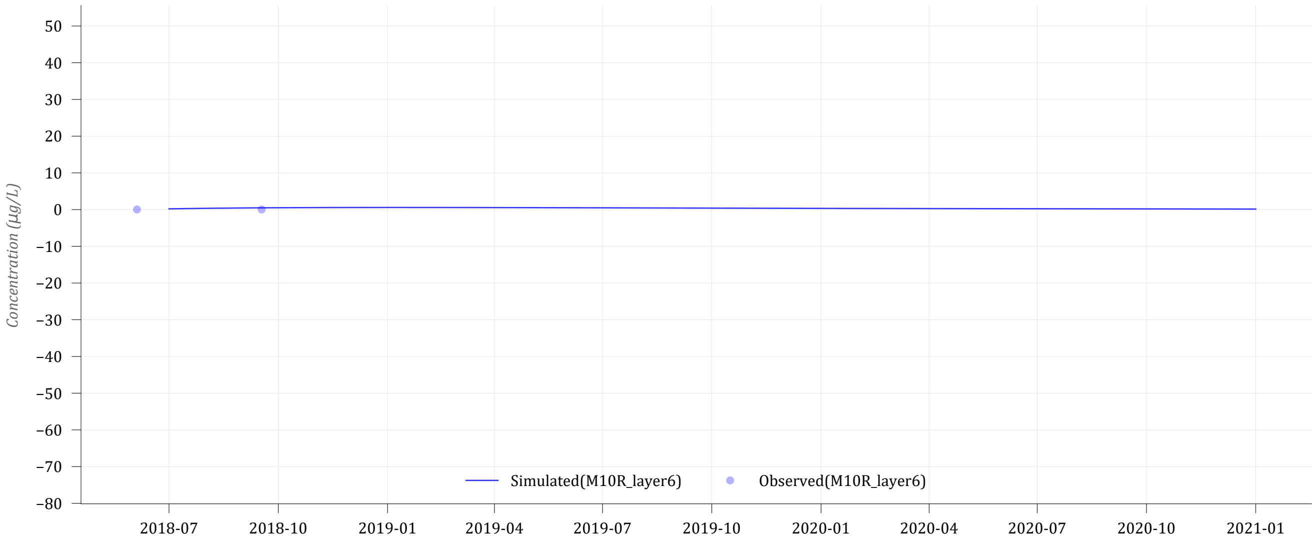
L22



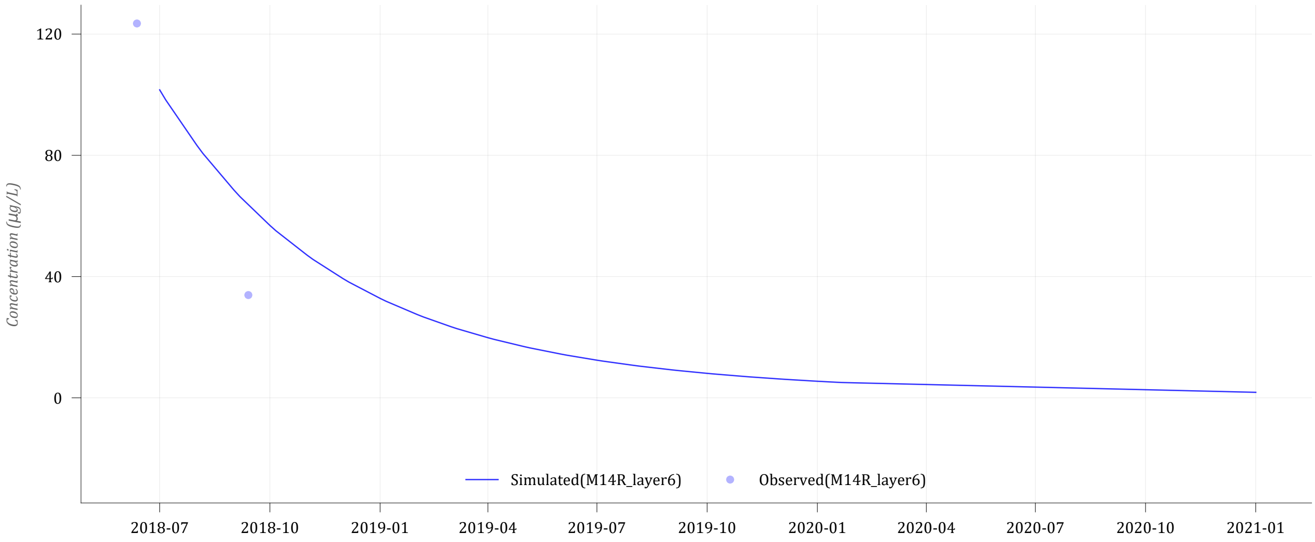
M1


Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M1_layer6)
Observed(M1_layer6)

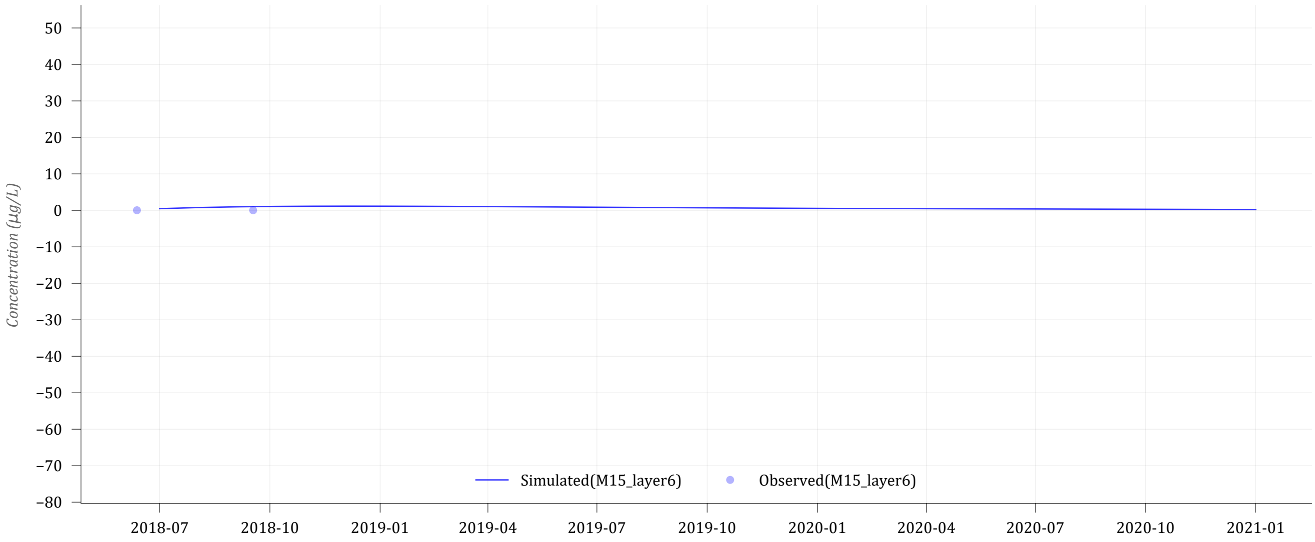
M10R


Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M10R_layer6)
Observed(M10R_layer6)

M14R

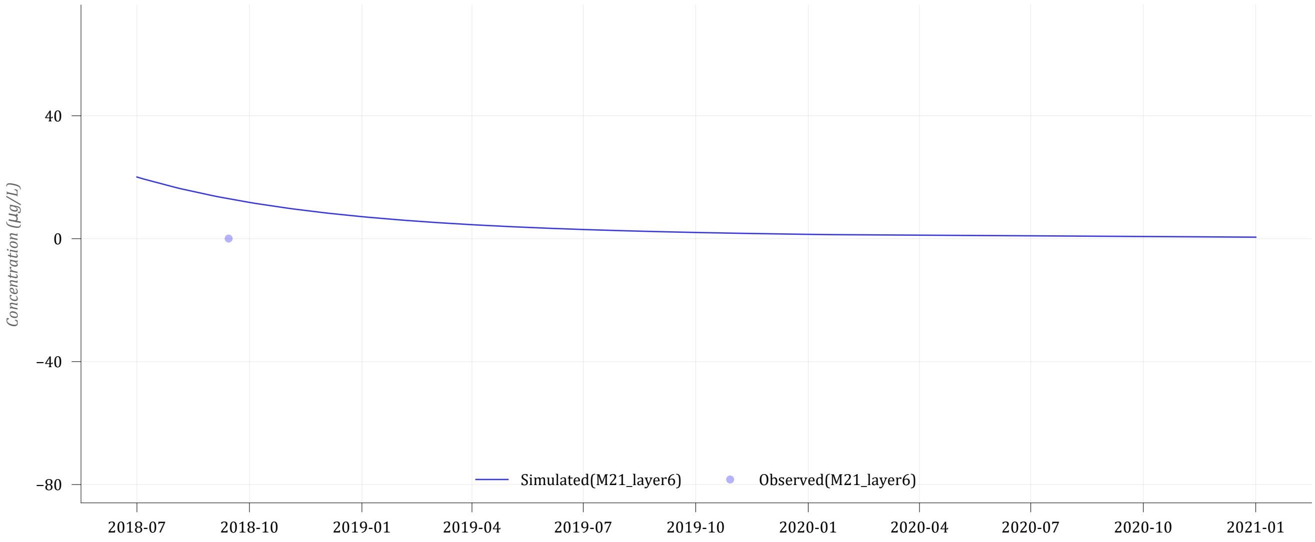

Concentration (µg/L)
120
80
40
0
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M14R_layer6)
Observed(M14R_layer6)

M15



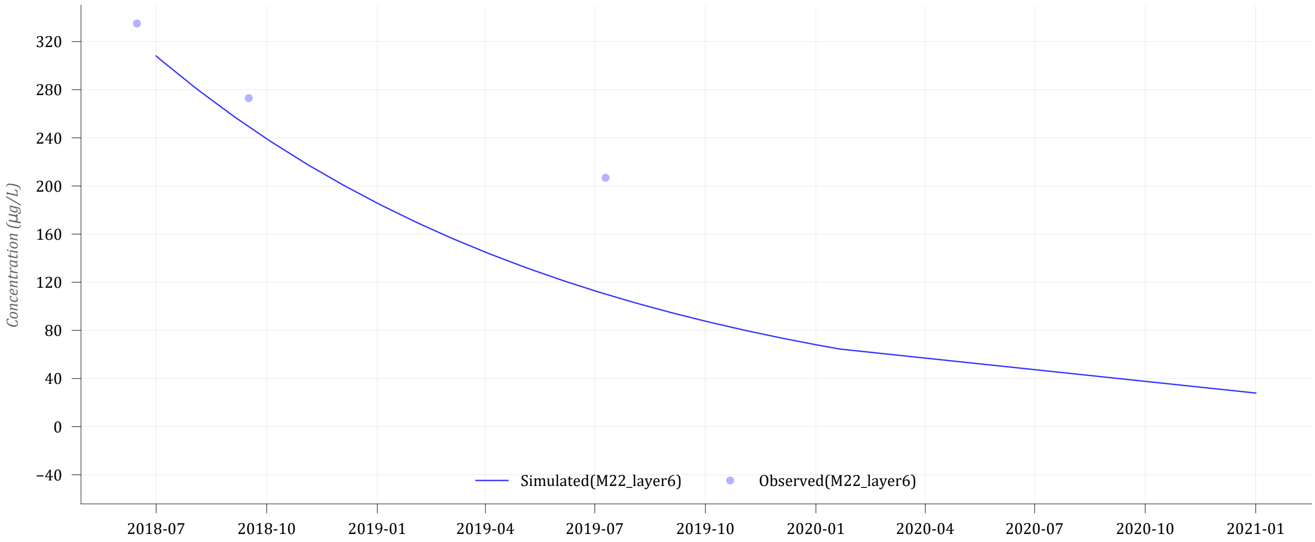
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M15_layer6)
Observed(M15_layer6)

M21



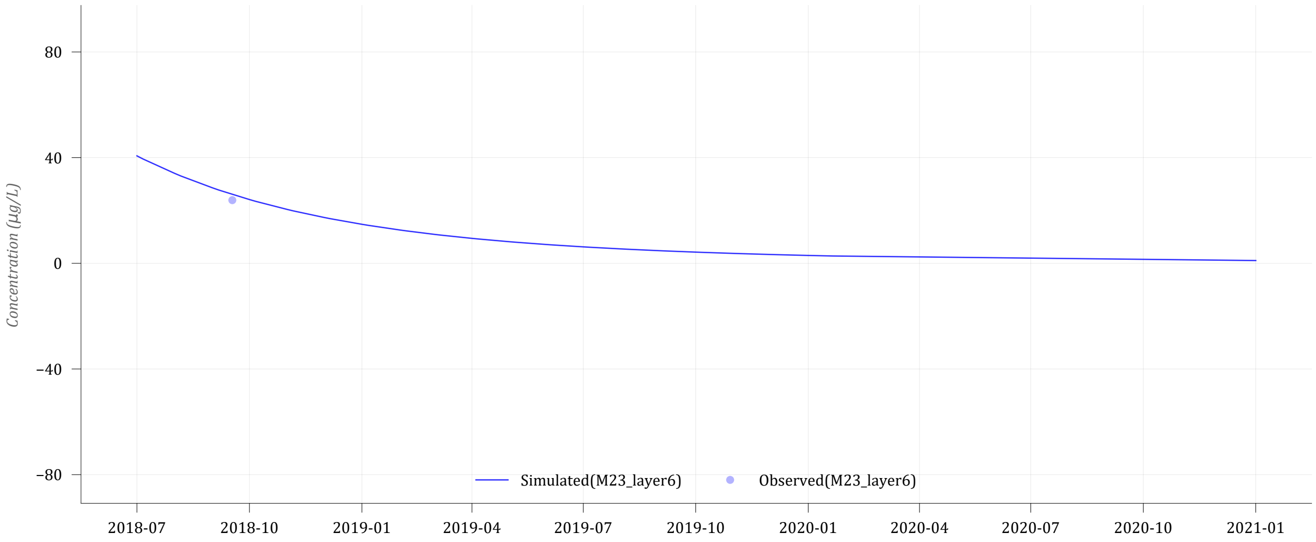
Concentration (µg/L)
40
0
−40
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M21_layer6)
Observed(M21_layer6)

M22



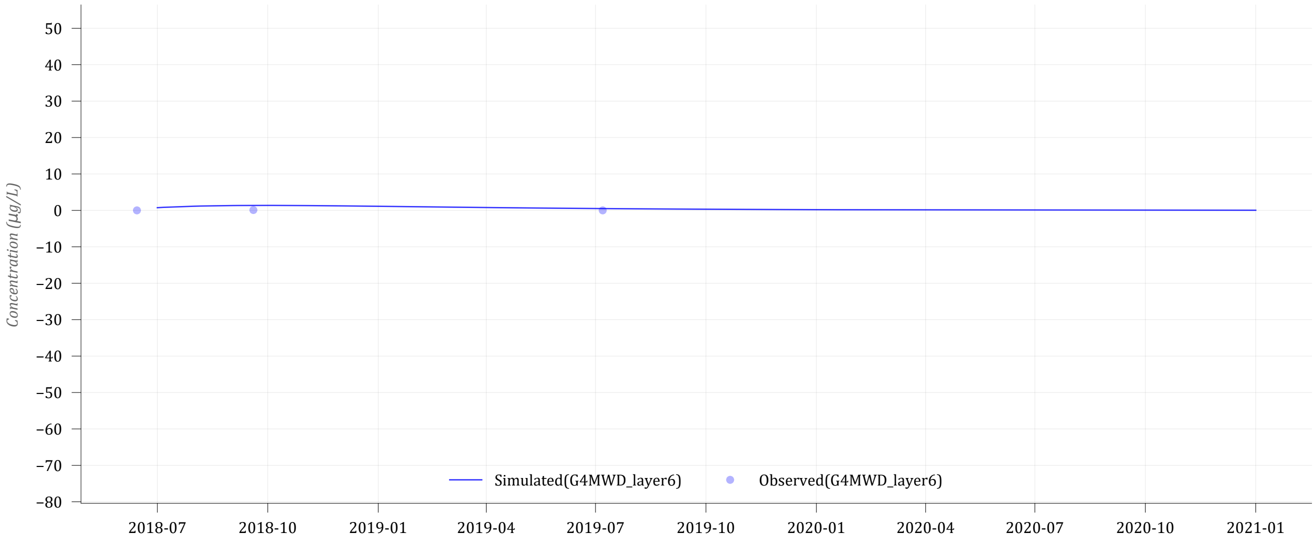
Concentration (µg/L)
320
280
240
200
160
120
80
40
0
−40
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M22_layer6)
Observed(M22_layer6)

M23

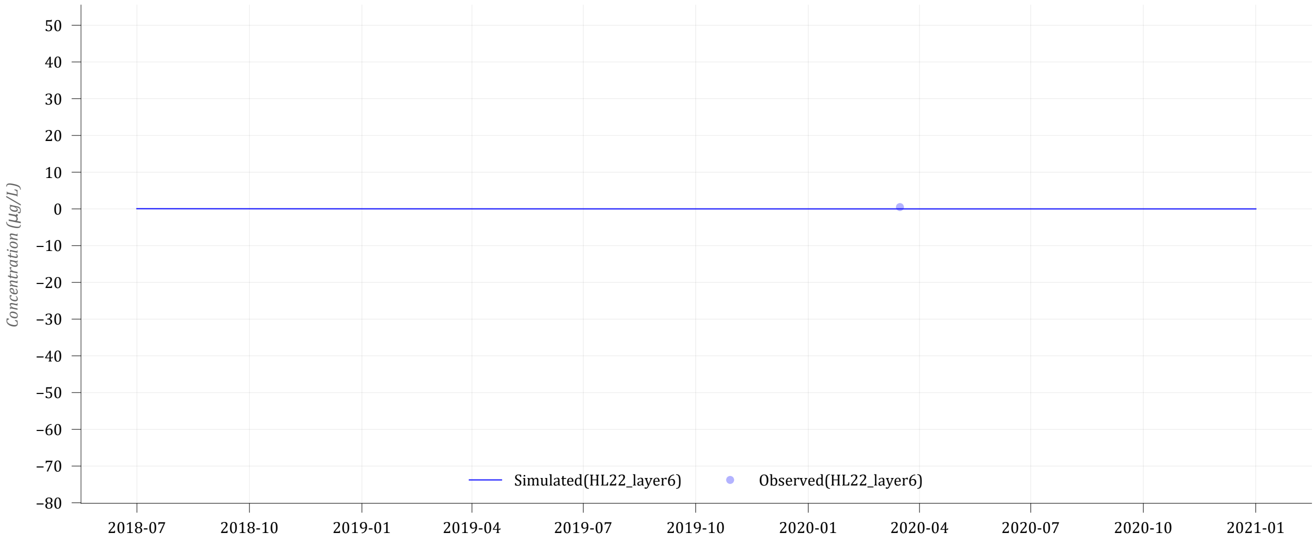

80
40
0
−40
−80
Concentration (µg/L)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M23_layer6)
Observed(M23_layer6)

Appendix C 2 Modelled versus observed concentration time series plots - Benzene

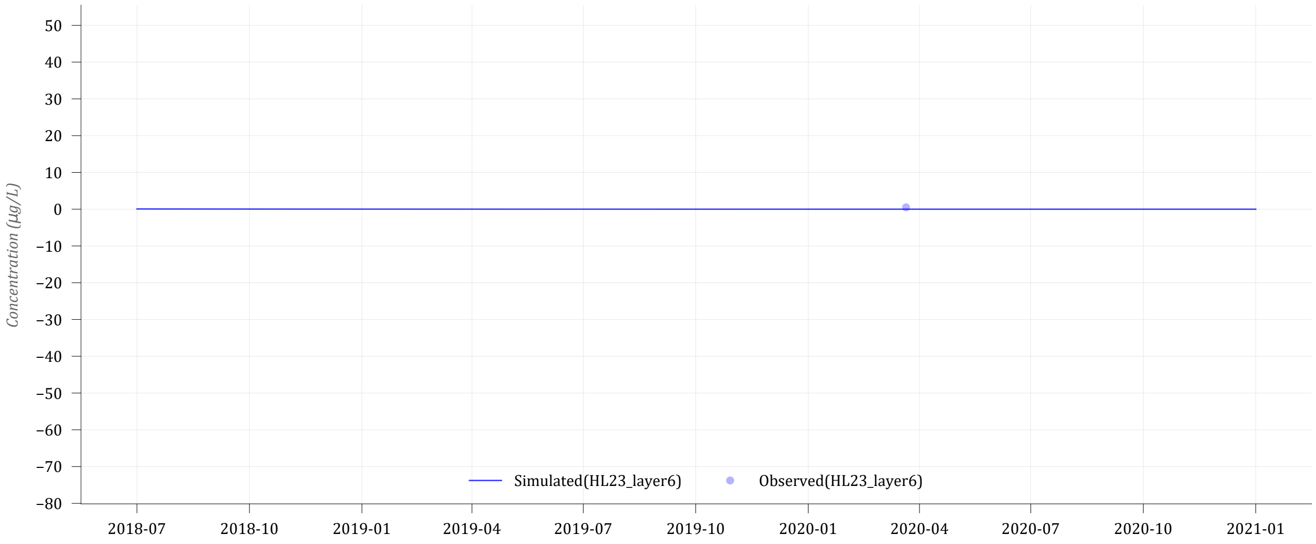
G4MWD

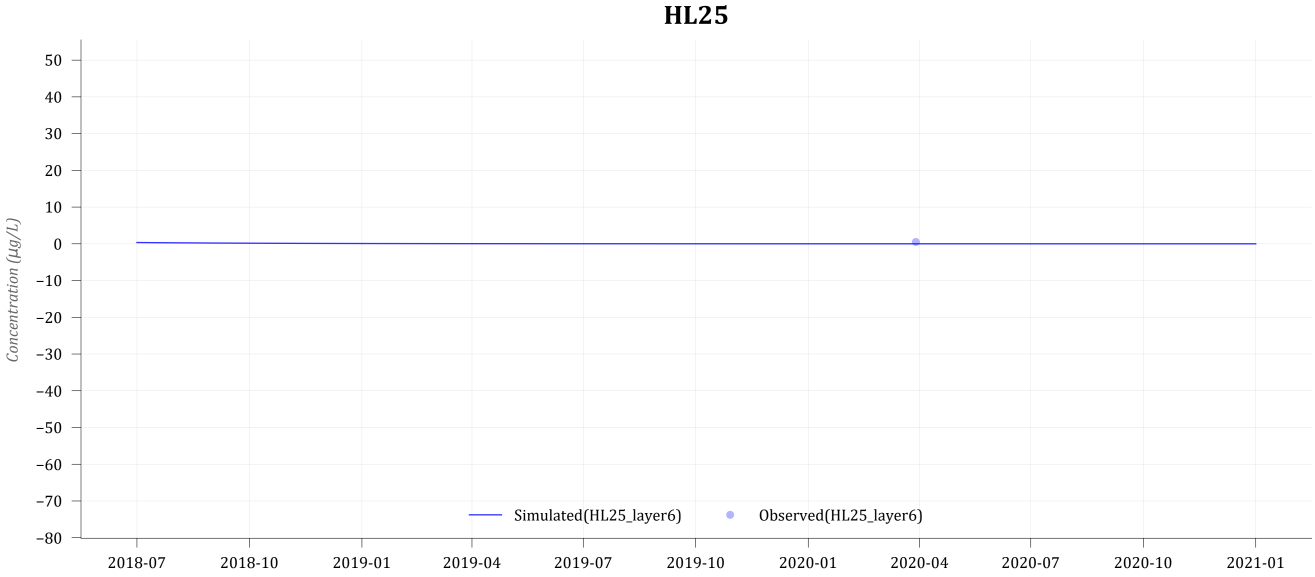


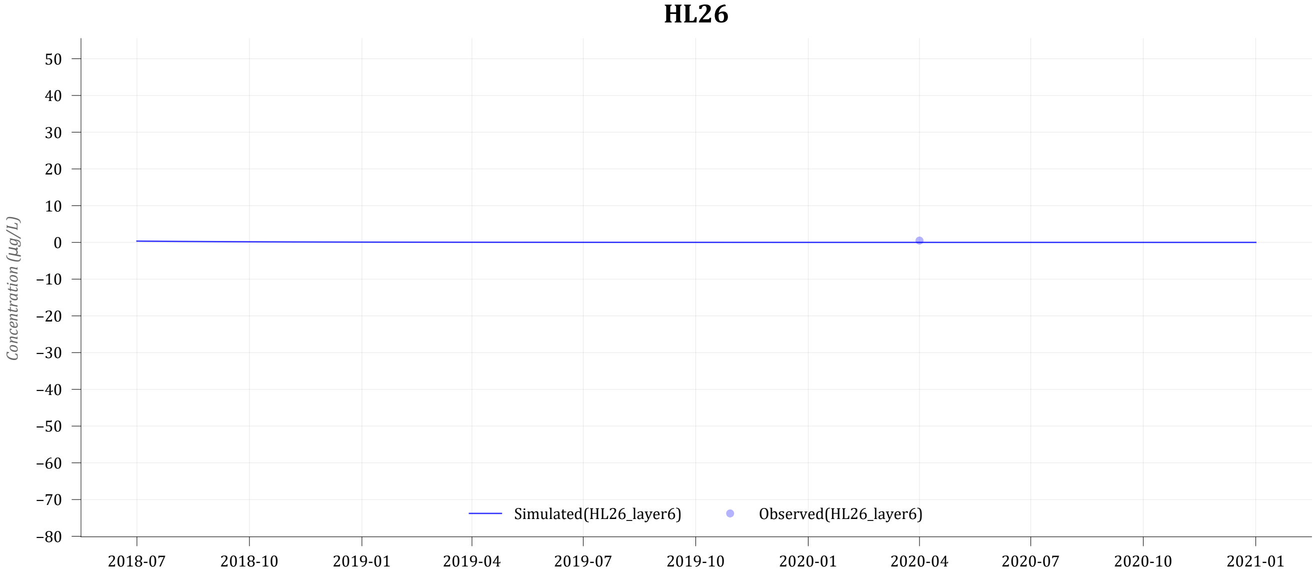
HL22

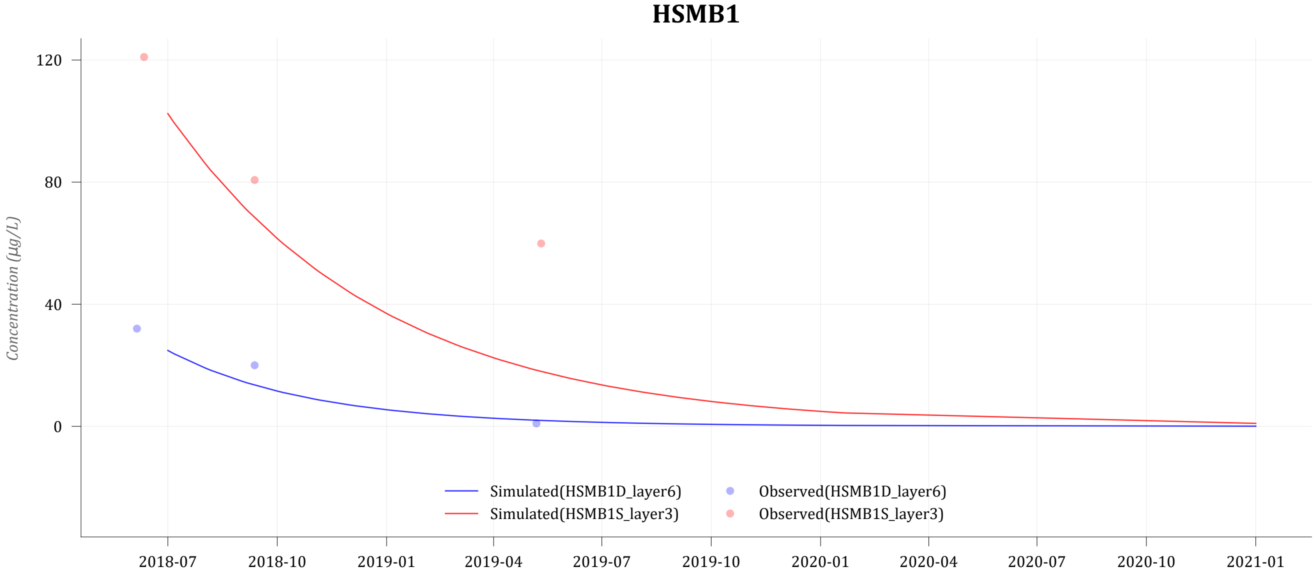


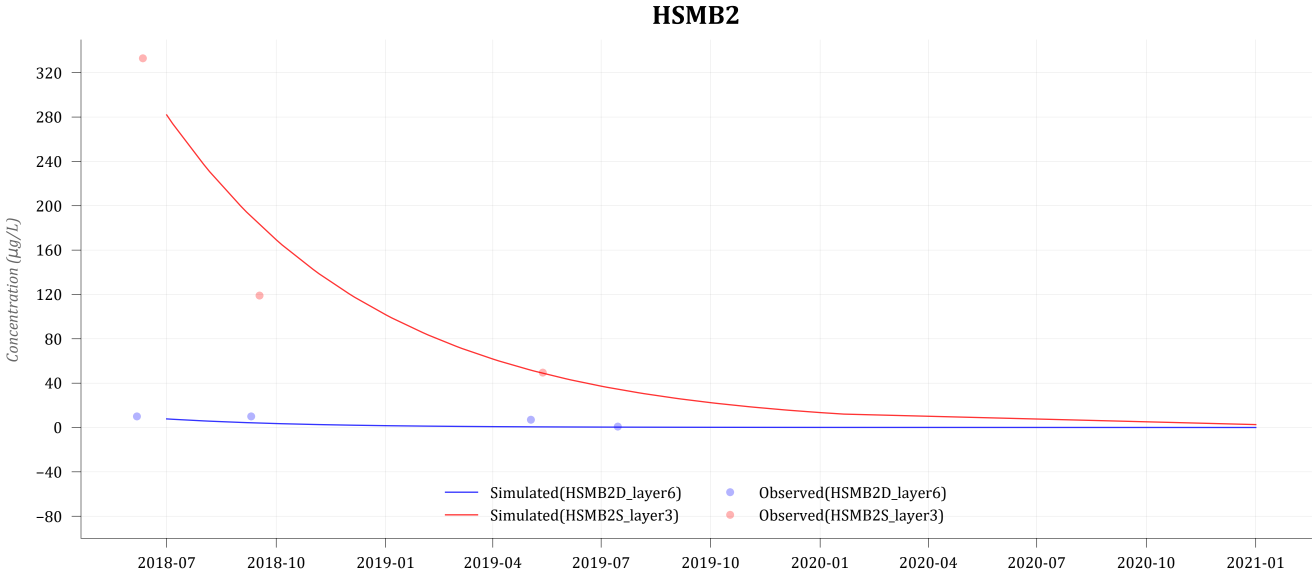
HL23

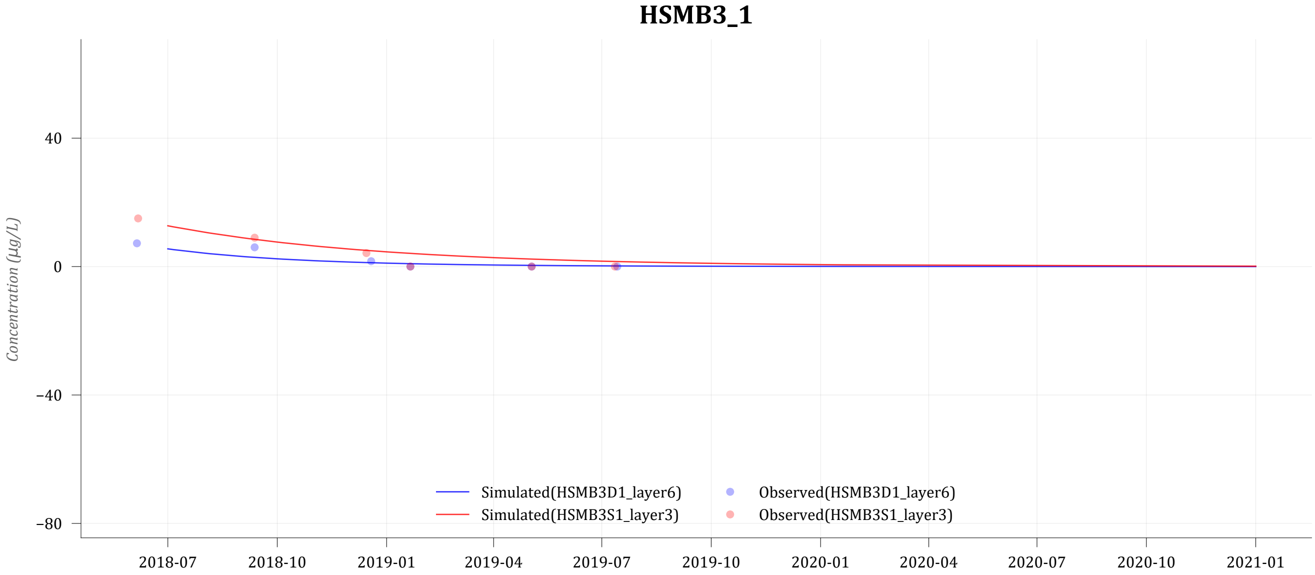


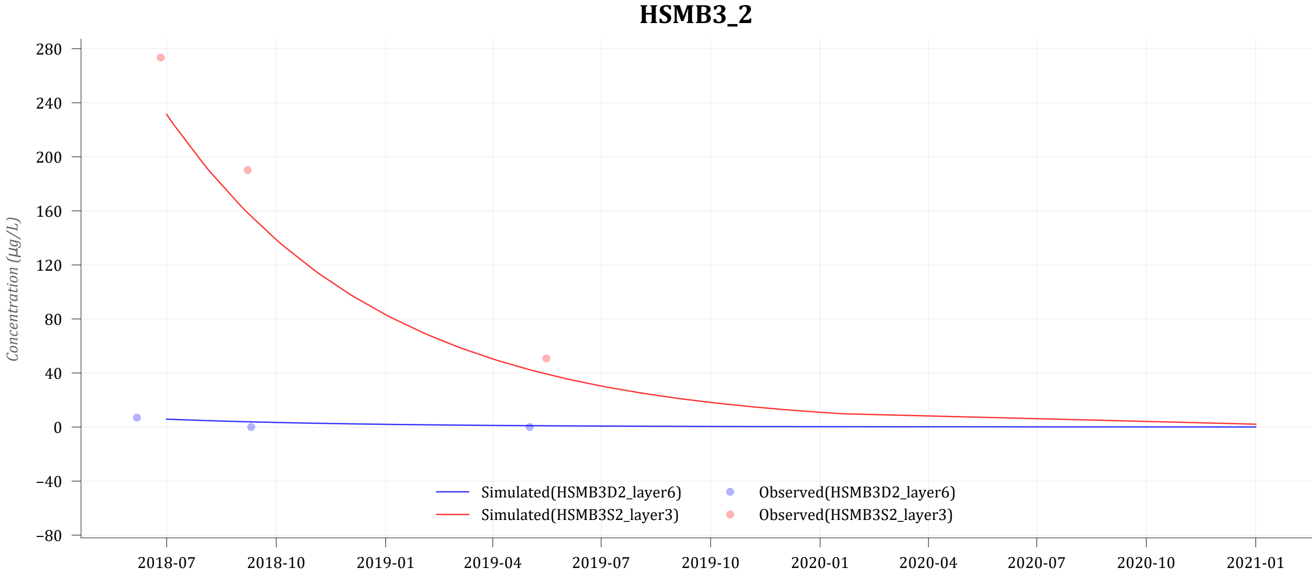

HL25
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
Simulated(HL25_layer6)
Observed(HL25_layer6)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01


HL26
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
Simulated(HL26_layer6)
Observed(HL26_layer6)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01

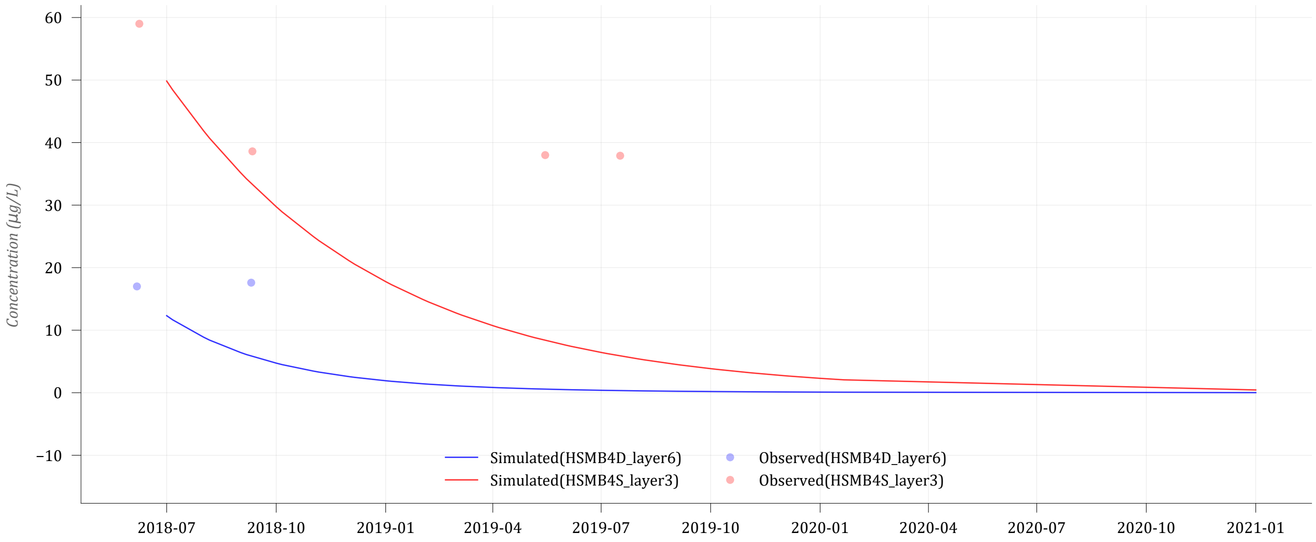

HSMB1
Concentration (µg/L)
120
80
40
0
Simulated(HSMB1D_layer6)
Simulated(HSMB1S_layer3)
Observed(HSMB1D_layer6)
Observed(HSMB1S_layer3)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01


HSMB2
Concentration (µg/L)
320
280
240
200
160
120
80
40
0
−40
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB2D_layer6)
Simulated(HSMB2S_layer3)
Observed(HSMB2D_layer6)
Observed(HSMB2S_layer3)

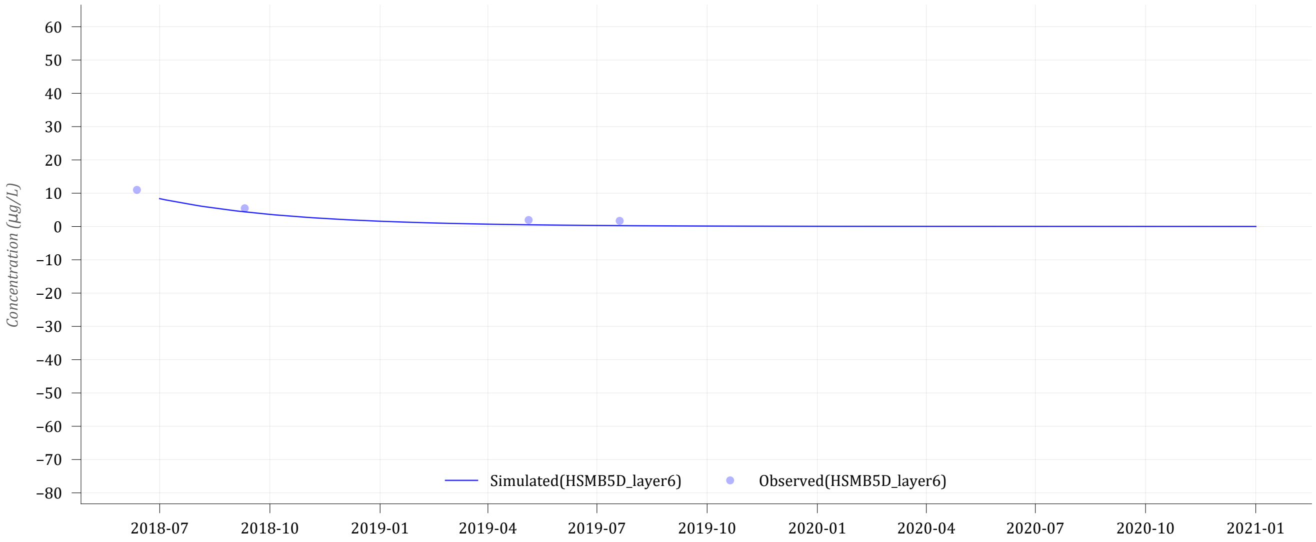

HSMB3_1
Concentration (µg/L)
40
0
−40
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB3D1_layer6)
Simulated(HSMB3S1_layer3)
Observed(HSMB3D1_layer6)
Observed(HSMB3S1_layer3)


HSMB3_2
Concentration (µg/L)
280
240
200
160
120
80
40
0
−40
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(HSMB3D2_layer6)
Simulated(HSMB3S2_layer3)
Observed(HSMB3D2_layer6)
Observed(HSMB3S2_layer3)

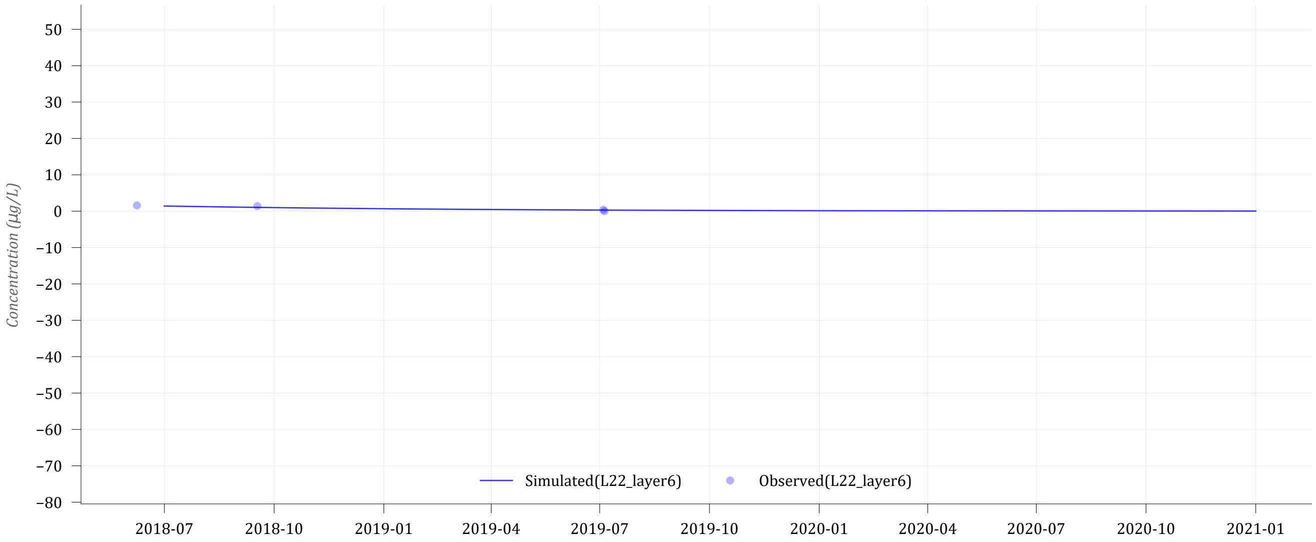
HSMB4



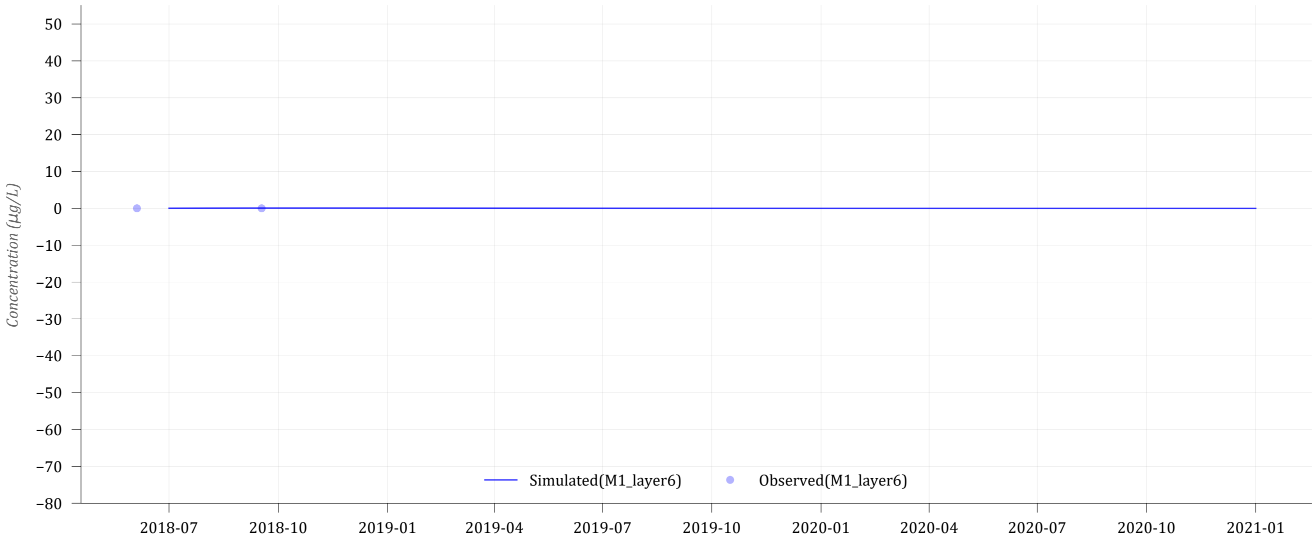
HSMB5D



L22

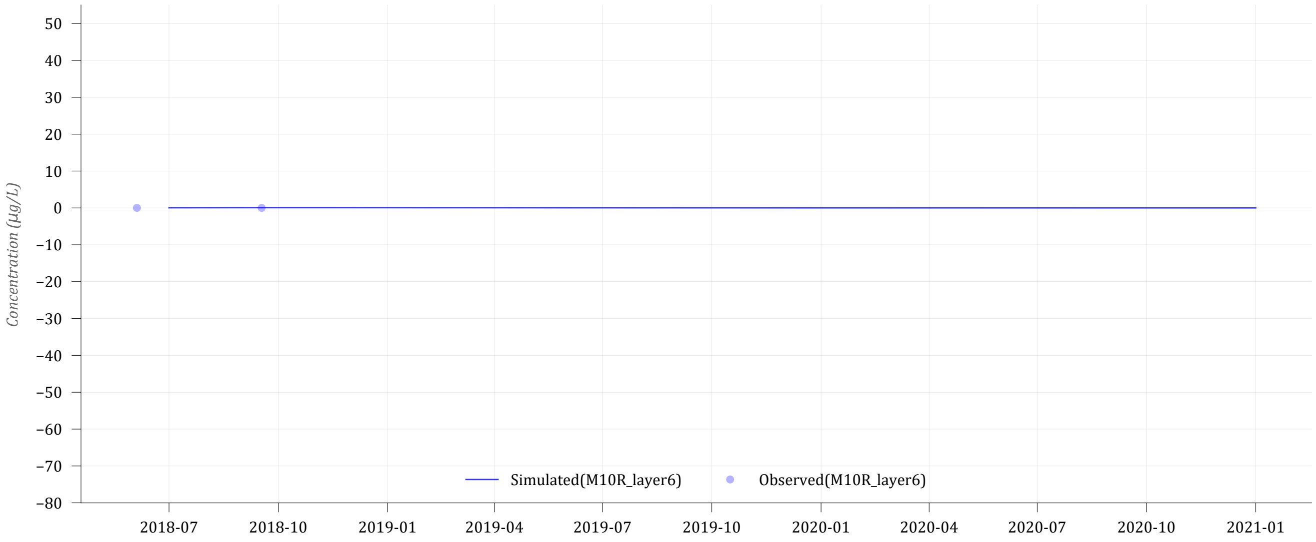


M1



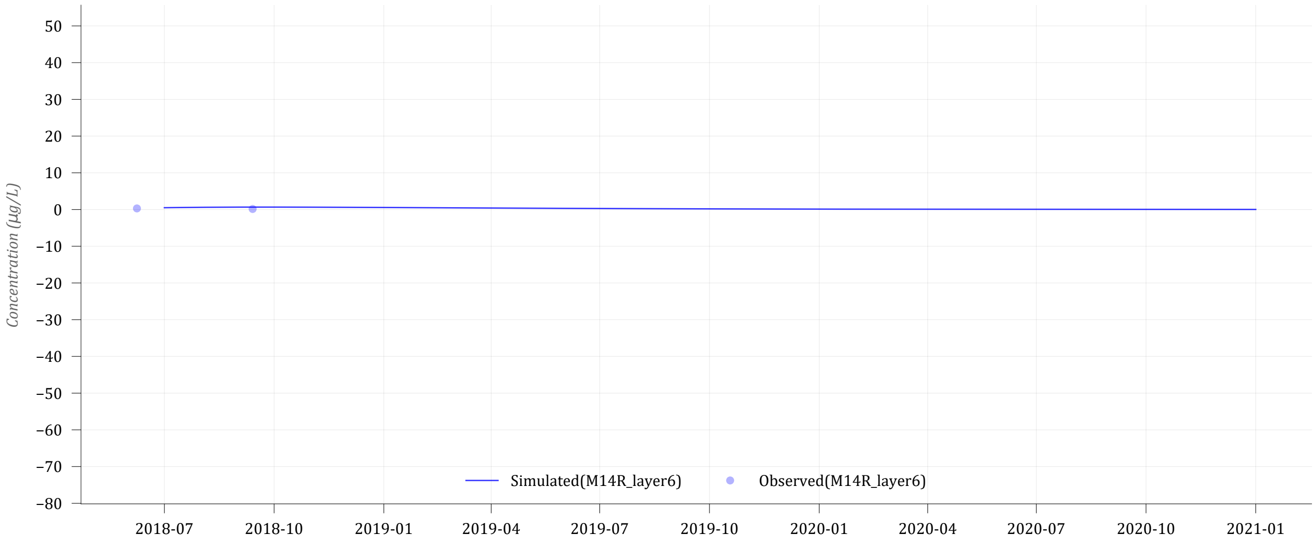
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M1_layer6)
Observed(M1_layer6)

M10R

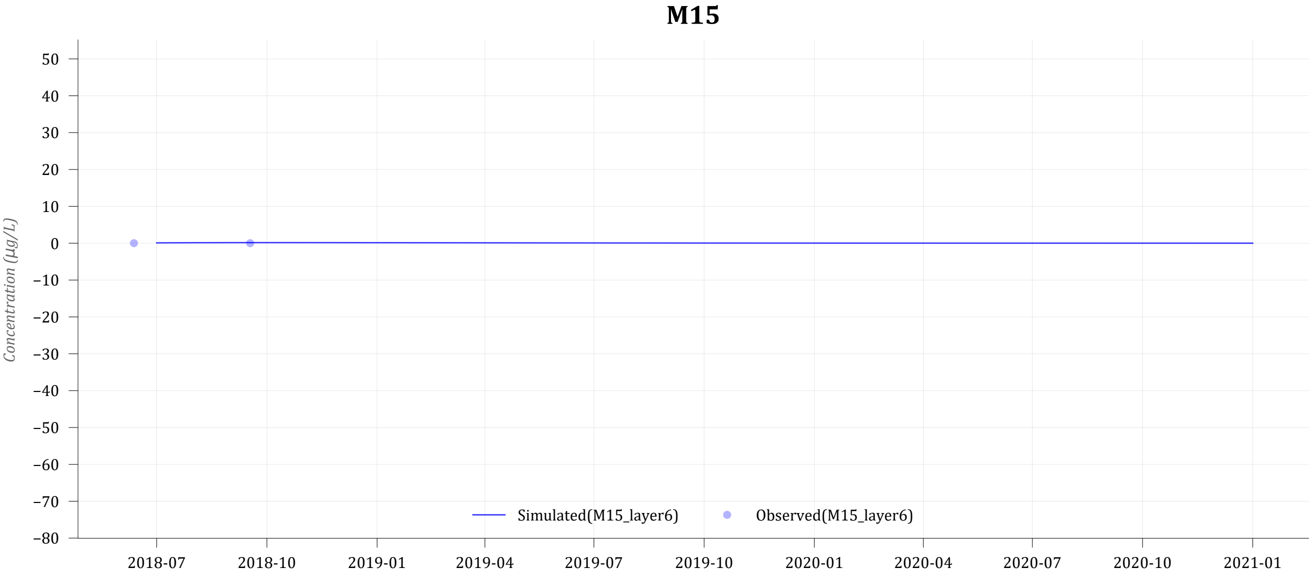


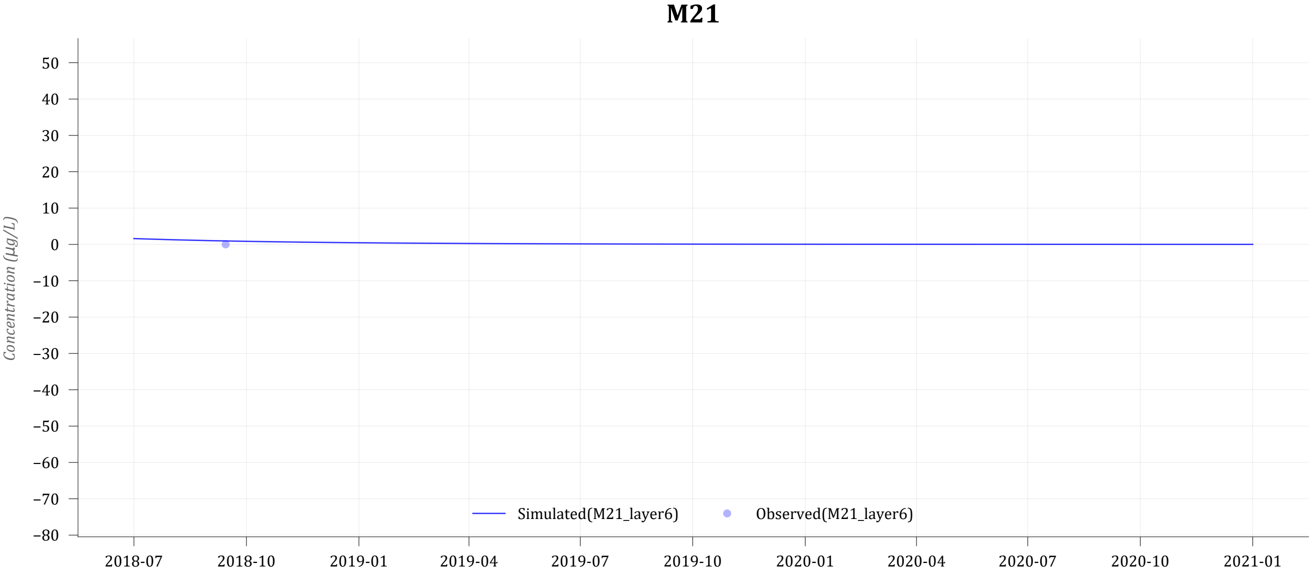
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M10R_layer6)
Observed(M10R_layer6)

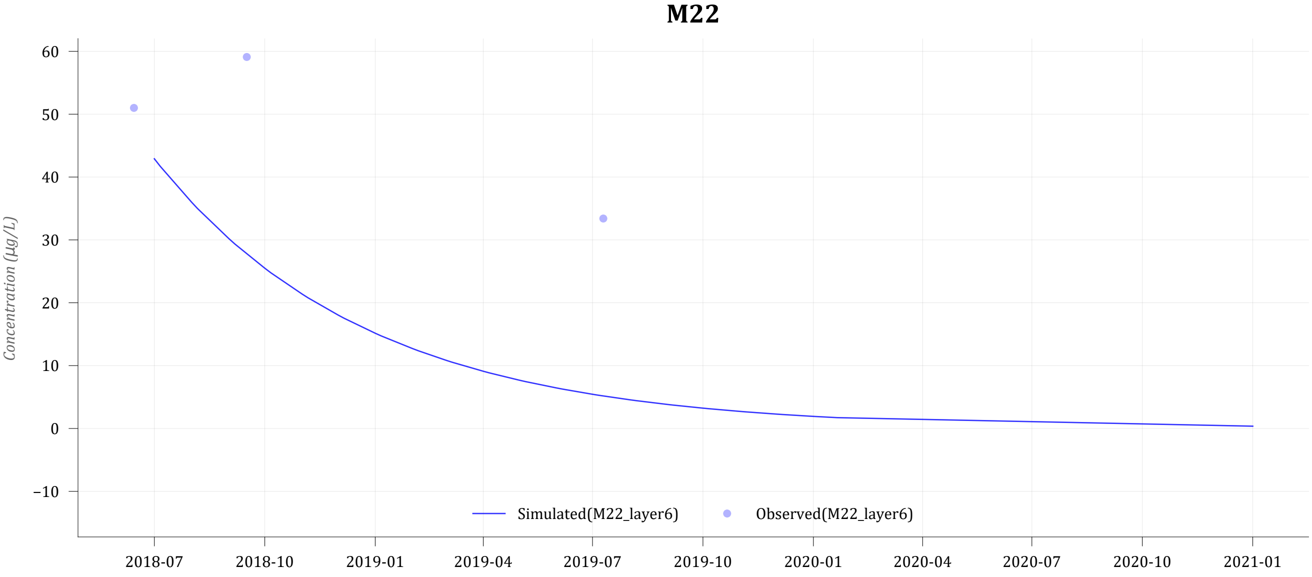
M14R



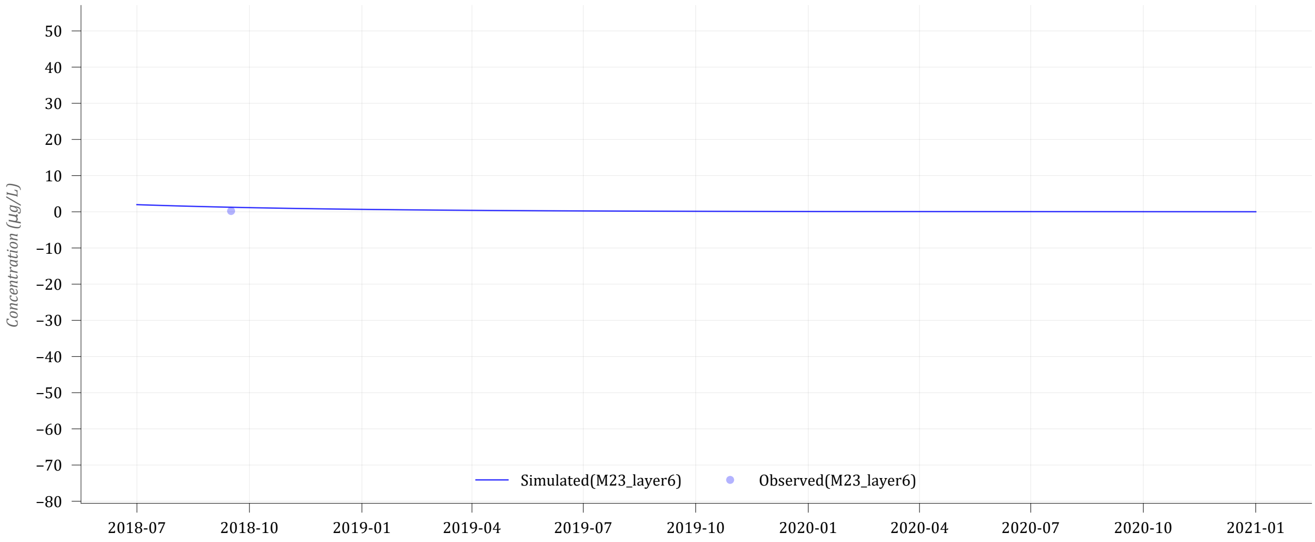
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M14R_layer6)
Observed(M14R_layer6)


M15
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
Simulated(M15_layer6)
Observed(M15_layer6)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01


M21
Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
Simulated(M21_layer6)
Observed(M21_layer6)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01


M22
Concentration (µg/L)
60
50
40
30
20
10
0
−10
Simulated(M22_layer6)
Observed(M22_layer6)
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01

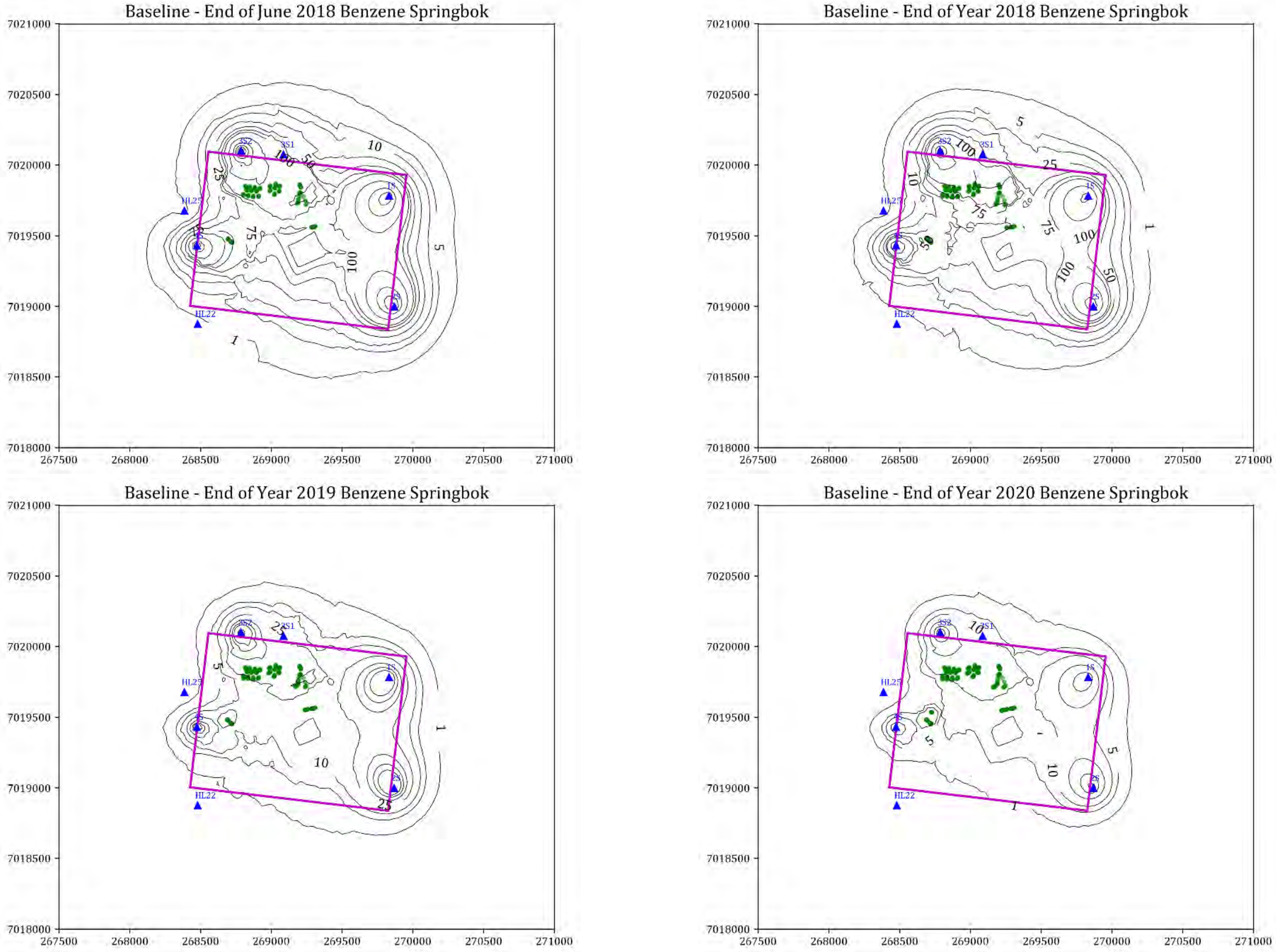
M23



Concentration (µg/L)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
2018-07
2018-10
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
Simulated(M23_layer6)
Observed(M23_layer6)

Appendix D Model predictions

Predicted Benzene Conc ($\mu g/L$) Baseline Scenario - Springbok, 2018 to 2040

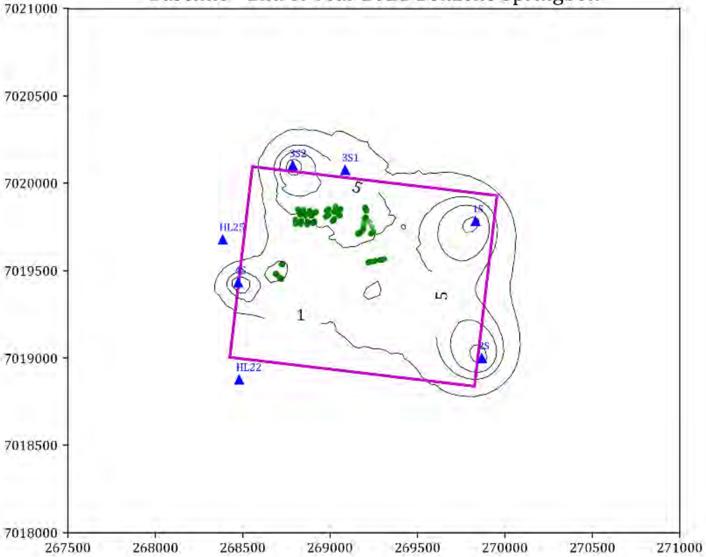


Baseline - End of June 2018 Benzene Springbok

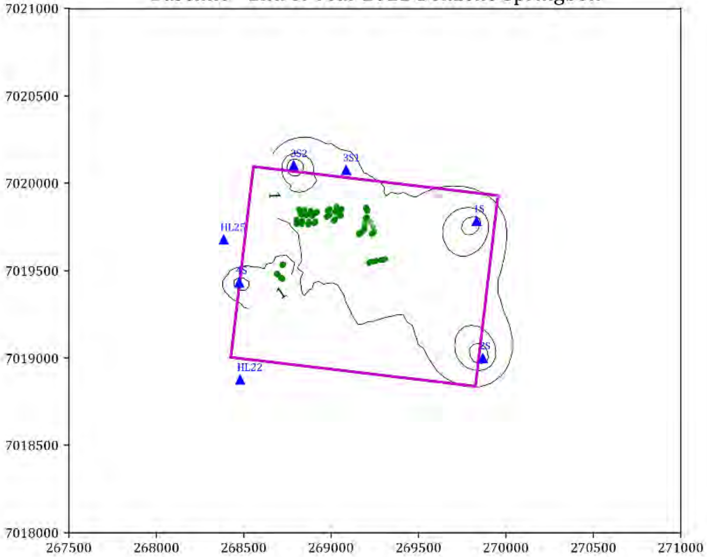
Baseline - End of Year 2018 Benzene Springbok

Baseline - End of Year 2019 Benzene Springbok

Baseline - End of Year 2020 Benzene Springbok

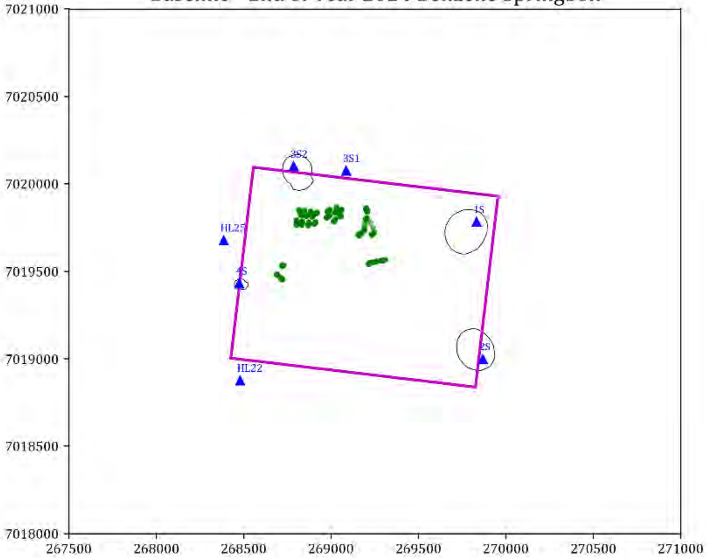


Baseline - End of Year 2021 Benzene Springbok

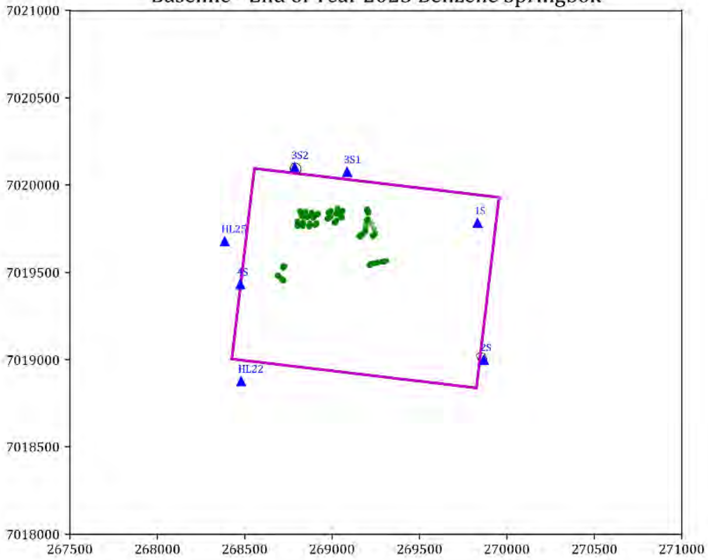


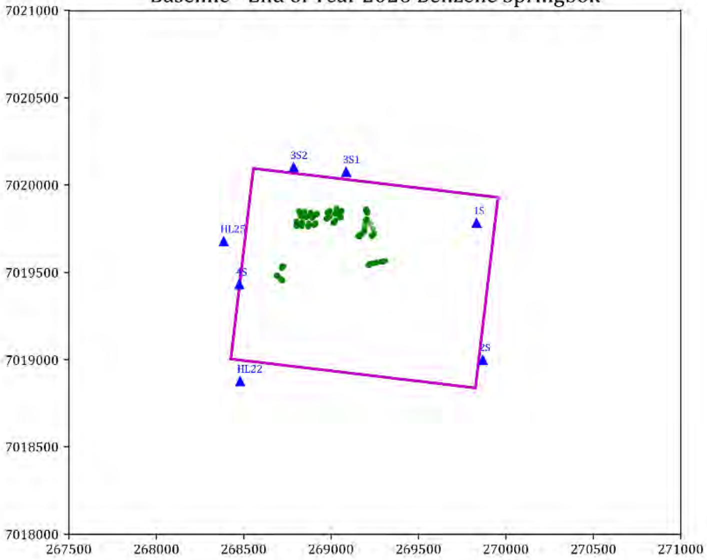
Baseline - End of Year 2022 Benzene Springbok

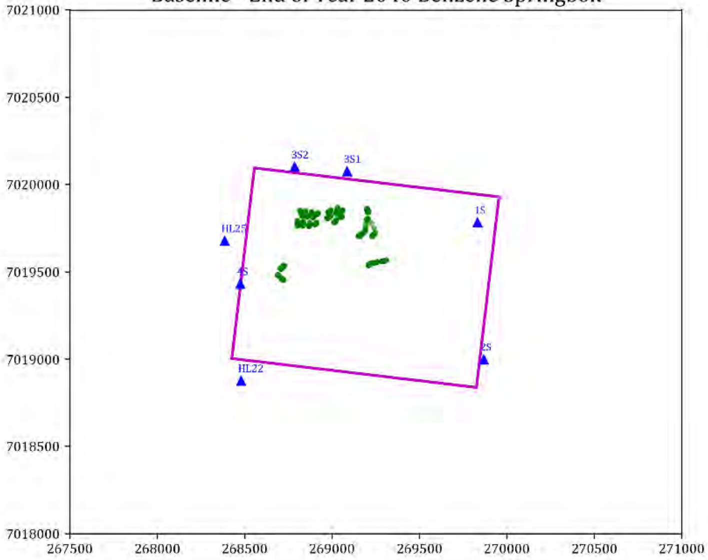
Baseline - End of Year 2023 Benzene Springbok



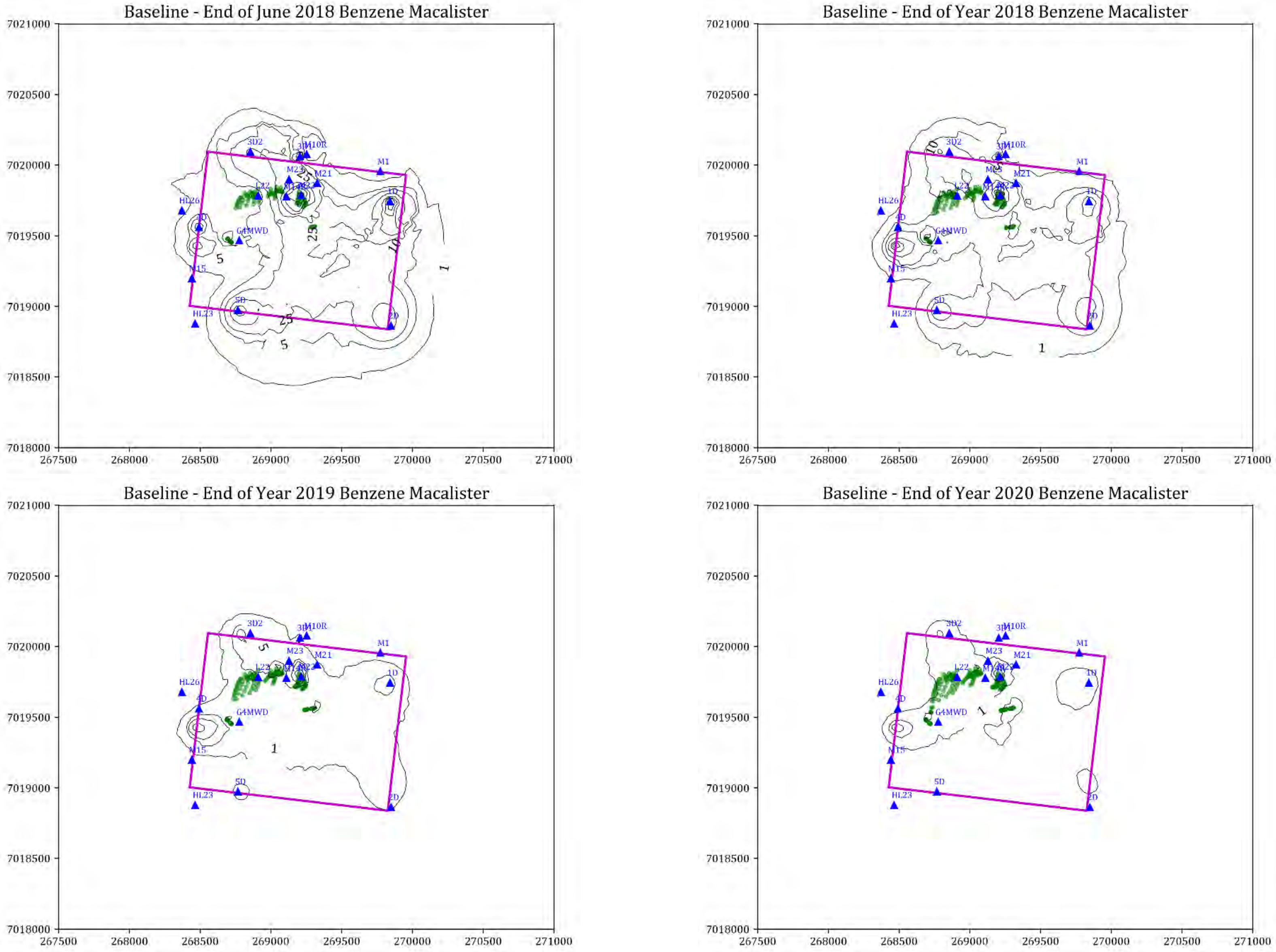
Baseline - End of Year 2024 Benzene Springbok


Baseline - End of Year 2025 Benzene Springbok


Baseline - End of Year 2026 Benzene Springbok


Baseline - End of Year 2040 Benzene Springbok

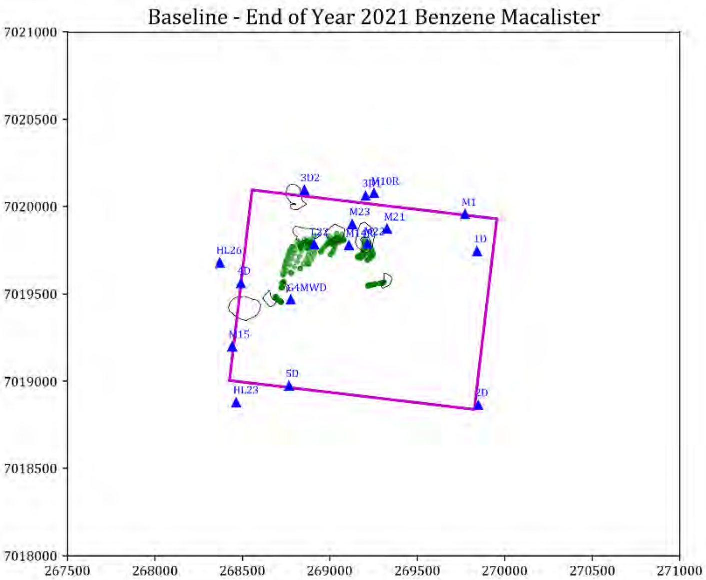
Predicted Benzene Conc ($\mu g/L$) Baseline Scenario - Macalister, 2018 to 2040

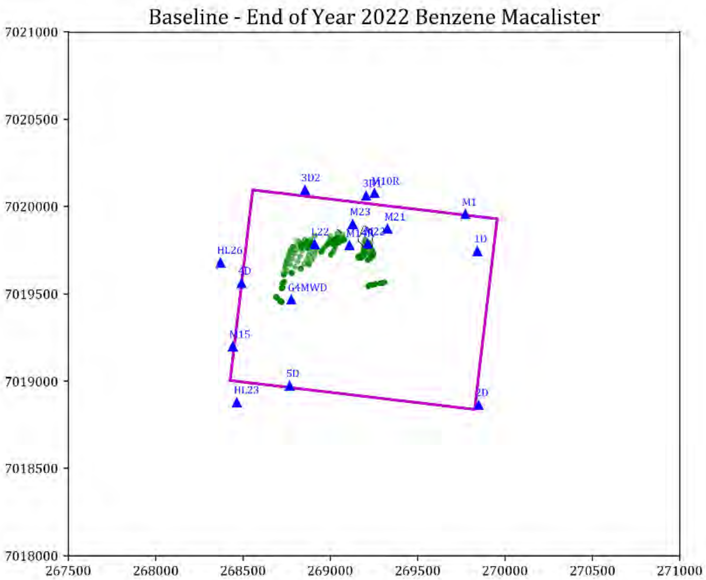

Baseline - End of June 2018 Benzene Macalister

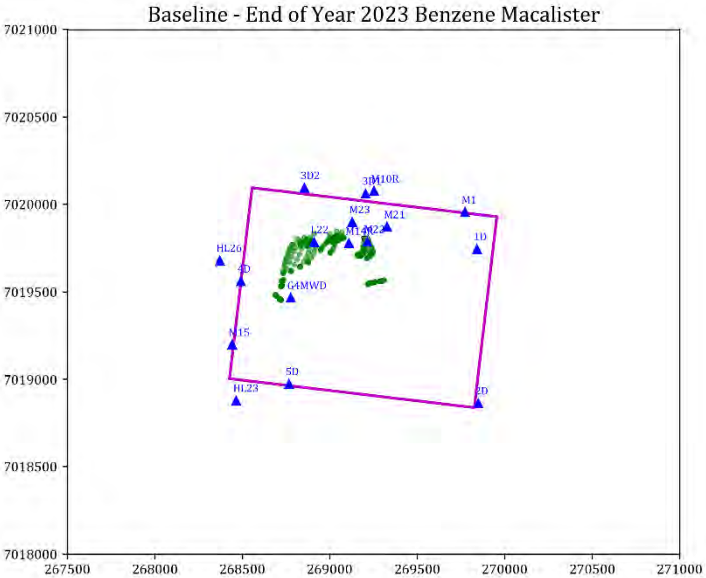
Baseline - End of Year 2018 Benzene Macalister

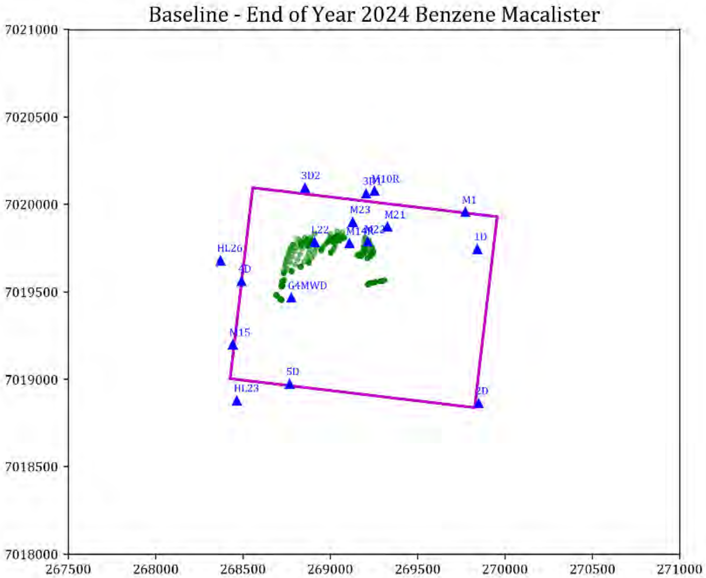
Baseline - End of Year 2019 Benzene Macalister

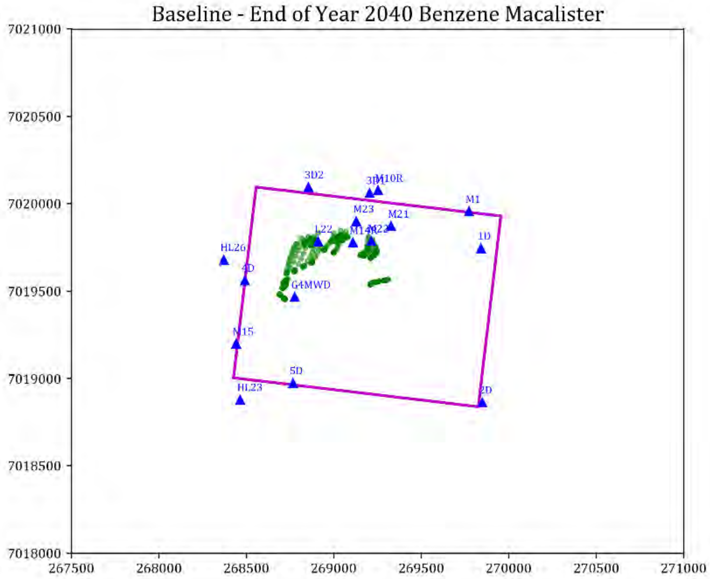
Baseline - End of Year 2020 Benzene Macalister


Baseline - End of Year 2021 Benzene Macalister

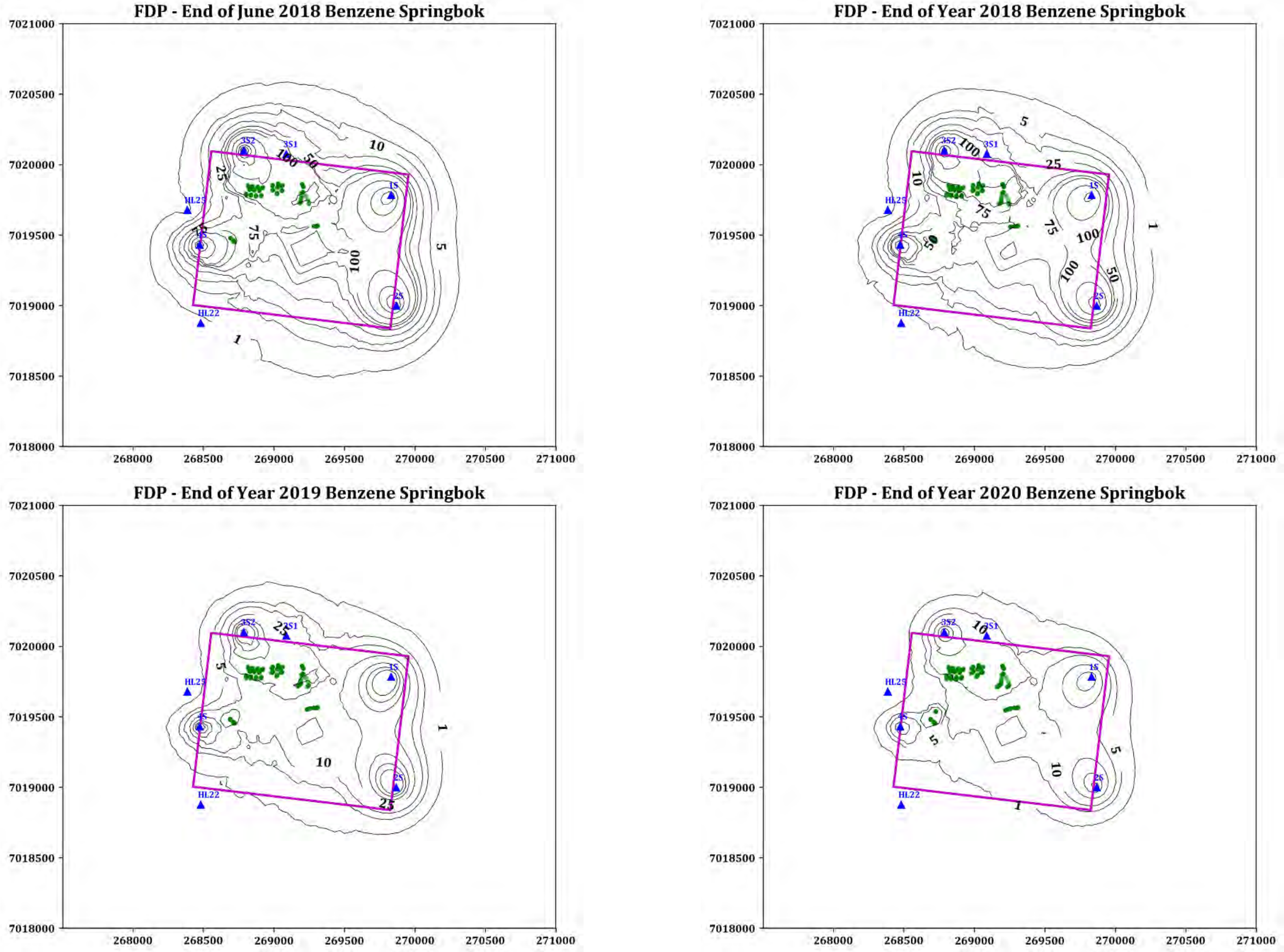

Baseline - End of Year 2022 Benzene Macalister


Baseline - End of Year 2023 Benzene Macalister


Baseline - End of Year 2024 Benzene Macalister


Baseline - End of Year 2040 Benzene Macalister
7021000
7020500
7020000
7019500
7019000
7018500
7018000
267500
268000
268500
269000
269500
270000
270500
271000
3D2
3D1
M10R
M1
M23
M21
L22
M14R
M22
1D
HL26
4D
G4MWD
M15
5D
HL23
2D

Predicted Benzene Conc ($\mu g/L$) Full FDP Development Scenario - Springbok, 2018 to 2040

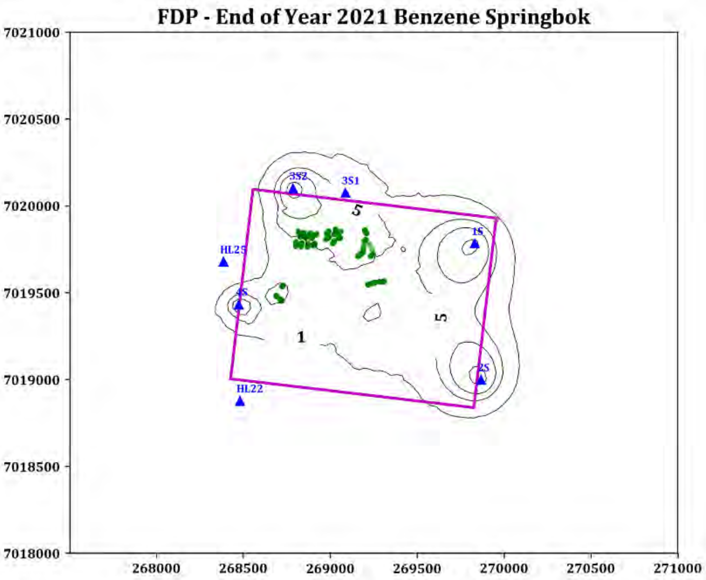


FDP - End of June 2018 Benzene Springbok

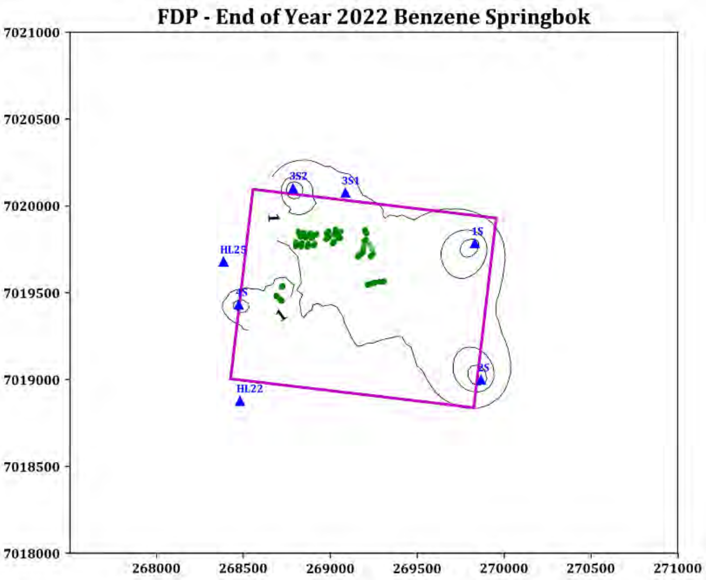
FDP - End of Year 2018 Benzene Springbok

FDP - End of Year 2019 Benzene Springbok

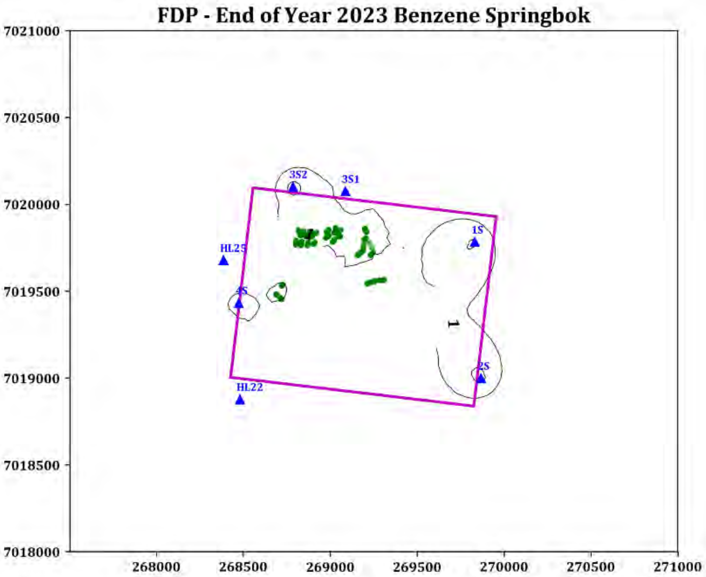
FDP - End of Year 2020 Benzene Springbok



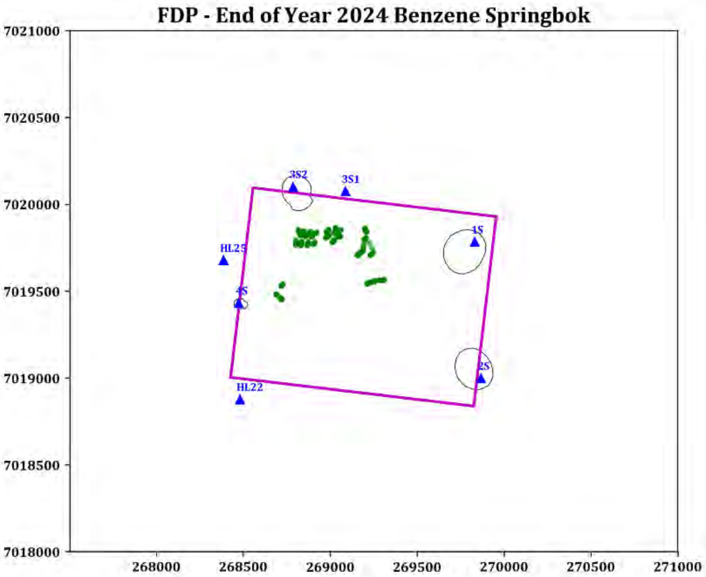
FDP - End of Year 2021 Benzene Springbok



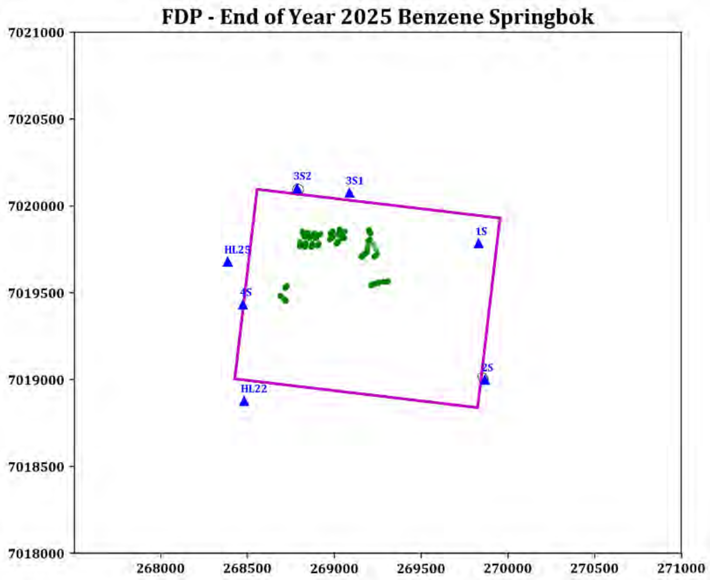
FDP - End of Year 2022 Benzene Springbok



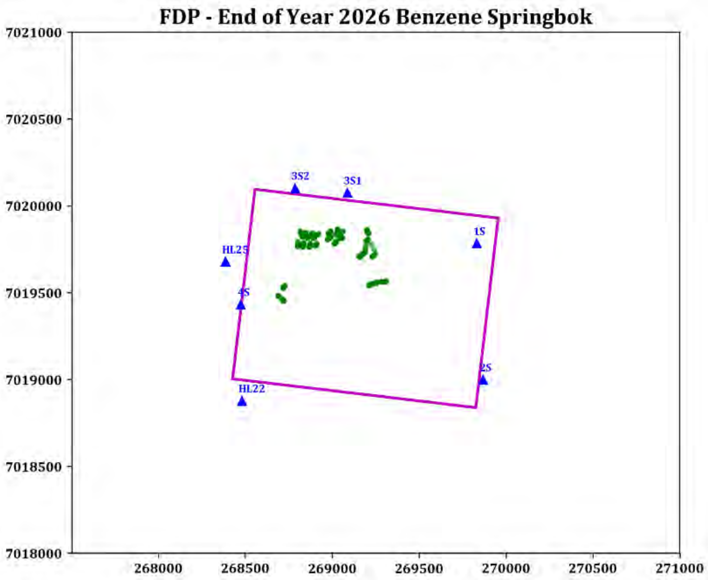
FDP - End of Year 2023 Benzene Springbok



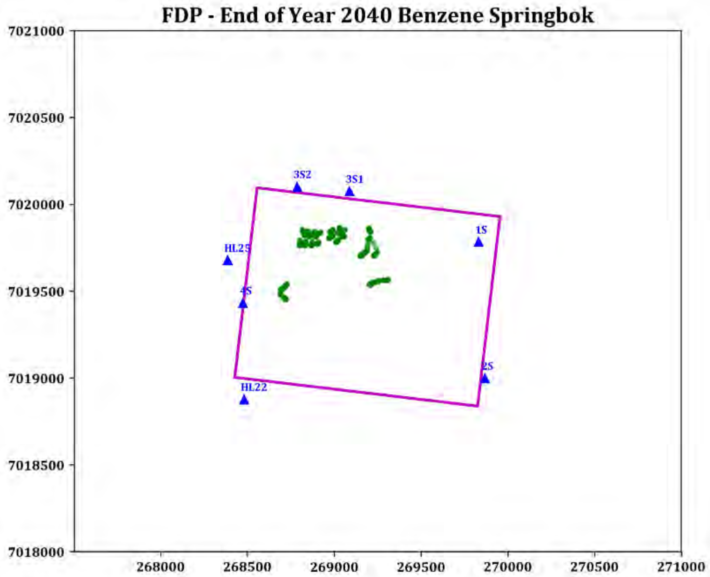
FDP - End of Year 2024 Benzene Springbok



FDP - End of Year 2025 Benzene Springbok

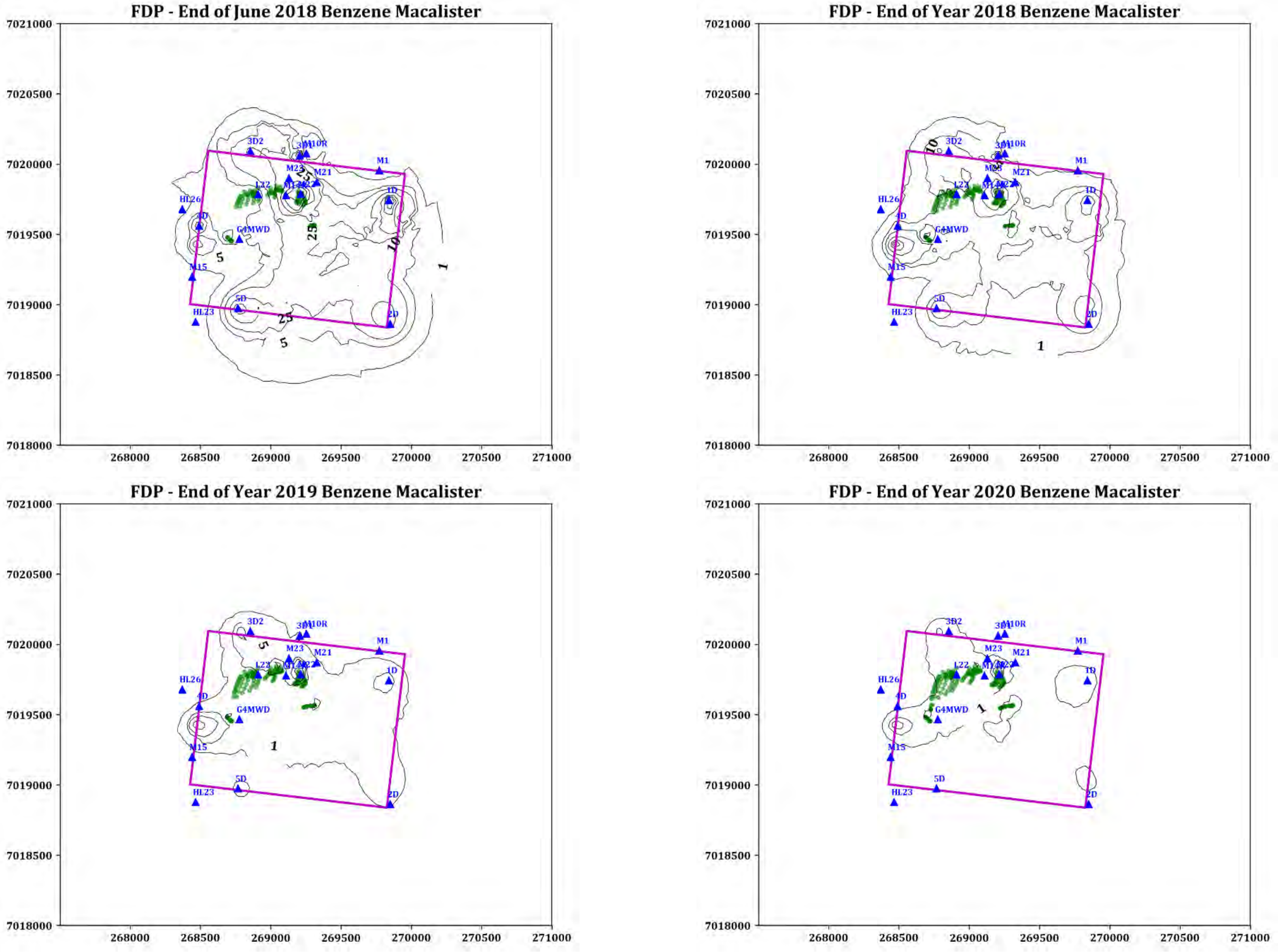


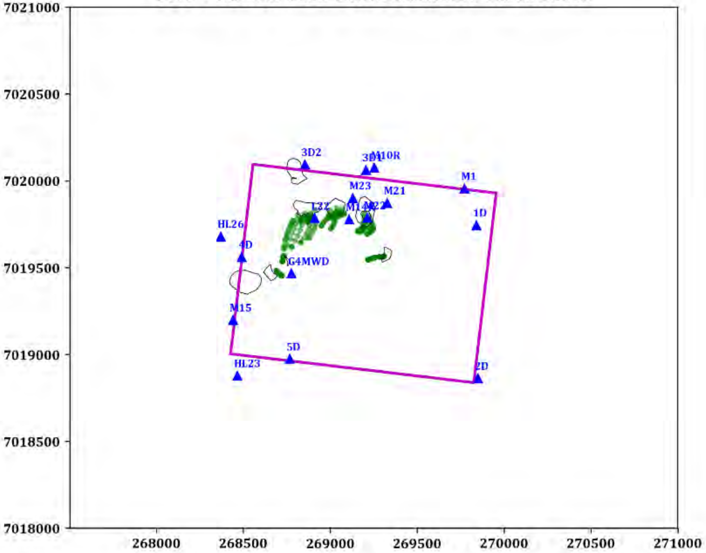
FDP - End of Year 2026 Benzene Springbok



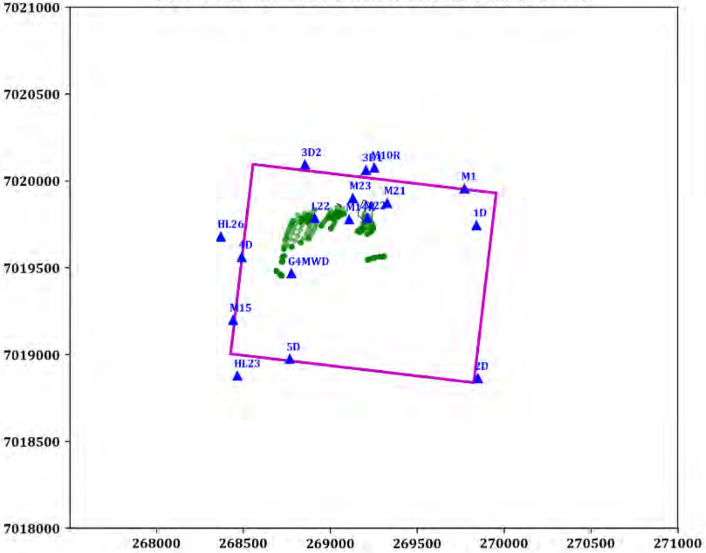
FDP - End of Year 2040 Benzene Springbok

Predicted Benzene Conc ($\mu g/L$) Full FDP Development Scenario - Macalister, 2018 to 2040

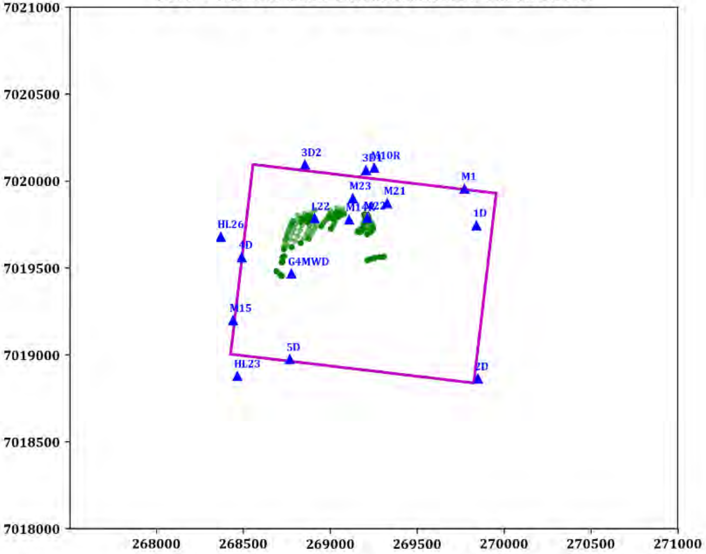




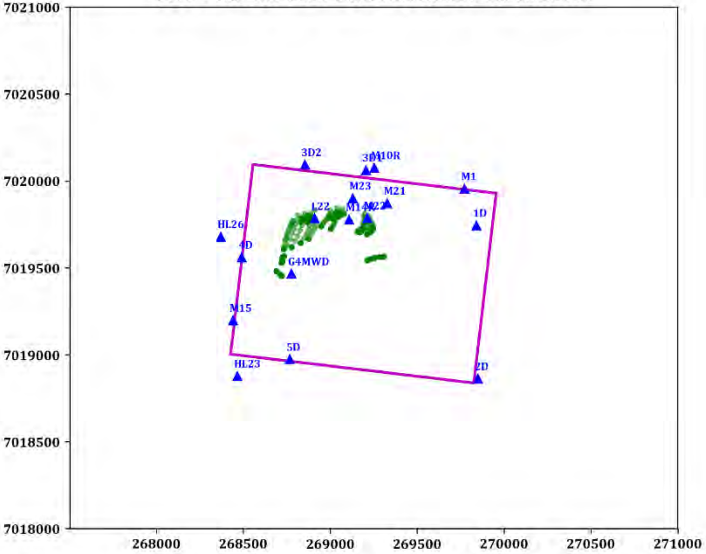
FDP - End of Year 2021 Benzene Macalister



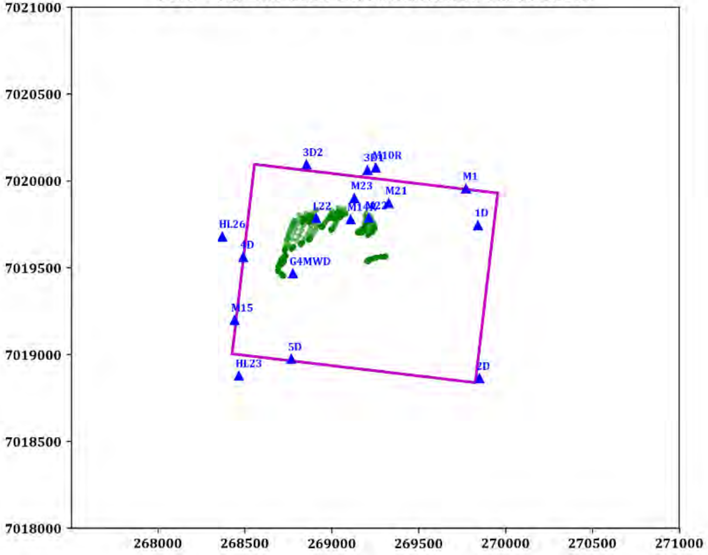
FDP - End of Year 2022 Benzene Macalister



FDP - End of Year 2023 Benzene Macalister

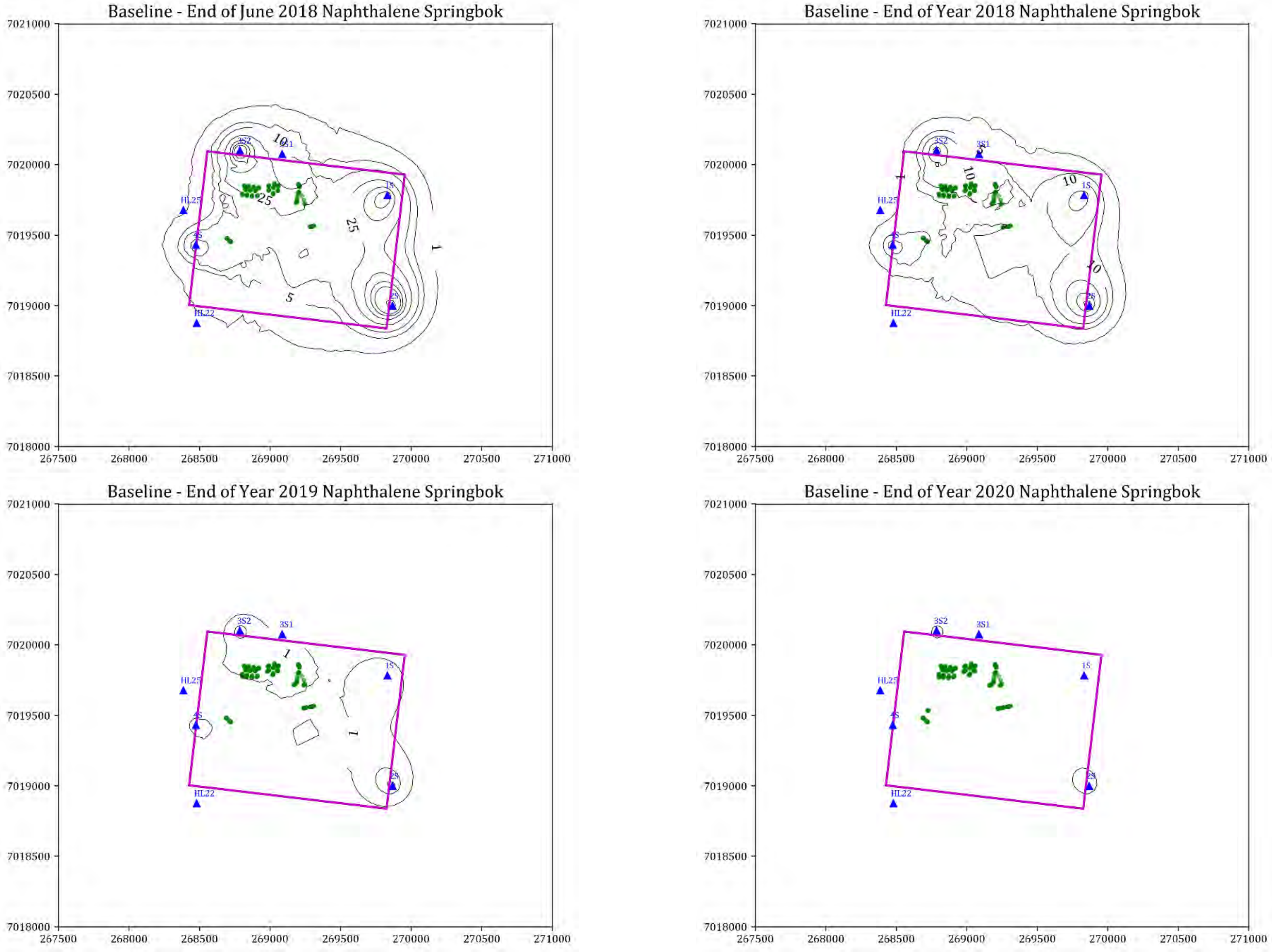


FDP - End of Year 2024 Benzene Macalister



FDP - End of Year 2040 Benzene Macalister

Predicted Naphthalene Conc ($\mu g/L$) Baseline Scenario - Springbok, 2018 to 2040

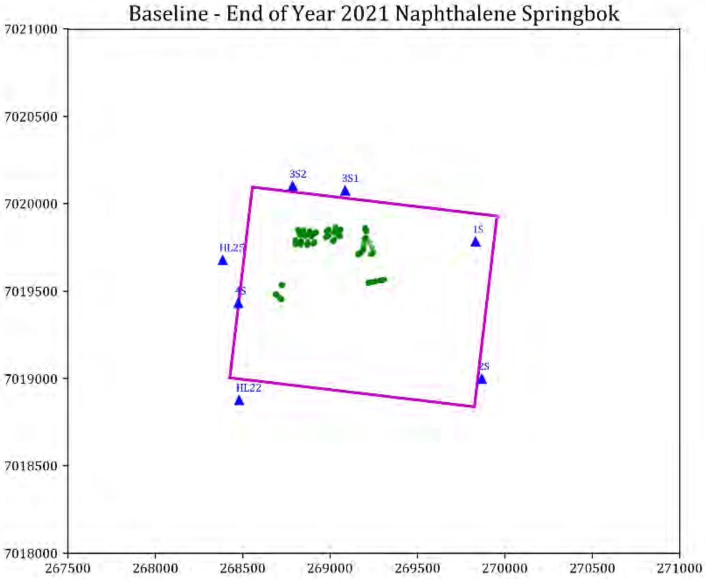


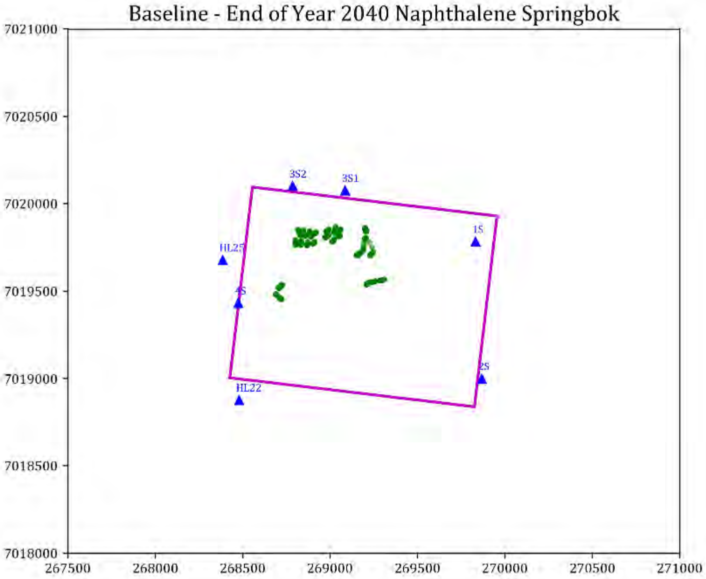
Baseline - End of June 2018 Naphthalene Springbok

Baseline - End of Year 2018 Naphthalene Springbok

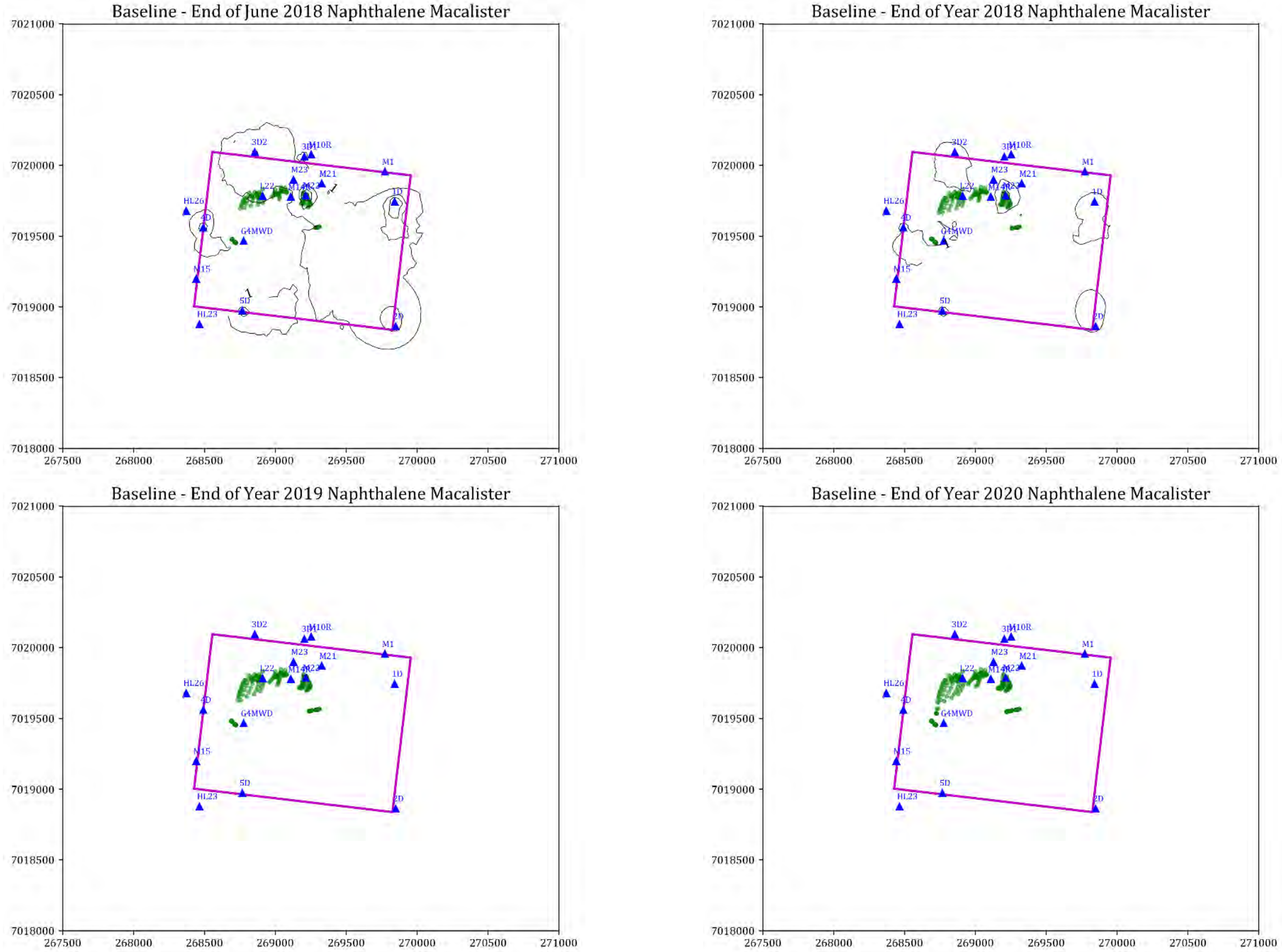
Baseline - End of Year 2019 Naphthalene Springbok

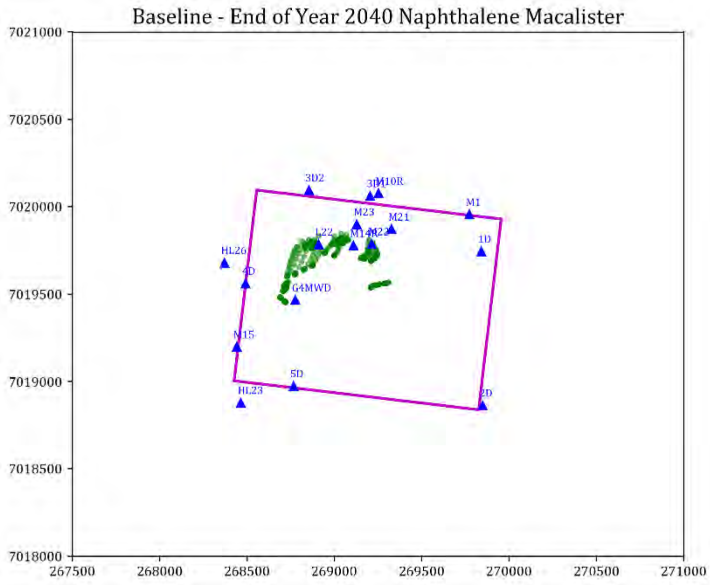
Baseline - End of Year 2020 Naphthalene Springbok


Baseline - End of Year 2021 Naphthalene Springbok


Baseline - End of Year 2040 Naphthalene Springbok

Predicted Naphthalene Conc ($\mu g/L$) Baseline Scenario - Macalister, 2018 to 2040




Baseline - End of Year 2040 Naphthalene Macalister
7021000
7020500
7020000
7019500
7019000
7018500
7018000
267500
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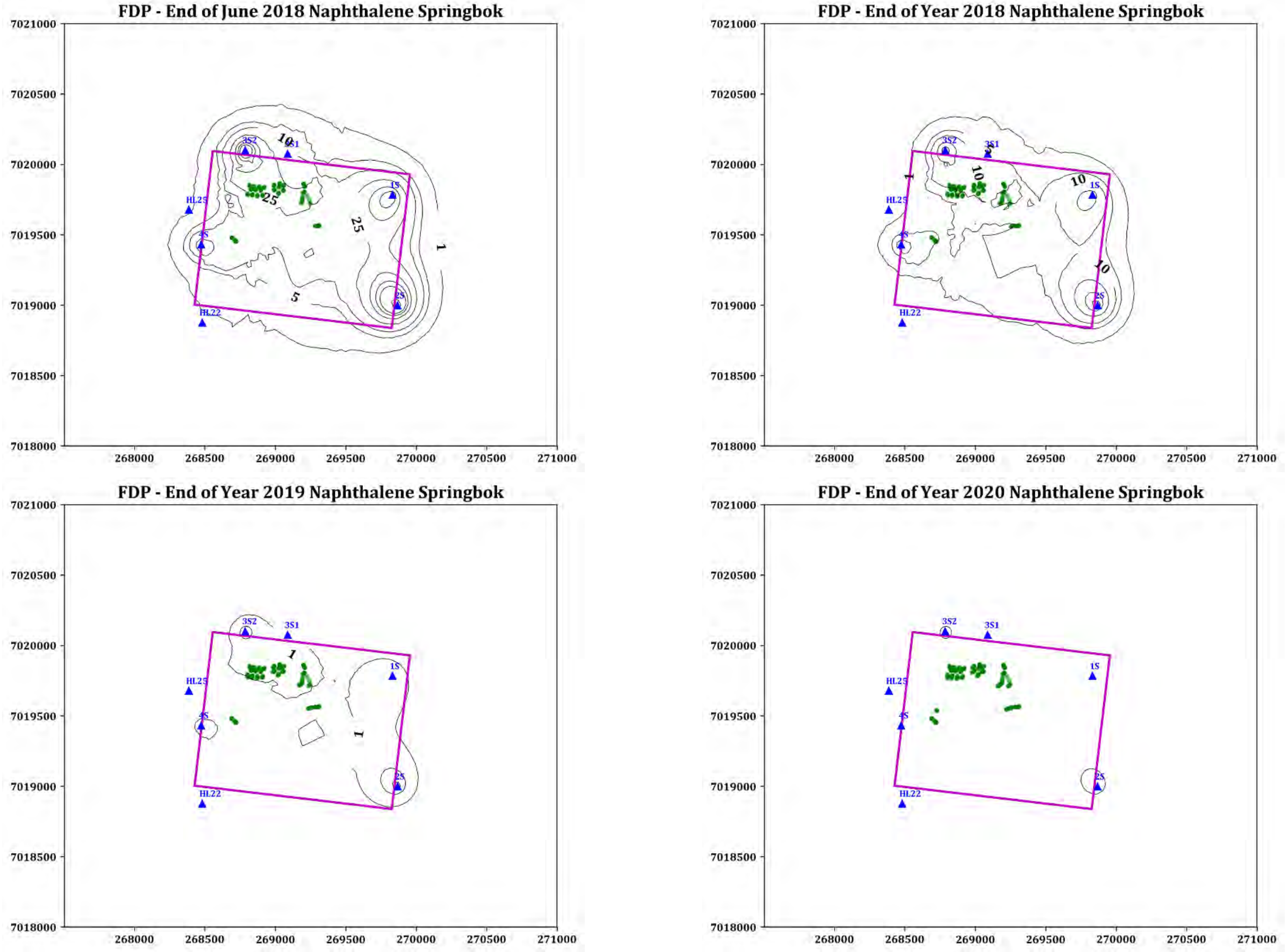
269000
269500
270000
270500
271000
3D2
3D1
M10R
M1
M23
M21
L22
M14R
M22
1D
HL26
4D
G4MWD
M15
5D
HL23
2D

Predicted Naphthalene Conc ($\mu g/L$) Full FDP Development Scenario – Springbok, 2018 to 2040

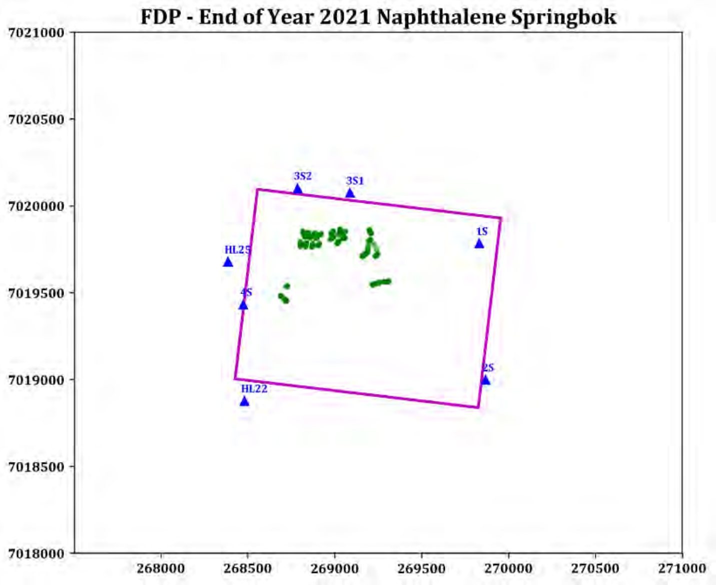


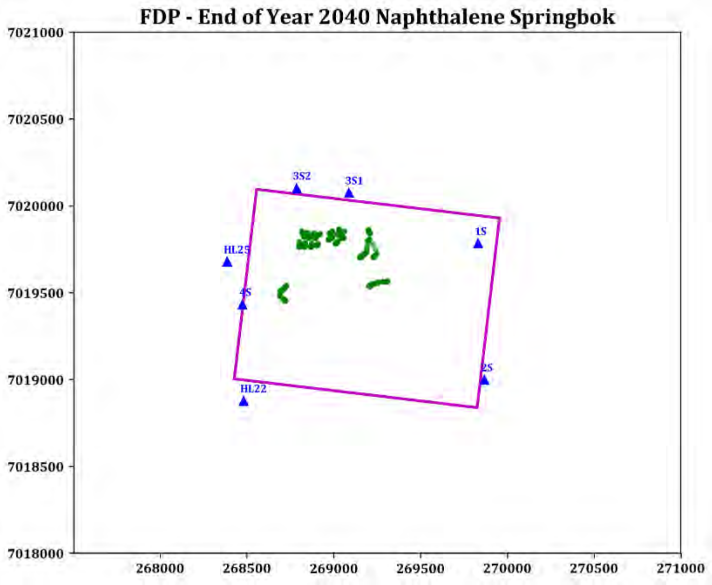
FDP - End of June 2018 Naphthalene Springbok

FDP - End of Year 2018 Naphthalene Springbok

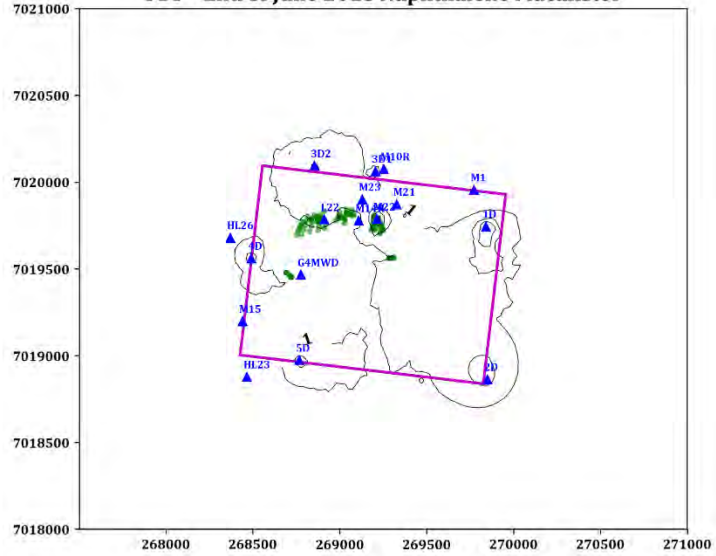
FDP - End of Year 2019 Naphthalene Springbok

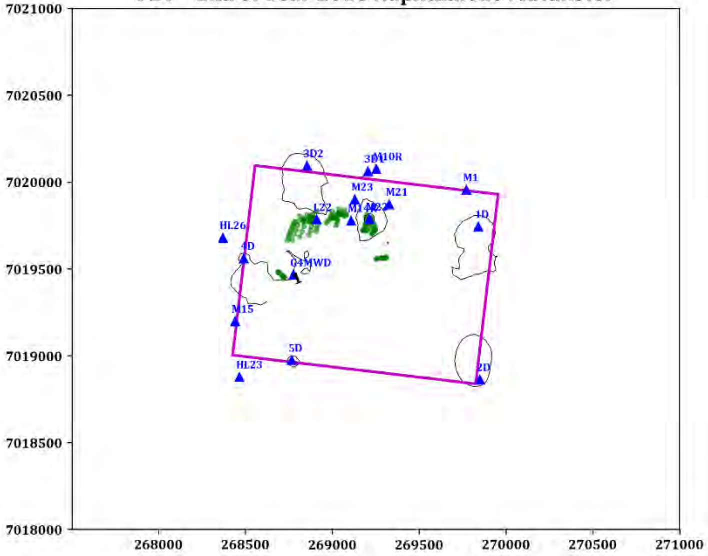
FDP - End of Year 2020 Naphthalene Springbok

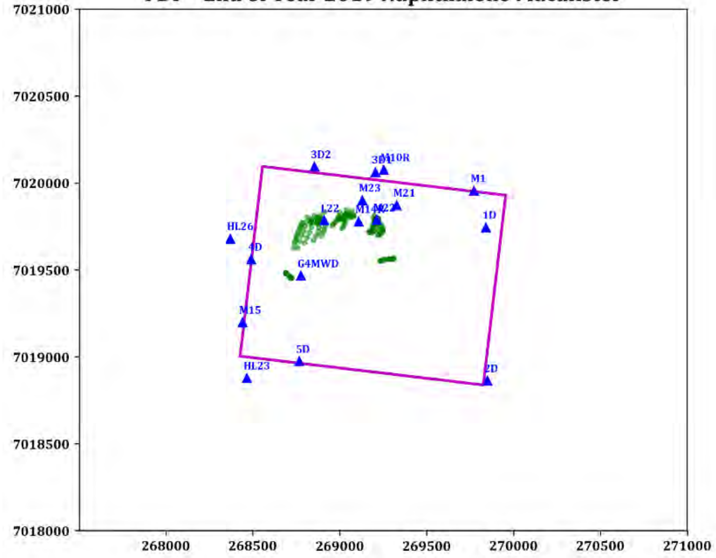

FDP - End of Year 2021 Naphthalene Springbok

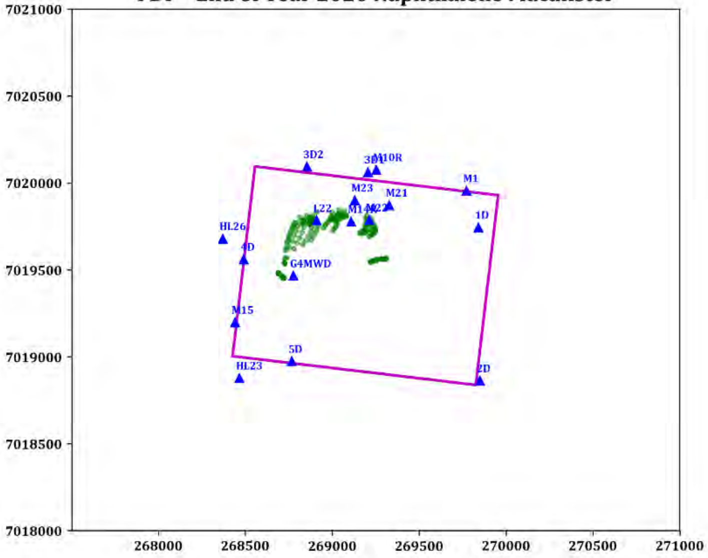

FDP - End of Year 2040 Naphthalene Springbok

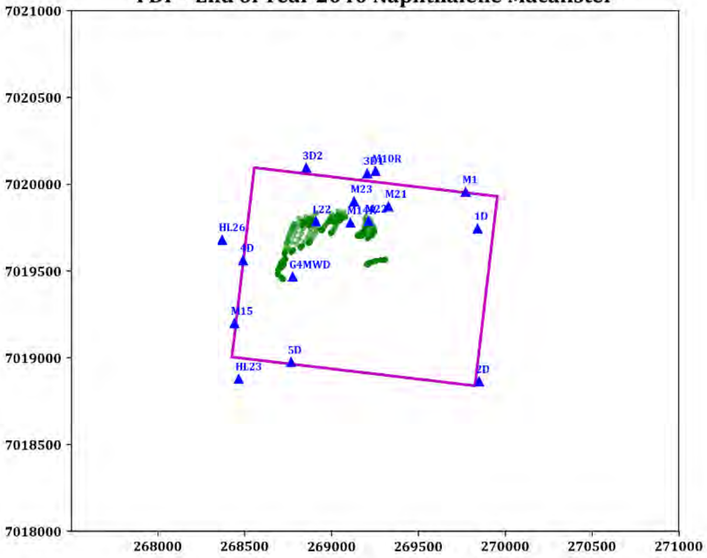
Predicted Naphthalene Conc ($\mu g/L$) Full FDP Development Scenario – Macalister, 2018 to 2040


FDP - End of June 2018 Naphthalene Macalister


FDP - End of Year 2018 Naphthalene Macalister

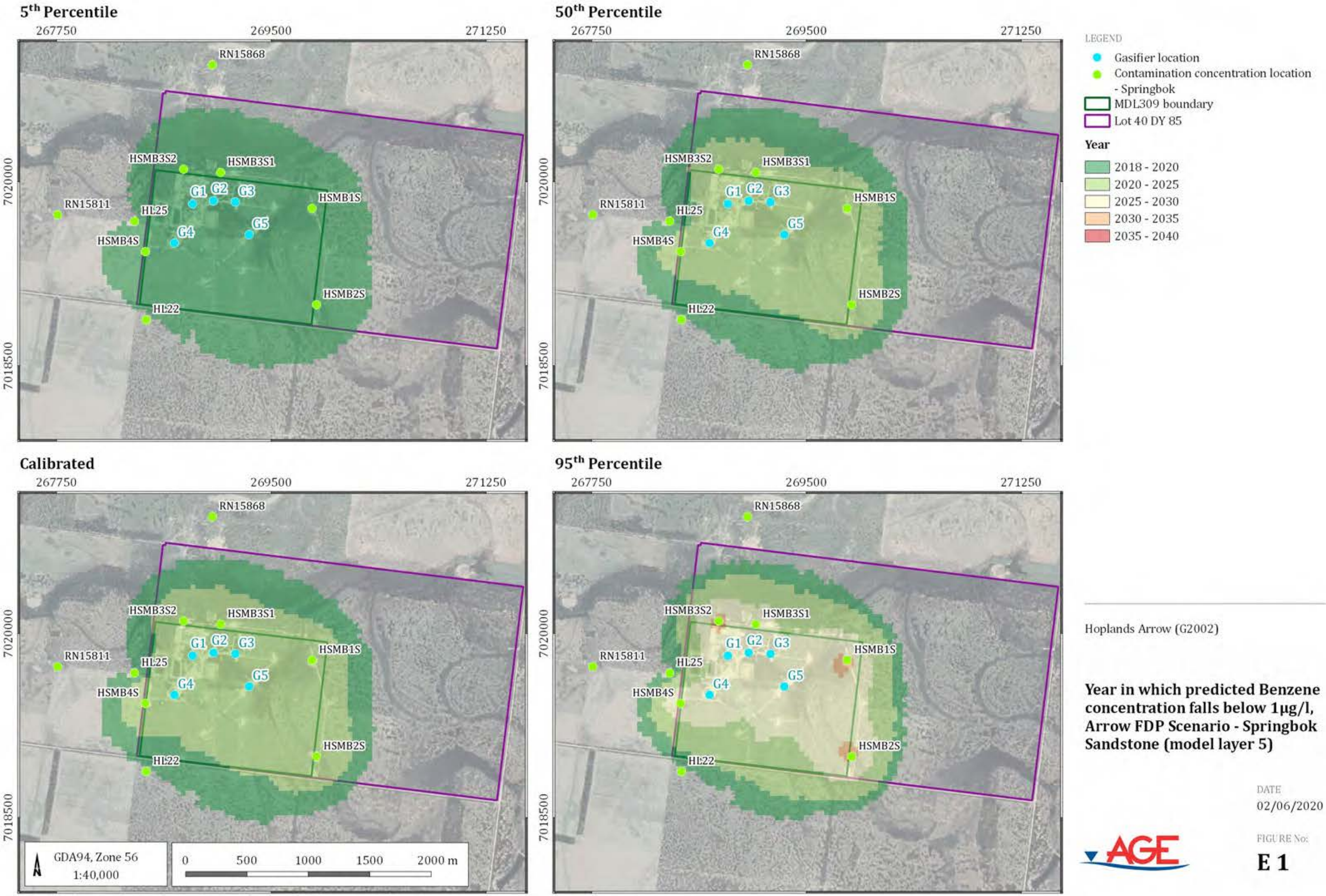

FDP - End of Year 2019 Naphthalene Macalister


FDP - End of Year 2020 Naphthalene Macalister



FDP - End of Year 2040 Naphthalene Macalister

Appendix E Uncertainty analysis results



Hoplands Arrow (G2002)

Year in which predicted Benzene concentration falls below 1µg/l, Arrow FDP Scenario - Springbok Sandstone (model layer 5)

DATE
02/06/2020

FIGURE No:
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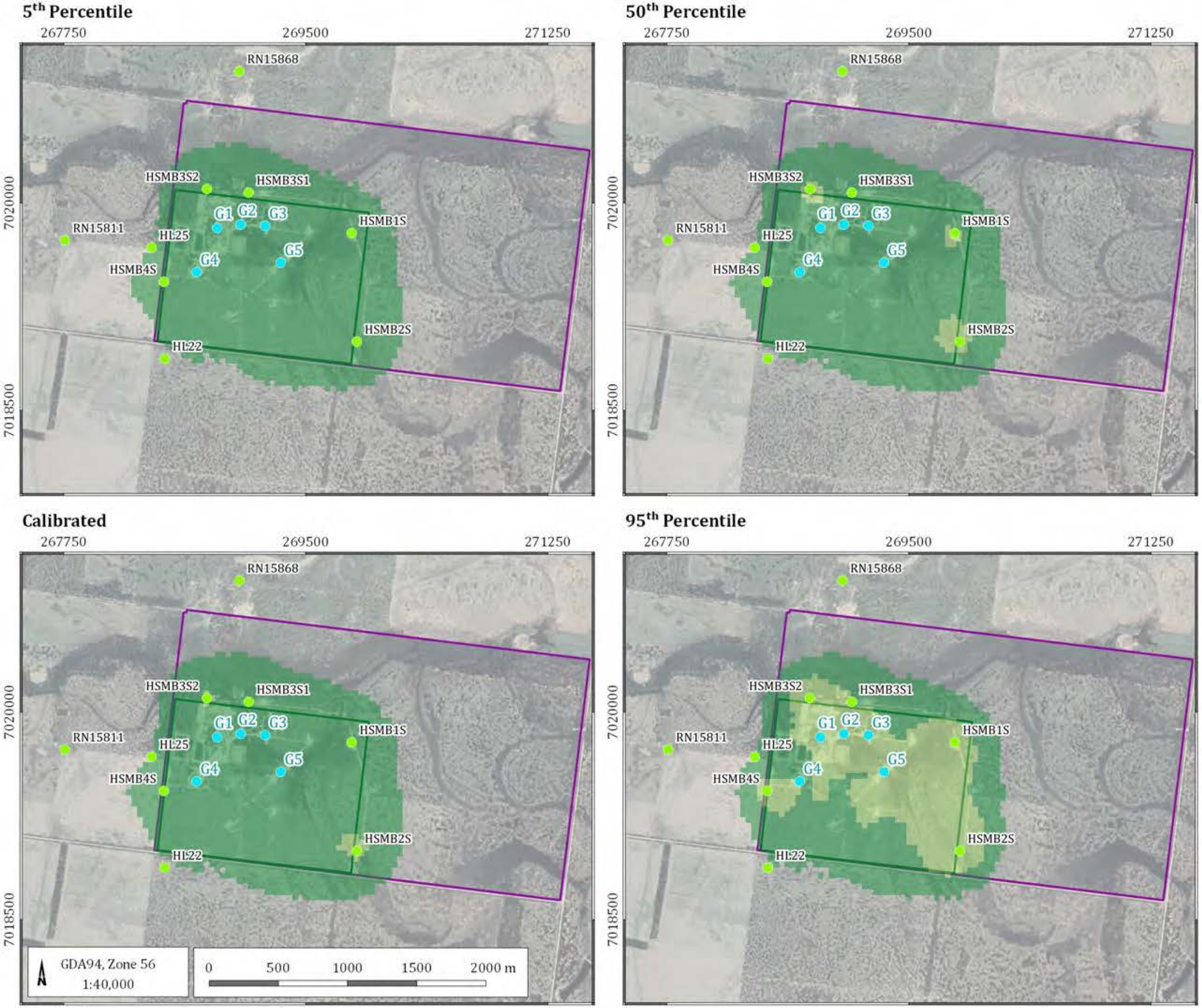

Hoplands Arrow (G2002)

Year in which predicted Napthalene concentration falls below 1µg/l, Arrow FDP Scenario - Springbok Sandstone (model layer 5)

DATE
02/06/2020

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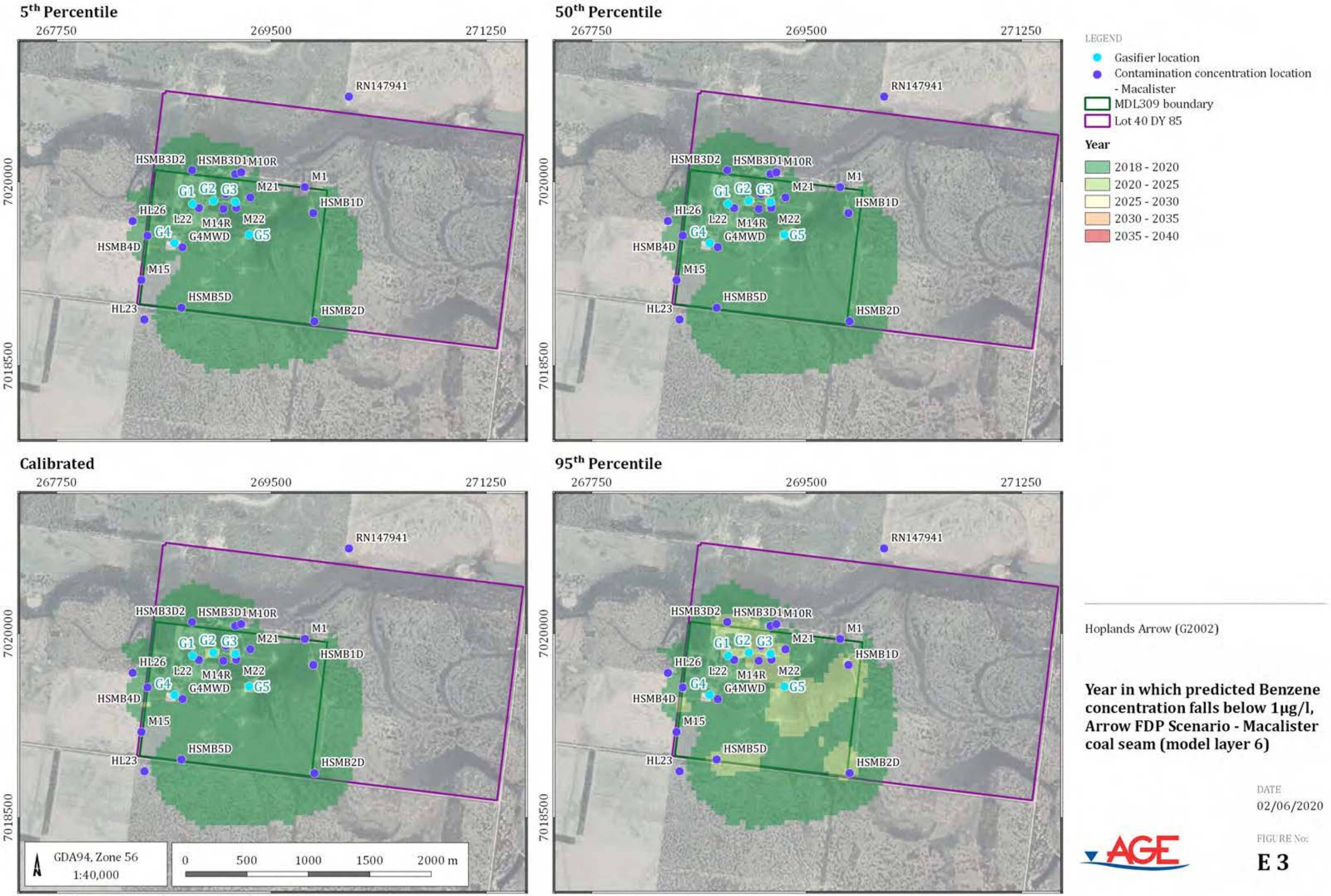

Hoplands Arrow (G2002)

Year in which predicted Benzene concentration falls below 1µg/l, Arrow FDP Scenario - Macalister coal seam (model layer 6)

DATE
02/06/2020

AGE

FIGURE No:
E 3

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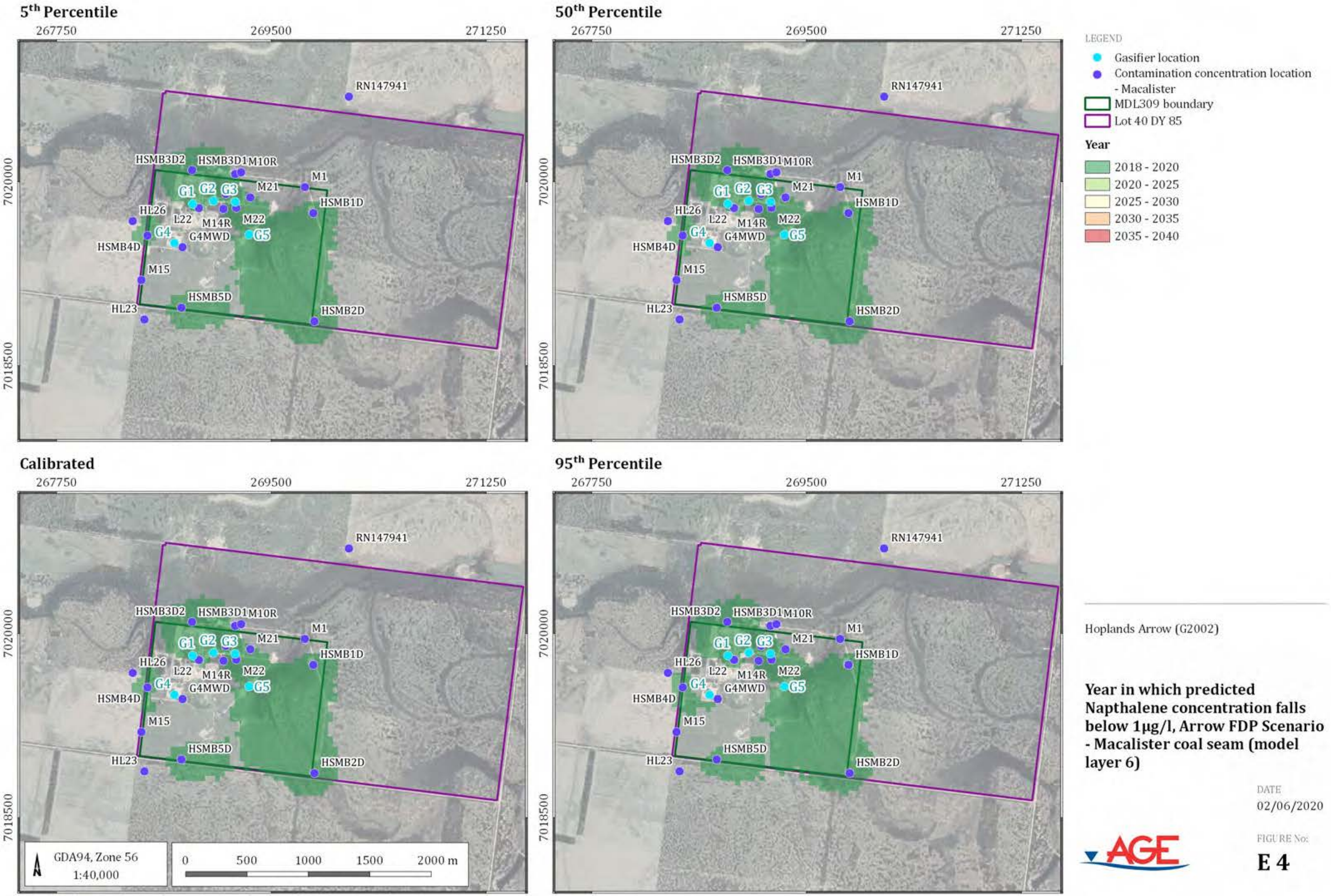

Hoplands Arrow (G2002)

Year in which predicted Napthalene concentration falls below 1µg/l, Arrow FDP Scenario - Macalister coal seam (model layer 6)

DATE
02/06/2020

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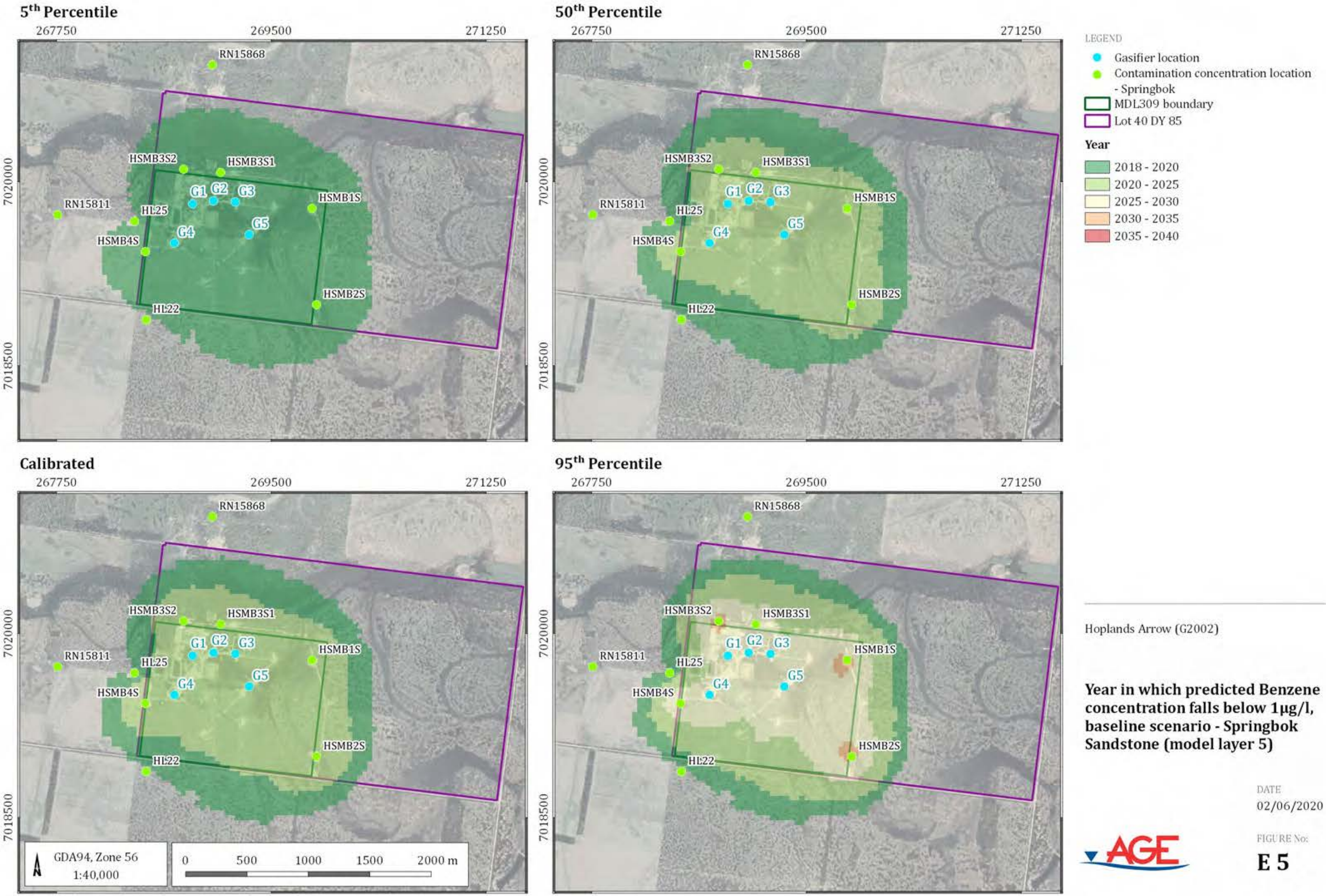

Hoplands Arrow (G2002)

Year in which predicted Benzene concentration falls below 1µg/l, baseline scenario - Springbok Sandstone (model layer 5)

DATE
02/06/2020

FIGURE No:
E 5

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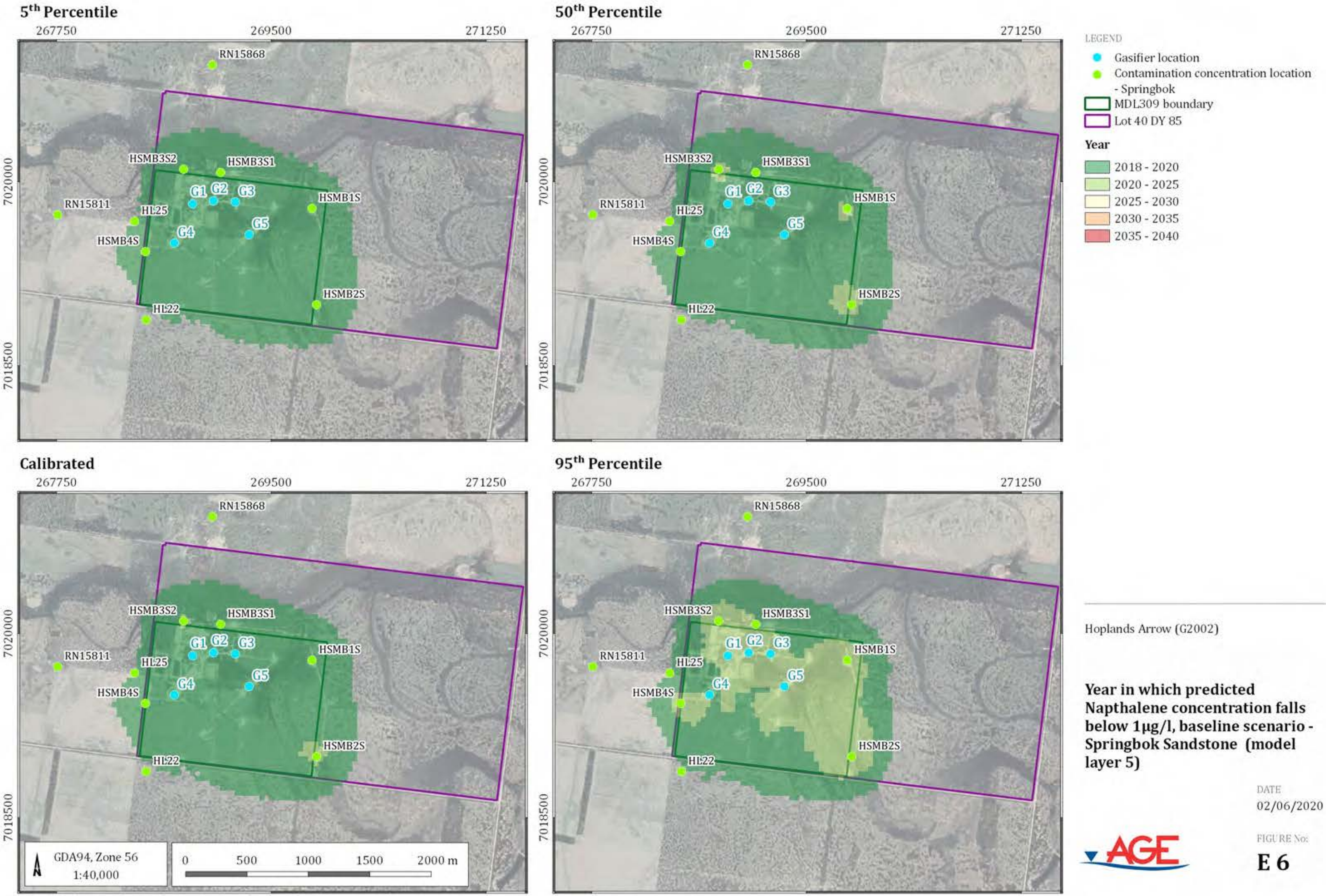

Hoplands Arrow (G2002)

Year in which predicted Napthalene concentration falls below 1µg/l, baseline scenario - Springbok Sandstone (model layer 5)

DATE
02/06/2020

FIGURE No:
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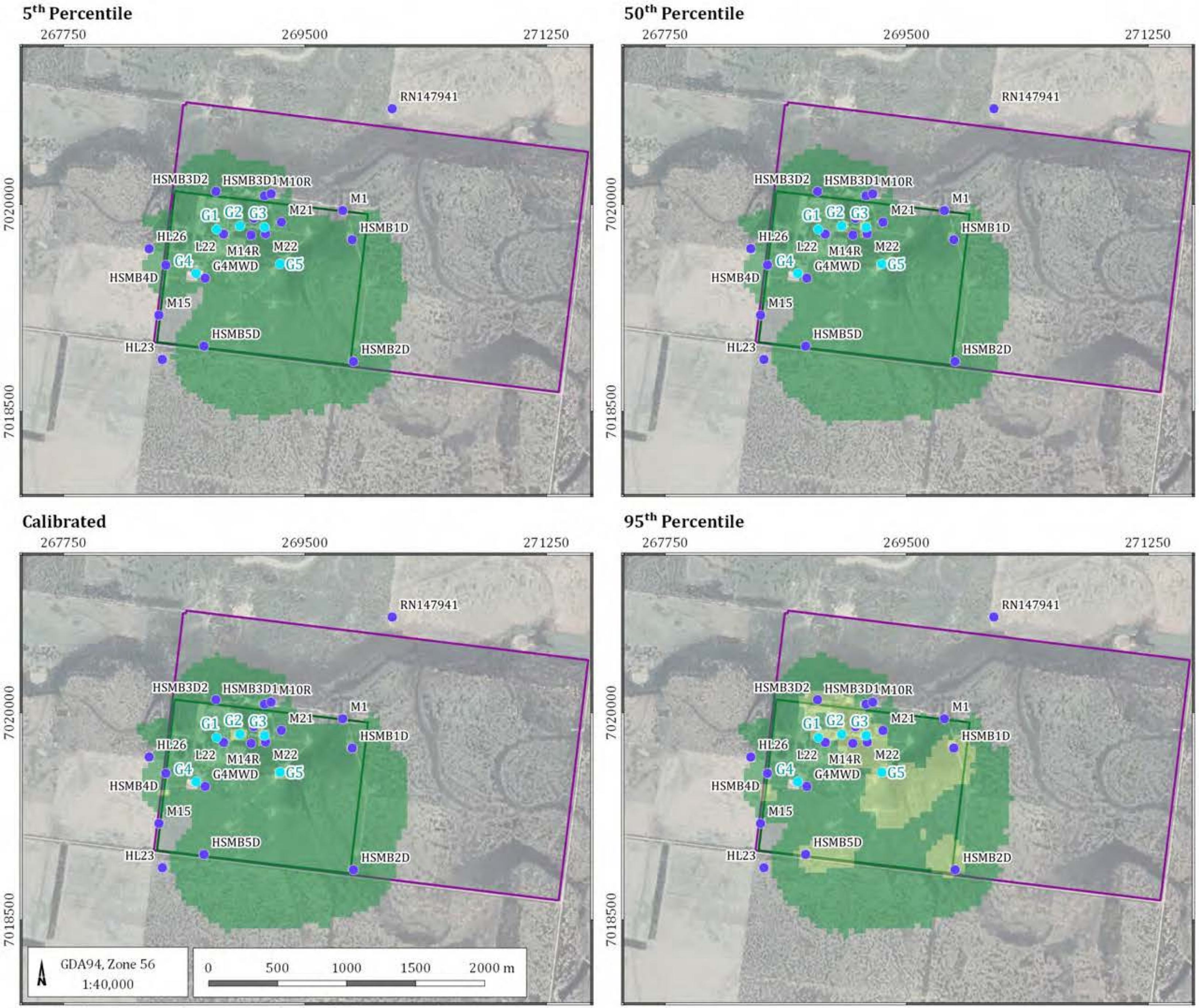

5th Percentile

50th Percentile

Calibrated

95th Percentile

Hoplands Arrow (G2002)

Year in which predicted Benzene concentration falls below 1μg/l, baseline scenario - Macalister coal seam (model layer 6)

DATE
02/06/2020

FIGURE No:
E 7

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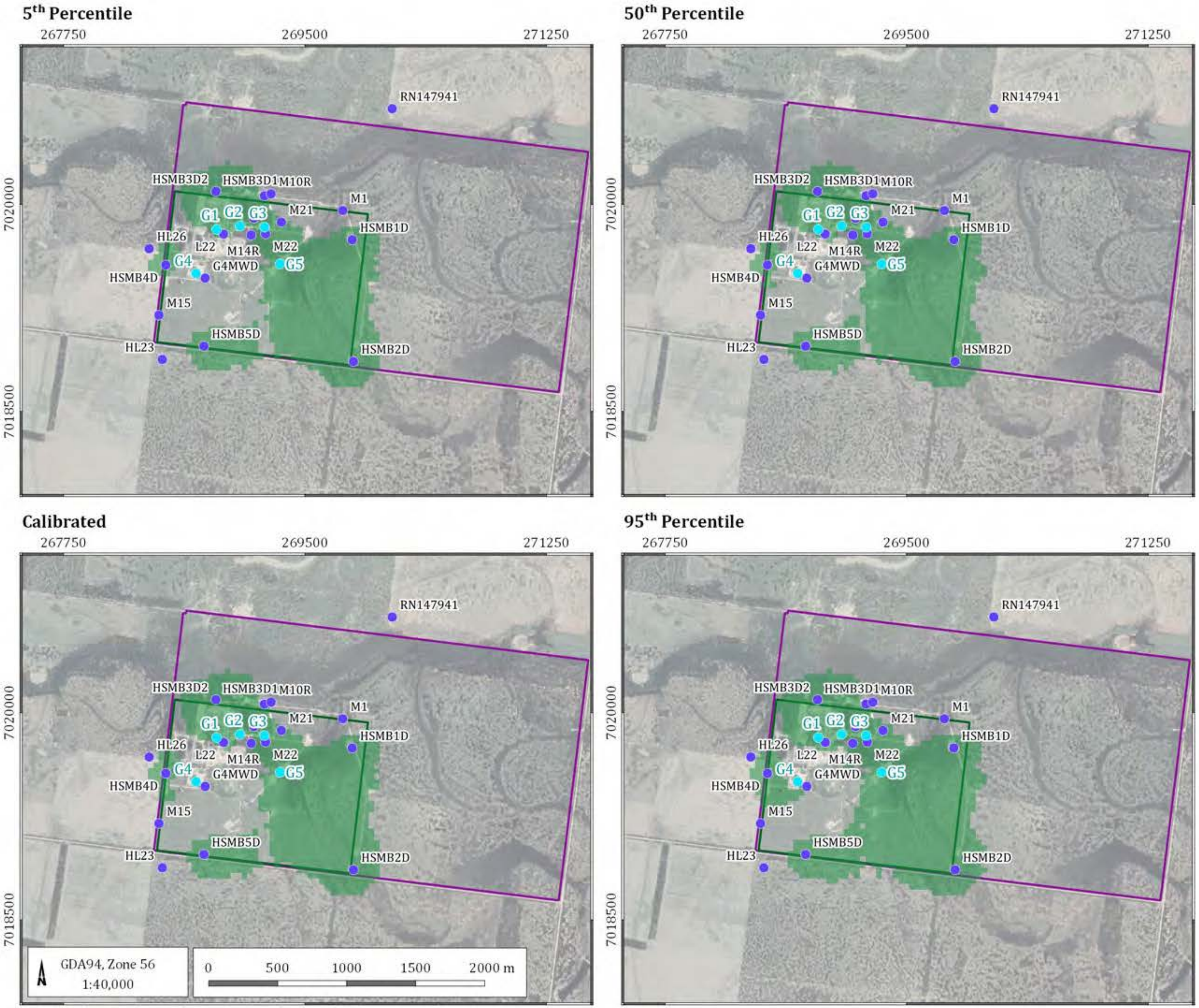

Hoplands Arrow (G2002)

Year in which predicted Napthalene concentration falls below 1µg/l, baseline scenario - Macalister coal seam (model layer 6)

DATE
02/06/2020

FIGURE No:
E 8

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Appendix F SQP Declarations

Australasian Groundwater
and Environmental Consultants Pty Ltd
Level 2 / 15 Mallon Street
Bowen Hills, QLD 4006 Australia

ABN: 64 080 238 642
T. +61 7 3257 2055
F. +61 7 3257 2088
brisbane@ageconsultants.com.au
www.ageconsultants.com.au

11 June 2020

To whom it may concern,

Letter of Competency and Authorisation

I have been employed at Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) for ten years.

Qualifications and Experience

- Bachelor of Science (Geography), University of Canterbury Christchurch NZ, 2005.
- Master of Science (hons) (Hydrogeology/Engineering Geology), University of Canterbury Christchurch NZ, 2008.
- Trainee Groundwater Modeller, Rio Tino Iron Ore/University of Canterbury, 2007-2008.
- Groundwater Modeller/Hydrogeologist, Matrixplus/METServe, 2008-2010.
- Principal Groundwater Modeller/Technical Modelling Lead, Australiasian Groundwater and Environmental Consultants Pty Ltd, 2010-2020
- Doctor of Philosophy Candidate (Groundwater modelling uncertainty/Chem. Eng.), University of Queensland, 2020-2024

Competency Declaration

- I have not knowingly included false, misleading or incomplete information in the document.
- I have not knowingly failed to reveal any relevant information or document to the administering authority.
- The document addresses the relevant matters for the function and is factually correct.
- The opinions expressed in the document are honestly and reasonably held.

Yours sincerely,

Neil Manewell
Principal Groundwater Modeller | Technical Modelling Lead

Australasian Groundwater
and Environmental Consultants Pty Ltd
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Bowen Hills, QLD 4006 Australia

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brisbane@ageconsultants.com.au
www.ageconsultants.com.au

11 June 2020

To whom it may concern,

Letter of Competency and Authorisation

I have been employed at Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) for the past 12 months.

Qualifications and Experience

- Bachelor of Science (Geography) with Honours, University of Bristol, 1992.
- Master of Science (Water Resource System Engineering), University of Newcastle, 1994.
- Hydrogeologist, Knight Piesold Ltd, 1995-1999.
- Senior/Principal Hydrogeologist, Entec UK Ltd, 1999-2007.
- Principal Hydrogeologist, GHD Pty Ltd, 2007-2014.
- Director Hydrogeology and Modelling, The Office of Groundwater Impact Assessment, 2014-2019.

Competency Declaration

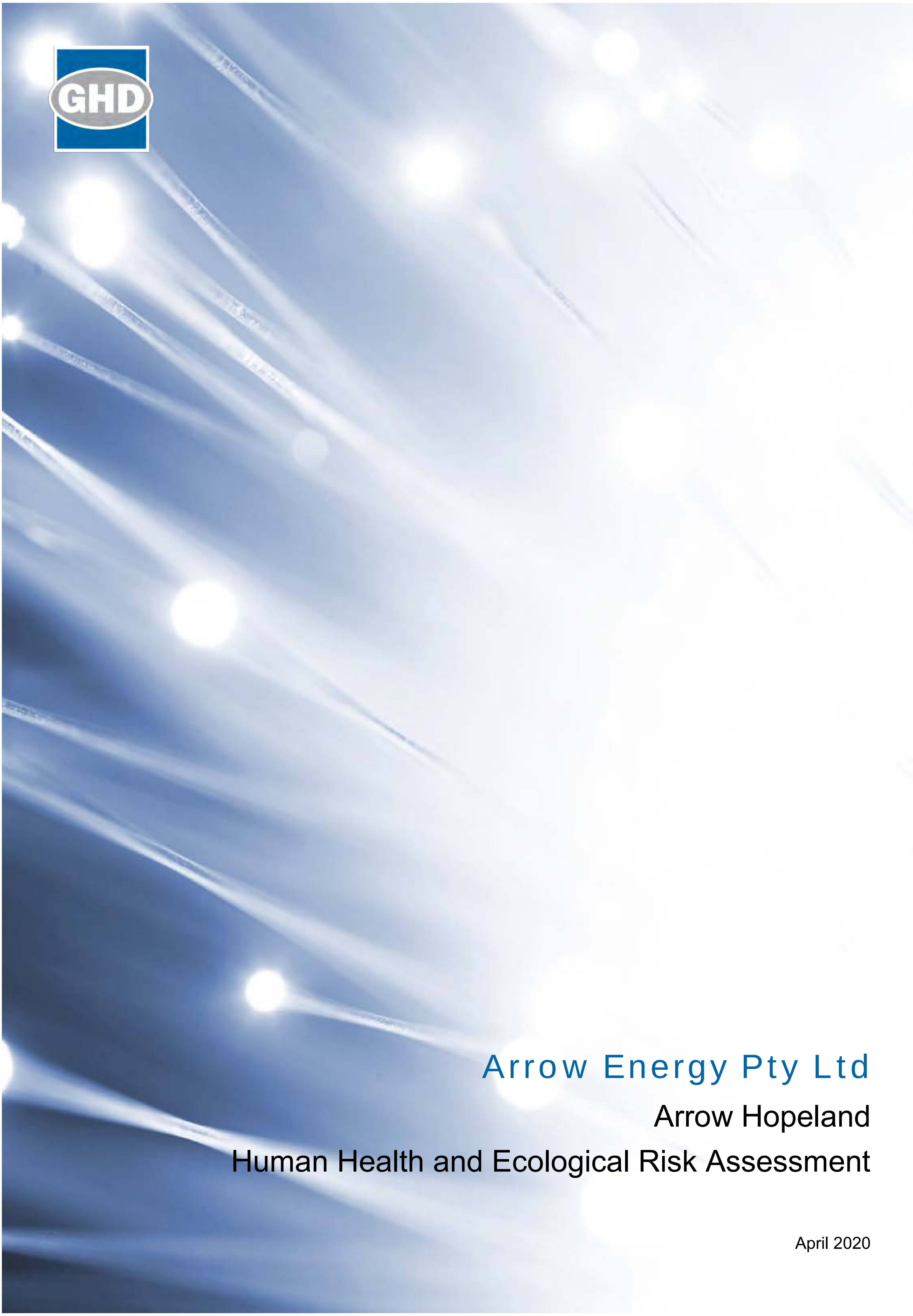
- I have not knowingly included false, misleading or incomplete information in the document.
- I have not knowingly failed to reveal any relevant information or document to the administering authority.
- The document addresses the relevant matters for the function and is factually correct.
- The opinions expressed in the document are honestly and reasonably held.

Yours sincerely,

Keith Phillipson

Principal Hydrogeologist | Team Lead

Appendix F – Hopeland HHERA Report



Arrow Energy Pty Ltd

Arrow Hopeland

Human Health and Ecological Risk Assessment

April 2020

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

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Appendices

1. Introduction

Arrow Energy Pty Ltd (Arrow) engaged GHD Pty Ltd (GHD) to undertake a Human Health and Ecological Risk Assessment (HHERA) for Lot 40 DY85 (the site). The site is located within Petroleum Lease (PL) PL253, at 357 Kummerows Road, Hopeland, approximately 20 km south-west of Chinchilla, QLD (*Figure 1; Appendix A*).

Arrow plan to develop PLA 253 for future Coal Seam Gas (CSG) extraction. In Queensland, an environmental authority (EA) is required to undertake industrial, resource or intensive agricultural activities with the potential to release contaminants into the environment. The EA that is relevant to the proposed CSG extraction activities at PLA 253 is EA0001401.

Linc Energy formerly operated the site as an Underground Coal Gasification (UCG) pilot trial site, which may have caused contamination of the underlying Walloon Coal Measures and Springbok Sandstone aquifers. The QLD Department of Environment and Science (DES) has expressed concern that the development of PLA 253 will contribute to the potential migration of this contamination offsite. As a consequence, as outlined within EA0001401, DES require Arrow to monitor groundwater quality and flow directions within the Springbok Sandstone aquifer and Walloon Coal Measures, to provide early notification of any changes in groundwater quality that may occur in response to CSG extraction.

The HHERA will focus on the development of Site Specific Trigger Values (SSTV) for groundwater quality within the Springbok Sandstone aquifer and Walloon Coal Measures, to support an application to reassess the groundwater quality triggers defined in the EA0001401.

1.1 Background

EA0001401 currently includes groundwater quality triggers for pH, electrical conductivity (EC), sixteen total and dissolved metals, phenolic compounds, polycyclic aromatic hydrocarbons (PAHs), total recoverable hydrocarbons (TRH), total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN). For phenolic compounds, PAHs, TPH, TRH and BTEXN the triggers are the laboratory limit of detection (LoR). Consequently, any detection above the LoR of these compounds in the groundwater monitoring points around the internal boundary of the site triggers a requirement for Arrow to undertake an investigation into the potential for environmental harm.

The groundwater quality triggers currently presented in EA0001401 do not represent the concentrations of these compounds that are potentially harmful for human health or the environment. For a number of the compounds, the triggers are also below the levels that may be present in groundwater as a result of natural processes, rather than anthropogenic activities. Arrow has engaged GHD to apply a risk-based approach to deriving SSTV for groundwater quality.

1.2 Scope and objectives

The overarching objective of the HHERA is to support an application by Arrow proposing revised groundwater quality triggers defined in EA0001401.

To achieve this objective, the HHERA has developed SSTV for compounds of potential concern (CoPC) including sixteen total and dissolved metals, phenolic compounds, PAHs, TPH, TRH and BTEXN in groundwater within PLA 253 within the Springbok Sandstone aquifer and Walloon Coal Measures. The SSTV have been derived following consideration of the following:

- Potential risks to human health and the environment that may be associated with the presence of the CoPC in the Springbok Sandstone aquifer and Walloon Coal Measures; and
- Levels of the CoPC that may be present in these aquifers as a result of natural processes rather than anthropogenic activities.

1.3 Risk assessment framework and methodology

This HHERA has been prepared with reference to the following legislation and guidance:

- QLD DES (2018) *Guideline - Environmental Protection (Water) Policy 2009 - Deciding aquatic ecosystem indicators and local water quality guidelines* ("QWQG" [1])
- Australia and New Zealand and Australian State and Territory Governments (ANZAST) (2018) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
- National Environmental Protection Council (NEPC) (2013) *National Environment Protection (Assessment of Site Contamination) Amendment Measure* (the "ASC NEPM")
- Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*

Risk assessments in Australia primarily follow the methodology outlined in the ASC NEPM Schedule B4, B5 and B7. The ASC NEPM outlines a methodical tiered approach to HHERA involving progressively more detailed levels of data collection and analysis.

Fundamental to the HHERA process is the development of a Conceptual Site Model (CSM), which is a description of the plausible mechanisms ('pathways'), by which people, sensitive environments or species ('receptors') may be exposed to chemicals in the environment ('sources'). Potential risks to the environment cannot occur unless there is a complete Source-Pathway-Receptor (SPR) linkage associated with an area of contamination. Conversely, a complete SPR linkage does not, by default, indicate that a receptor will be at risk. The risk assessment process is used to evaluate the extent of the potential risks to receptors identified in the CSM.

The overall approach adopted for the HHERA is outlined in the following diagram (modified from enHealth 2012a), and addressed in the following sections:

- Summary of relevant site information and available data relevant to the development of a CSM for chemicals groundwater at the site (Sections 2 and 3)
- Identification of published screening level guidelines that are protective of the potential effects of chemicals in groundwater on human health, livestock, crops and ecological health (Section 4)
- Characterisation of the concentrations of chemicals that are present in groundwater in the vicinity of the site, due to processes external to site operations (e.g. naturally occurring background) (Section 5)
- The selection of the SSTVs that could be applied by Arrow during the ongoing monitoring of groundwater within the Springbok Sandstone aquifer and Walloon Coal Measures, in a risk-based approach to the monitoring of groundwater quality at the site.

---

[1] QWQG- Queensland Water Quality Guidelines: Accessed 14/1/20 at: https://environment.des.qld.gov.au/__data/assets/pdf_file/0029/88148/deriving-local-water-quality-guidelines.pdf

1.4 Background documentation

To support the preparation of the HHERA, GHD was supplied with the following information.

- AECOM (2018a) *Bore Completion Reports* (separate documents for HSMB1D, HSMB1S, HSMB2D, HSMB2S, HSMB3D1, HSMB3D2, HSMB3S1, HSMB3S2, HSMB4D, HSMB4S, HSMB5D)
- AECOM (2018b) *Hopeland groundwater monitoring network - bore locations* (PDF map)
- An excel file entitled *Chemistry.xls,* which Arrow has indicated contains the analytical results obtained in groundwater monitoring activities undertaken by DES in the AECOM (2018a) onsite groundwater monitoring bores
- An excel file entitled *Bore Use.xls*, which Arrow has indicated contains details of the private landholder bores that are subject to monitoring by Arrow in the vicinity of the site
- An excel file entitled *SPbk_WCM.xls*, which Arrow has indicated contains the analytical results obtained for hydrocarbons in groundwater monitoring activities undertaken by Arrow in private landholder bores in the vicinity of the site
- An excel file entitled *20200402_chem request_GHD.xls*, which Arrow has indicated contains the analytical results obtained for metals in groundwater monitoring activities undertaken by Arrow in private landholder bores in the vicinity of the site
- GHD (GHD, 2019a) *Hopeland environmental authority groundwater characteristics monitoring program*
- GHD (GHD, 2019b) *Arrow Hopeland Groundwater Study - Groundwater Modelling Report (PL253)*
- GHD (GHD, 2019c) *Arrow Hopeland Groundwater Study - Preliminary Site Investigation*
- Arrow (2018) *Surat Gas Project Technical Note - Conceptual Groundwater Model and Assessment*
- Arrow (2019) *Hopeland Environmental Authority Groundwater Characteristics Monitoring Program Annual Report*.

1.5 Purpose of this report

The purpose of this report is to derive risk-based SSTV for the groundwater in the Walloon Coal Measures and Springbok Sandstone Aquifers underlying PLA 253 . The CoPC addressed in the SSTVs are metals (arsenic, barium, beryllium, boron, cadmium, chromium VI, chromium total, cobalt, copper, mercury, manganese, nickel, lead, vanadium and zinc), phenolic compounds, TPH, PAH and BTEXN.

1.6 Limitations

This report has been prepared by GHD for Arrow Energy Pty Ltd and *may only be used and relied on by Arrow Energy Pty Ltd for the purpose agreed between GHD and the Arrow Energy Pty Ltd as set out in Section 1.4 of this report.*

GHD otherwise disclaims responsibility to any person other than Arrow Energy Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer to Section 1.7 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Arrow Energy Pty Ltd and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has not been involved in the preparation of the an application to reassess the groundwater quality triggers defined in the EA0001401 and has had no contribution to, or review of the an application to reassess the groundwater quality triggers defined in the EA0001401 other than in the Arrow Hopeland Human Health and Ecological Risk Assessment. GHD shall not be liable to any person for any error in, omission from, or false or misleading statement in, any other part of the application to reassess the groundwater quality triggers defined in the EA0001401.

1.7 Assumptions

This report has been prepared on the basis of the following assumptions:

- The use of the site and surrounding properties will remain similar into the future as it was at the time of reporting.
- The health and environmental guidelines used in this HHERA were consistent with the regulatory guidance in place at the time of reporting.
- The findings presented within this report are primarily based upon the dataset provided by Arrow, as outlined in Section 1.4. The conclusions drawn in this HHERA are based on the assumption that this dataset is an accurate representation of conditions at the site.

2. Site description and setting

2.1 Site description

The site details are summarised in Table 2-1.

Table 2-1 Site details

Site name	Linc Energy Underground Coal Gasification Pilot Operations
Site address	357 Kummerows Road, Hopeland, Queensland 4413
Registered lot and plan Petroleum lease	Lot 40 on DY85 Surrounded by PLA 253
Site coordinates	Latitude : -26.92550, Longitude: 150.68356 (GDA 94)
Site area	5,176,710 m2 (517.67 ha)
Registered site owner	Linc Energy Ltd Site is managed by Queensland Government – DNRME
Local Government Authority	Western Downs Regional Council (WDRC)
Current zoning	Agricultural Land Classification – Class A
Current land use	The site is currently not in use QLD Globe Land use mapping indicates that the site mostly comprises of Grazing native vegetation, with portions mapped as Utilities associated with the UCG operations, Dam for process water and cropping
Source: GHD (2019c) *Arrow Hopeland Groundwater Study - Preliminary Site Investigation*	

2.2 Surrounding land use

Table 2-2 summarises the surrounding land uses.

Table 2-2 Surrounding land uses

Direction	Description
North	Agricultural land: cropping land and pasture production (adjacent)
East	Agricultural land: livestock and cropping land (adjacent) Woodland (~ 3 km) Kogan Creek Power Station (~6 km)
South	Agricultural land: livestock and cropping land (adjacent)
West	Agricultural land: livestock and cropping land (adjacent)

2.3 Climate

The site experiences hot, wet summers and cool, dry winters. Average evaporation exceeds rainfall in all months. The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI, 2019) database indicates that between 1989 to 2018 the site had an annual average rainfall of 591 mm and evaporation of 1,929 mm/yr.

2.4 Topography and drainage

The site is located in a westerly draining basin, with ground elevations ranging from approximately 209 m Australian Height Datum (AHD) in the west to 420 m AHD in the south. The site is relatively flat, ranging from approximately 315 to 320 m AHD. The site and its surrounds is drained by the westerly flowing Condamine River that passes through the central portion of the domain, as well as the south-westerly flowing Charleys Creek and the north-westerly flowing Wambo Creek (GHD, 2019c).

The nearest surface water bodies to the site are as follows:

- Wambo Creek – approximately 6 km to the west of the site
- Condamine River – approximately 7.5 km to the northeast of the site
- Kogan Creek – approximately 6 km to the east of the site

These watercourses are subject to flooding. There are also several minor unnamed non-perennial watercourses that generally follow the topography across the site and its surrounds (*Figure 2; Appendix A*).

2.5 Geology

2.5.1 Regional geology

The site located within the Surat Basin. The stratigraphic units reported to underlie the Surat Basin are detailed in Figure 1 below and can be described as follows:

- *Tertiary Alluvium* – Quaternary cover – comprises clay, clayey silt and clayey sand, with an average thickness of 30 to 40 m, deposited on the Condamine river floodplain during regular flooding events.
- *Westbourne Formation* – sequence of medium grey interbedded carbonate cemented lithic-feldspathic siltstones.
- *Springbok Sandstone* – fine sandstones with minor carbonaceous mudstone, mudstone and coal stringers. Medium to coarse grained, weakly cemented quartzo-feldspathic sandstone lenses less than 1 m in thickness are noted in many drill-holes in the region in a zone between 90 and 100 m deep, and form localised but discontinuous water-bearing zones. Near the contact with the underlying Walloon Coal Measures, the fine sandstone and siltstone becomes increasingly interbanded/interlaminated with carbonaceous mudstone and rare coal stringers.
- *Walloon Coal Measures* – comprising the upper (Juandah Coal Measures) and lower (Taroom Coal Measures) Macalister seams with an average thickness of 6 and 4 m respectively, and form an approximately 10 m thick unit. The unit occurs between 125 and 136 m bgl. The upper and lower seams are separated by an approximately 1 m layer of fine siltstone, with thickness increasing eastward. The seams are confined water-bearing units. The seams are subbituminous and further divided into the Kogan, Macalister, Wambo, Argyle, Upper Taroom and Condamine lithostratigraphic coal seam packages.
- *Jurassic-aged Hutton Sandstone* – sublabile to quartzose sandstones with interbedded siltstone and shale, with minor coal and mudstone.

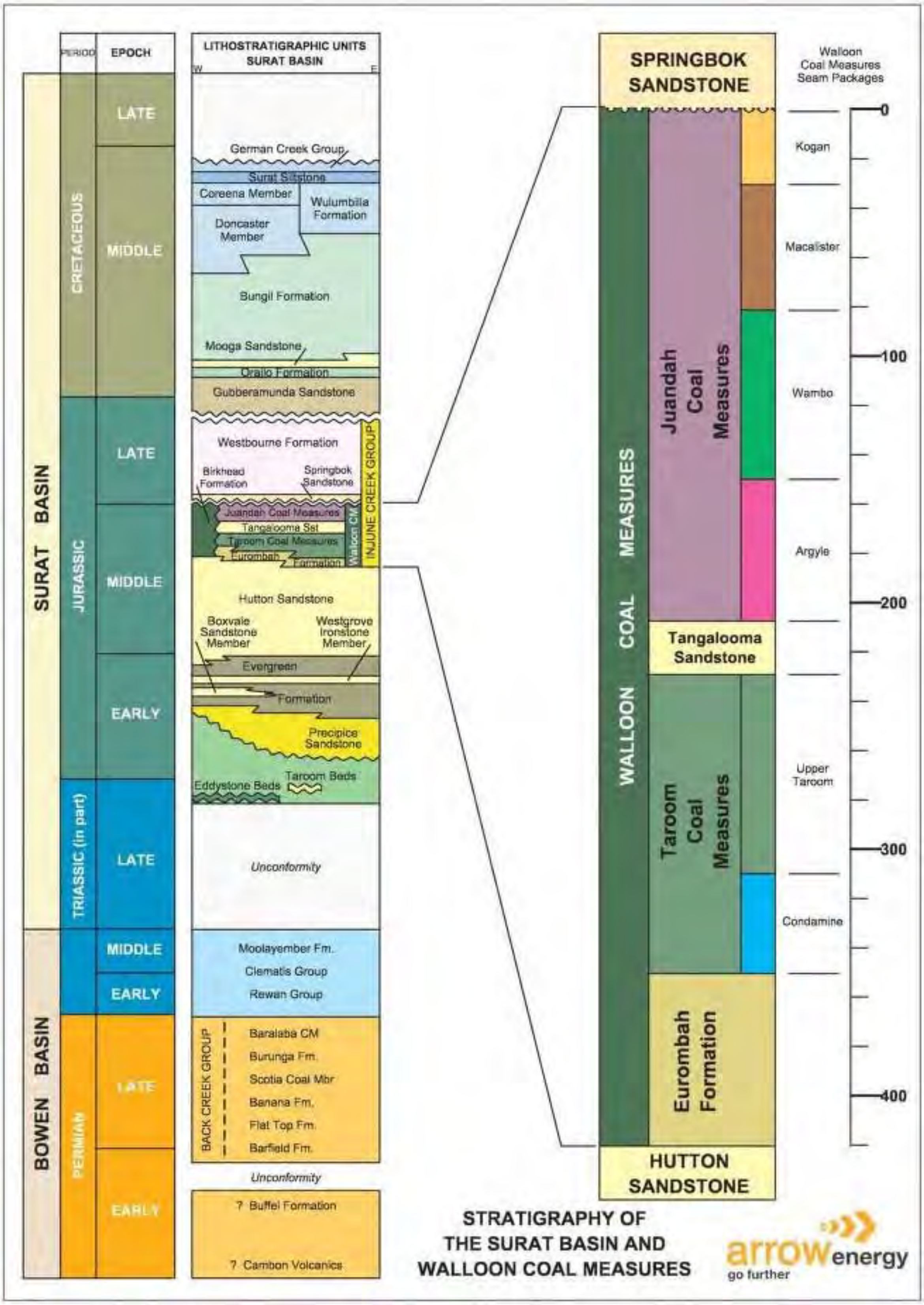


Figure 1 Surat Basin stratigraphic units (Arrow Energy, 2018)

2.5.2 Local geology

Based on the bore reports from Qld Globe database (QLD Government, 2020), the typical subsurface strata profile encountered within the site comprises the following:

- unconsolidated sediments (between 0 and 27 – 55.5 m bgl);
- Springbok Sandstone (between 27 – 55.5 and 108 -125 m bgl); and
- Walloon Coal Measures (starting at 108 – 125 m bgl), with the uppermost Macalister seam package of the Walloon Coal Measures generally occurring between 112-129 m and up to a depth of 166 m bgl (limit of drilling).

2.6 Hydrogeology

Regional groundwater flow follows the overall dip direction of the strata, generally from east to west in all aquifers (GHD, 2019c).

A generalised basin-wide schematic of the primary aquifers underlying the site are illustrated in Figure 2 below and include the following:

Condamine Alluvium

The Condamine Alluvium aquifer comprises gravels, fine-to coarse-grained channel sand interbedded with clays and is an unconfined aquifer that is generally less than 20 m thick in the area of the site. The water table sites several metres below the ground surface and responds to rainfall recharge events. The hydraulic gradient in the area of the site is downwards from the Condamine Alluvium to the Walloon Coal Measures. In the vicinity of the site the Condamine Alluvium is characterised by total dissolved solid (TDS levels ranging from 400-3000 mg/L TDS and a neutral to slightly alkaline pH (Arrow Energy, 2018).

Springbok Sandstone

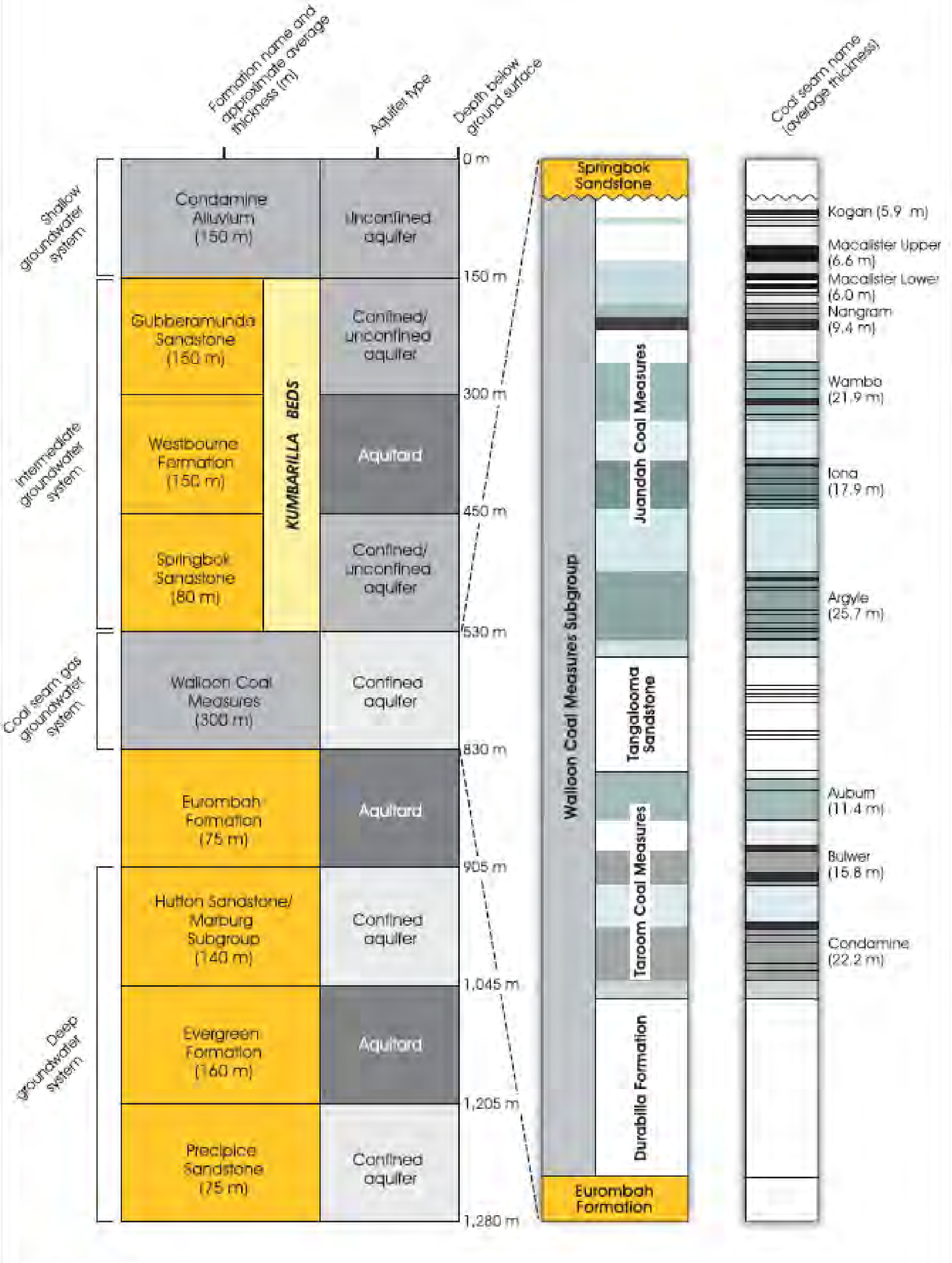
The Springbok Sandstone aquifer occurs as both a confined aquifer with sub-artesian pressures and an unconfined aquifer in areas where it outcrops. In the unconfined areas, water levels are likely to respond to rainfall infiltration. The hydraulic gradient in the area of the site is downwards from the Condamine Alluvium to the Walloon Coal Measures. The Springbok Sandstone is characterised by localised and discontinuous water-bearing zones. The Springbok Sandstone is also of variable water quality across the basin. In the vicinity of the site the Springbok Aquifer has reported TDS of < 9000 mg/L and a slightly alkaline pH (Arrow Energy, 2018).

Walloon Coal Measures

The Walloon Coal Measures is a confined aquifer. The thin permeable coal seams site within the Walloon Coal Measures, within a sequence of mainly low permeability mudstones, siltstones or fine-grained sandstones. As a series of discontinuous confined zones within the Walloon Coal Measures water bearing zones are sub-artesian and are not expected to show responses to rainfall events. In the vicinity of the site the Walloon Coal Measures are characterised by TDS levels ranging from approximately 1400-8000 mg/L TDS and a slightly alkaline pH of up to 8.8 (Arrow Energy, 2018).

Precipice Sandstone and Hutton Sandstone

The Precipice Sandstone and Hutton Sandstone aquifers are typically laterally continuous, have significant water storage and permeability and are extensively developed for groundwater use. These units are separated by aquitards (Arrow Energy, 2018).



Source: Data form Arrow Energy, Scott et al (2004)

Figure 2 Surat Basin aquifers (Arrow Energy, 2018)

2.7 Environmental values

To manage groundwater quality DES has carried out an extensive hydro-geochemical study of the Murray-Darling Basin hydrogeological units. The study mapped the groundwater sub-areas into zones, each of which has been designated Environmental values (EVs) and water quality objectives (WQOs)[2].

The site is located within the North Eastern Walloons zone of the Lower Great Artesian Basin division. The groundwater is this zone is characterised as saline (NaCl) and hard with occasional scaling during general use. The electrical conductivity (EC) and sometimes Na maybe excessive for sensitive crops.

The EVs for 'North East Walloons' zone are:

- Aquatic ecosystems
- Irrigation
- Farm water supply/use
- Stock watering
- Aquaculture
- Drinking water supply (suitable for treatment before supply as drinking water)
- Industrial use
- Cultural, spiritual and ceremonial values

2.8 Groundwater use

A search of the QLD Government Globe database[3] and Bureau of Meteorology Groundwater Bore database[4] and excel datasheets provided by Arrow indicates the presence of more than 80 registered bores within a 5 km radius of the centre of the site. Of these, 16 are registered for stock and domestic use, with the remainder being registered as 'Other'. The available data suggests that registered groundwater bores are installed within all of the primary aquifers detailed in Section 2.6. *Figure 3* of *Appendix* A shows the registered bores located within a 5 km radius of the site within the Study Area (GHD, 2019).

A summary of the bores that are known to be located in the vicinity of the site is presented in Appendix B.

Groundwater bores in the area surrounding the site are typically used for water supply for the purposes of stock watering (including intensive situations such as feedlots), irrigation and general domestic use (e.g. on gardens, in toilets). Within the site, groundwater is typically used for CSG-related purposes and extracted from a number of monitoring bores for the purposes of laboratory analysis.

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[2] https://www.environment.des.qld.gov.au/management/water/policy/consultations

[3] https://qldglobe.information.qld.gov.au/

[4] http://www.bom.gov.au/weave/explorer.html?max=true

2.9 Site history

Linc Energy operated five UCG gasifiers at the site. In a pilot trial between 1999 and 2013. The project moved into a decommissioning phase in November 2013. The target coal seams were the Upper and Lower Macalister seams of the Walloon Coal Measures, at the depth of about 120 m and with an average thickness of 6 and 4 m respectively (GHD, 2019c).

GHD understands that Linc Energy, through its operation of the UCG gasifiers within the Walloon Coal Measures at the site, allowed contaminants to escape into the overlying Springbok aquifer (Queensland Government, 2018), although specific information on the nature and extent of this contamination was not available for review at the time of reporting. The Queensland Government initiated legal proceedings, and Linc Energy was found guilty of five counts of wilfully and unlawfully causing serious environmental harm. The Queensland Government acquired responsibility for the management of the site, which is currently under care and maintenance. The DNRME now has responsibility for the site and DES remains actively involved in environmental management and site rehabilitation.

Access to the property is via Kummerows Road, which runs along the southern boundary of the site. At the time of reporting the site infrastructure remained intact and the site was in care and maintenance mode, overseen by DNRME. The UCG infrastructure is located within the south-western portion of the site.

2.10 Ongoing groundwater monitoring works

GHD understands that DES and Arrow are undertaking the ongoing monitoring of groundwater quality onsite, immediately external to the site perimeter and in the private wells located within surrounding properties. The information provided by Arrow indicated that DES is responsible for the monitoring of eleven bores installed within the Springbok Sandstone and Walloon Coal Measures aquifers, immediately inside the site boundary (Bore IDs HSMB1D, HSMB1S, HSMB2D, HSMB2S, HSMB3D1, HSMB3D2, HSMB3S1, HSMB3S2, HSMB4D, HSMB4S and HSMB5D). Arrow has also indicated that, at the time of reporting, Arrow was installing additional groundwater monitoring bores in the Springbok Sandstone and Walloon Coal Measures in the area surrounding the site boundary. GHD understands that these additional offsite bores and a number of private offsite landowners bores will be subject to ongoing monitoring under EA0001401.

3. Conceptual site model

3.1 Sources

GHD understands that, due to Linc’s activities at the site, CoPC may be present within the groundwater underlying the site. The sources of potential contaminants are the ash and char within the gasifiers and the contaminants that have migrated into surrounding strata via induced fractures and possibly the annulus of inadequately sealed boreholes (GHD, 2019c).

According to EA0001401, DES require Arrow to monitor the concentrations of sixteen total and dissolved metals (arsenic, barium, cadmium, chromium [VI and total], cobalt, copper, mercury, manganese, nickel, lead, vanadium, zinc, beryllium, boron and selenium), phenolic compounds, PAHs, TPH, TRH and BTEXN in groundwater around the boundary of the site within the Springbok Sandstone aquifer and Walloon Coal Measures. The focus of this HHERA is therefore the derivation of SSTV for these CoPC within the Springbok Sandstone and Walloon Coal Measure aquifers. It is noted that a number of the CoPC occur naturally within both the Springbok Sandstone aquifer and Walloon Coal Measures.

Detailed information on the specific nature and extent of the onsite contamination was not available for review at the time of reporting but Arrow provided GHD with an excel file containing the raw results obtained during the sampling of a variety of onsite groundwater monitoring wells (*Chemistry_Results.xls*). This raw data indicated that the PAH compounds that have been detected in onsite groundwater have included anthracene, acenaphthylene, acenaphthene, fluorene, naphthalene, pyrene and phenanthrene and that the phenol compounds that have been detected in onsite groundwater have included phenol, 2-methylphenol, 3-& 4-methylphenol and 2,4-dimethylphenol.

A summary of the CoPC concentrations identified in the onsite boundary monitoring wells (HSMB1D, HSMB1S, HSMB2D, HSMB2S, HSMB3D1, HSMB3D2, HSMB3S1, HSMB3S2, HSMB4D, HSMB4S, HSMB5D), as indicated in the *Chemistry_Results.xls* spreadsheet is provided in Table 3-1. The available dataset indicates that petroleum hydrocarbons, polycyclic aromatic hydrocarbons and phenols have been identified in all of the onsite boundary monitoring wells.

Table 3-1 Summary of CoPC concentrations reported in onsite boundary monitoring wells

Chemical	Concentrations reported in onsite boundary monitoring wells (mg/L)
Metals	
Arsenic (Total)	<LoR - 0.005
Arsenic (Dissolved)	<LoR - 0.005
Barium (Total)	0.01 - 51.1
Barium (Dissolved)	<LoR - 10.4
Beryllium (Total)	<LoR
Beryllium (Dissolved)	<LoR
Boron (Total)	0.08 - 2.81
Boron (Dissolved)	0.05 - 0.53
Cadmium (Total)	<LoR - 0.0072
Cadmium (dissolved)	<LoR - 0.0001
Chromium (VI) (Total)	ND
Chromium (VI) (dissolved)	ND
Chromium (total) (Total)	<LoR - 0.153
Chromium (total) (Dissolved)	<LoR - 0.002
Cobalt (Total)	<LoR - 0.05
Cobalt (Dissolved)	<LoR - 0.013
Copper (Total)	0.004 - 6.36
Copper (Dissolved)	<LoR - 0.4
Mercury (Total)	<LoR
Mercury (Dissolved)	<LoR
Manganese (Total)	<LoR - 10.4
Manganese (dissolved)	<LoR - 6.63
Nickel (Total)	<LoR - 0.435
Nickel (Dissolved)	<LoR - 0.087
Lead (Total)	0.005 - 2.35
Lead (Dissolved)	<LoR - 0.007
Selenium (Total)	<LoR
Selenium (Dissolved)	<LoR
Vanadium (Total)	<LoR - 0.01
Vanadium (Dissolved)	<LoR - 0.01
Zinc (Total)	<LoR - 2.8
Zinc (Dissolved)	<LoR - 1.24
Phenolic compounds*	
Phenol	<LoR - 0.0155
2-methylphenol	<LoR - 0.0036
3-& 4-methylphenol	<LoR - 0.0059
2,4-dimethylphenol	<LoR - 0.0015
Total petroleum hydrocarbons	
TPH>C_{10}–C_{16}	<LoR - 8.17
TPH>C_{16}–C_{34}	
TPH>C_{34}–C_{40}	

Chemical	Concentrations reported in onsite boundary monitoring wells (mg/L)
Polycyclic aromatic hydrocarbons	
Anthracene	<LoR - 0.0015
Acenaphthylene	<LoR - 0.0139
Acenaphthene	<LoR - 0.0044
Fluorene	<LoR - 0.088
Naphthalene	<LoR - 0.345
Pyrene	<LoR - 0.0015
Phenanthrene	<LoR - 0.073
BTEX	
Benzene	<LoR - 1.59
Toluene	<LoR - 0.3
Ethylbenzene	<LoR - 0.034
Xylenes	<LoR - 0.042

A number of additional volatile organic compounds have been detected in onsite groundwater, including styrene, chlorobenzene, vinyl chloride, 1,2,4-trimethylbenzene, 1,1,2-trichloroethane dibromochloromethane, chloroform, Methyl tert-butyl ether (MTBE), methane, 1.2-dichloroethane, 2-propanone (acetone), 2-butanone (MEK) and tetrachloroethene (PCE). These compounds are however outside the scope of this HHERA.

3.2 Migration pathways

The leaching of ash and char by waters infiltrating the gasifier may concentrate CoPC within the gasifier voids, however, any CoPC that have deposited within the strata may also be transported out of the gasifers either under the natural groundwater gradient or via induced migration through dewatering activities of adjacent CSG developments (GHD, 2019c).

The CoPC may migrate laterally in groundwater from the area of impact. Alternate contaminant transport pathways could also occur where upward vertical fracturing has created a pathway for transport upward from the coal into overlying interburden or the Springbok Sandstone and a driving pressure was present to move the contaminant into overlying units (GHD, 2019c).

3.3 Receptors

The aquifers of concern for this HHERA, the Springbok Sandstone and Walloon Coal Measures are located at depth and are therefore unlikely to discharge directly to surface water. Springs have not been identified in the vicinity of the site (GHD, 2019c). The rivers and landscapes surrounding the site have been identified as having a low potential to be groundwater dependent ecosystems (Bureau of Meteorology, 2020). On this basis, the exposure scenarios of greatest concern for the CoPC in onsite groundwater therefore relate to groundwater extraction and use. The receptors that may be exposed to extracted groundwater have been identified following consideration of both the reported uses of the bores installed within 5 km of the site (Section 2.8) and the EVs requiring protection (Section 2.7) and are as follows:

- *Human receptors* - offsite landholders operating bores for a variety of potential uses, including stock watering, domestic non-potable purposes and irrigation
- *Agricultural receptors* – livestock watered with extracted groundwater, crop plants irrigated with extracted groundwater and aquaculture species grown within surface water storage reservoirs (e.g. dams) filled with extracted groundwater

- *Ecological receptors* - aquatic and terrestrial organisms residing or watering within surface water storage reservoirs (e.g. dams) filled with extracted groundwater.

3.4 Conceptual Site Model summary

The Source-Pathway-Receptor linkages that are applicable to any CoPC that may be present in onsite groundwater are summarised in Table 3-2.

Table 3-2 Conceptual site model for onsite groundwater

Source	Transport pathway	Receptors	Exposure pathways	Comment
Metals, BTEXN, TRH and PAH in onsite groundwater	Lateral migration in groundwater, groundwater extraction and use	Human users of extracted groundwater in offsite areas	Direct contact (incidental ingestion and dermal contact) Inhalation of volatiles	People may be exposed to extracted groundwater during its use for non-potable domestic purposes (e.g. watering gardens, showering, filling swimming pools) or agricultural purposes (e.g. irrigation) The Australian drinking water guidelines (NHMRC, 2011) indicate that, based on taste, TDS in drinking water should not exceed 600 mg/L and that water will become increasingly undrinkable in the 1000 to 2000 mg/L range. Based on the TDS levels and hardness reported in the private bores installed within the Springbok Sandstone and Walloon Coal Measures in the area surrounding the site, it is unlikely that that extracted groundwater will used for potable purposes
		Livestock	Consumption	Livestock can tolerate water with TDS levels of between 2000 and 10,000 mg/L (ANZECC/ARMCANZ, 2000). Extracted groundwater may therefore be suitable for use as a primary water source for farmed livestock (including intensively reared animals)
		Crop plants	Direct contact and uptake	Extracted groundwater may be used for the irrigation of crop plants
	Lateral migration, groundwater extraction and storage (e.g. in a dam)	Human users of groundwater stored in dams	Direct contact (incidental ingestion and dermal contact)	People may be exposed to extracted groundwater stored in dams (e.g. swimming)
		Aquatic organisms (including aquaculture species)	Direct contact and uptake	Extracted groundwater may be stored within farm dams, inhabited native and/or aquaculture species
		Terrestrial organisms	Consumption	Terrestrial organisms may rely heavily on farm dams as a drinking water source. Extracted groundwater may be stored within farm dams.

4. Water quality guidelines

4.1 Introduction

The Tier 1 screening assessment process forms the ‘source’ characterisation component of the ‘source-pathway-receptor’ relationship. Broadly, the Tier 1 risk assessment involves the comparison of the measured CoPC concentrations in the environment with conservative published Tier 1 screening values. The aim of this process is to focus a contamination investigation and/or risk assessment on the CoPCs that have the potential to result in risk to human health or the environment.

In the context of the ongoing monitoring of groundwater quality at the site, published Tier 1 screening assessment process can be used to evaluate whether the CoPC concentrations identified within the groundwater monitoring network have the potential to be associated with a potential risk to human health or the environment or could result in the groundwater being unsuitable for agricultural use.

Due to the conservatism of the Tier 1 screening process, there is high confidence that if a constituent concentration is below the Tier 1 screening values, it does not pose a significant human health or ecological risk. However, constituents that are present at concentrations above the Tier 1 screening values do not necessarily pose a significant risk. Instead, exceedances of Tier 1 values indicate the need for additional evaluation based on site-specific conditions.

In this HHERA, the Tier 1 screening values have been chosen, as far as possible, to align with the SPR linkages identified in the CSM. Appropriate Tier 1 screening values were not however available for all of the identified SPR linkages and the approach adopted in these instances is detailed in the following subsections.

Where available, Australian guidelines have been used. In the absence of data from these sources, Tier 1 screening values from other recognised international sources were selected i.e. the United States Environmental Protection Agency (US EPA), National Oceanic and Atmospheric Administration (NOAA), World Health Organisation (WHO), Canadian Council of Ministers of the Environment (CCME),NZ Ministry for the Environment (MfE) and the Netherlands National Institute of Public Health and the Environment (RIVM). These agencies use published toxicological and ecotoxicological data and risk-based approaches to derive conservative and transparent screening benchmarks.

4.2 Summary of adopted water quality guidelines

The tier 1 screening values identified in association with each of the SPR linkages identified in the CSM are summarised in Table 4-1 and discussed in the following subsections.

Table 4-1 Summary of tier 1 screening levels

Chemical	Non-Potable Human Use (mg/L)	Livestock Watering (mg/L)	Irrigation (mg/L)	Aquatic organism protection (mg/L)
Metals				
Arsenic	0.1[1]	0.5[5]	0.1[6]	0.042[7]
Barium	13[2]	1.3[8]	-	-
Beryllium	0.6[1]	0.06[8]	0.1[6]	-
Boron	40[1]	5[5]	0.5[6]	0.68[7]
Cadmium	0.02[1]	0.01[5]	0.01[6]	0.0047[7,D]
Chromium (VI)	0.5[1]	1[5]	0.1[6]	0.006[7]
Chromium (total)	N/A[A]	N/A[A]	N/A[A]	N/A[A]
Cobalt	0.06[3]	1[5]	0.05[6]	0.0014[7]
Copper	20[1]	0.4[5]	0.2[1]	0.0018[7,D]
Mercury	0.01[1]	0.002[5]	0.002[6]	0.00006[7,C]
Manganese	5[1]	N/A[B]	0.2[6]	2.5[7]
Nickel	0.2[1]	1[5]	0.2[6]	0.013[7]
Lead	0.1[1]	0.1[5]	0.1[6]	0.0056[7,D]
Selenium	0.1[1]	0.02[5]	0.02[6]	0.005[7,C]
Vanadium	0.1[1]	0.01[8]	0.1[6]	0.006[7]
Zinc	30[1]	20[5]	2[6]	0.015[7]
Phenolic compounds*				
Phenol	58[3]	5.8[8]	1.8[2]	0.6 [7]
Cresols (sum)[F]	15[3]	1.5[8]	-	-
2,4-dimethylphenol	3.6[3]	0.36[8]	-	0.002[7]
Total petroleum hydrocarbons				
TPH>C_{10}–C_{16}	0.9 (aromatic) – >S[J] (aliphatic)[4]	S[10,H]	>S[10,H]	0.056 (aromatic) – S[H] (aliphatic) [9]
TPH>C_{16}–C_{34}	>S[4,H]	>S[10,H]	>S[10,H]	>S[9,H]
TPH>C_{34}–C_{40}	>S[H]	>S[H]	>S[H]	S[E]
Polycyclic aromatic hydrocarbons				
Anthracene	18[3]	1.8[8]	-	0.0015[7]

Chemical	Non-Potable Human Use (mg/L)	Livestock Watering (mg/L)	Irrigation (mg/L)	Aquatic organism protection (mg/L)
Acenaphthene	5.3[3]	0.53[8]	-	0.0058[11]
Acenapthylene	-	-	-	-
Fluorene	2.9[3]	0.29[8]	-	0.003[11]
Naphthalene	0.02[3]	0.16[11]	0.8[11]	0.037[7]
Phenanthrene				0.0006 [7,C]
BTEX				
Benzene	0.01[1]	4[11]	0.8[11]	1.3[7]
Toluene	8[1]	8[11]	39[11]	0.23 [7]
Ethylbenzene	3[1]	4[11]	18[11]	0.11[7]
Xylenes	6[1]	8[11]	13[11]	0.1[7,G]

- Appropriate published value not identified

* Screening criteria identified for the individual compounds identified in onsite groundwater, as indicated by the raw results excel file provided by Arrow (Section 3.1)

[1] NHMRC (2011) Australian drinking water guidelines, multiplied by 10

[2] WHO (2011) Drinking water guidelines; multiplied by 10

[3] US EPA (2019) Regional Screening Level (RSL) for tap water; multiplied by 10. Carcinogenic compounds multiplied by an additional factor of 10 to correct adjust the ILCR of 1:1,000000 to 1:100,00

[4] WHO (2008) Petroleum products in drinking water; multiplied by 10. Separate values presented for aromatic and aliphatic fractions

[5] ANZECC (2000) livestock drinking water trigger values

[6] ANZECC (2000) long term trigger values for irrigation water

[7] ANZAST (2018) 90% species protection value

[8] NHMRC (2011) Australian drinking water guidelines, adopted in accordance with the approach recommended by ANZAST (2018) for chemicals without livestock-specific guidelines

[9] Verbruegen (2004) Netherlands environmental quality standards for the protection of ecosystems. MPC (Maximum Permissible Concentrations) are provided for several THP fractions and the screening levels calculated by adding the relevant MPC

[10] Ministry for the environment (1999) values for the protection of stock health (Table 5.6 of the MfE report) and irrigation water quality (Table 5.7 of the MfE report)

[11] Canadian (CCME, 1999a) Environmental Water Quality Guidelines for PAH

[A] Limited data has been published regarding the toxicity of Cr (III) but the available data suggests that Cr (III)) is of relatively low toxicity following oral exposures (US EPA, 1998) and is less toxic than Cr(VI) to aquatic organisms (ANZAST, 2018)

[B] Limited oral toxicity (ANZECC, 2000)

[C] Potentially bioaccumulative substance – 99% species protection level adopted

[D] Hardness correction not made on the basis that a wide range of hardness levels has been reported (<1 to 252 mg/L) in the limited data provided by Arrow in excel format

[E] Solubility is too low to allow for the calculation of screening levels. Toxicity is consider negligible doe to the low solubility (Verbruggen, 2004)

[F] Cresol (sum) is the sum of 2-methylphenol (O-cresol), 3-methylphenol(m-cresol) and 4-methylphenol (p-cresol)

[G] Based on the lowest guideline of all xylenes reported, which corresponds to m-xylene.

Chemical	Non-Potable Human Use (mg/L)	Livestock Watering (mg/L)	Irrigation (mg/L)	Aquatic organism protection (mg/L)
[H] >S indicates calculated criterion exceeds the solubility limit for most compounds in this range, when present in a gasoline mixture, as indicated by the solubility limits presented by CRC CARE (2011)				

4.2.1 Water quality guidelines relevant to human health receptors

In the event that the CoPC in onsite groundwater migrate into offsite areas, landholders may be exposed to extracted groundwater during its use for non-potable domestic purposes (e.g. watering gardens, showering, filling swimming pools) or agricultural purposes (e.g. irrigation).

The NHMRC (2011) *Australian drinking water quality guidelines*, are designed to be protective of the potable use of water and represent the chemical concentrations that adult water users can use for potable purposes (i.e. consumption of 2L/day, 365 days/year) without risk of adverse health effects. Given that the groundwater within the Springbok Sandstone and Walloon Coal Measures is not potable, the use of these values for the monitoring of groundwater at the site is likely to overestimate risk.

NHMRC (2008) published the *Guidelines for Managing Risks in Recreational Water*, which are designed to protect human health from threats posed by the recreational use of surface waters. For chemical contaminants, NHMRC (2008) suggests that the chemical exposure that may occur during activities such as swimming could be equivalent to 10% of drinking water consumption (i.e. 200 mL/day). For a simple screening approach to the assessment of recreational water quality NHMRC (2008) therefore suggest multiplying drinking water quality guidelines by a factor of 10. This approach has been adopted in this HHERA to derive screening values applicable to the non-potable domestic use of groundwater.

In the absence of an appropriate guideline in the NHMRC (2011) *Australian drinking water quality guidelines*, drinking water guidelines have been sourced from the WHO (2017) *Guidelines for drinking water quality*, WHO (2008) *Petroleum products in drinking-water* and US EPA (2019) *Regional screening levels (RSLs) database*.

The ASC NEPM requires that risk assessments in Australia adopt an increased lifetime risk of cancer (ILCR) of 1:100,000, whereas the US EPA (2019) RSLs were calculated on the basis of an ILCR of 1:1,000,000. The RSLs for naphthalene has therefore been adjusted upwards by a factor of 10, in addition to the factor of 10 applied to calculate screening levels for the non-potable domestic use of groundwater.

4.2.2 Water quality guidelines relevant to the agricultural use of groundwater

At the time of reporting, ANZAST (2018) was referencing the ANZECC/ARMCANZ (2000) guidance for livestock drinking water as the source from which to obtain surface water quality guidelines for livestock, although it was noted that this was under review. The screening levels presented by ANZECC/ARMCANZ (2000) have therefore been adopted in this assessment.

The New Zealand Guidelines for Assessing and Managing Petroleum Hydrocarbon Sites in New Zealand Ministry for the Environment (MfE) (1999) have been adopted as screening levels for TPH and some PAHs, as this document includes a specific set of guidelines for livestock drinking water. These guidelines, however, do not account for palatability aesthetic impact for livestock (as no reliable information was available).

ANZAST (2018) also suggests that, in the absence livestock drinking water guidelines specific to individual chemicals, that the drinking water guidelines for human health be adopted. This approach has also been adopted in this assessment for chemicals without ANZECC (2000) or NZ MfE (1999) guidelines.

The long-term trigger values for irrigation water quality presented by ANZECC/ARMCANZ (2000) have been adopted for this potential groundwater usage scenario. In the absence of ANZECC (2000) irrigation guidelines for TPH, phenolic compounds and PAH, the New Zealand MfE (1999) irrigation guidelines have also been adopted. The New Zealand MfE irrigation guidelines have been derived on the basis of the following considerations:

- To protect the health of adults and children that might come in contact with groundwater during use for irrigation
- To protect against the adverse health effects that may be associated with the formation of vapours during irrigation
- To protect against the health effects of consuming home growth product irrigated with contaminated groundwater
- Aesthetic impacts, including odour

4.2.3 Water quality guidelines relevant to ecological receptors

ANZAST (2018) provides water quality guidelines, statistically derived to be protective of between 99% and 80% of aquatic organisms. These values have been used in this assessment for the protection of aquatic organisms, including plants, invertebrates and vertebrates inhabiting water storages that are filled with groundwater, potentially including aquaculture species.

Farm dams are generally isolated man-made structures, often with limited flushing and water quality issues such as nutrient enrichment due to use by livestock. These waterbodies have inherent ecological values but for practical reasons it is not feasible that they be maintained in slightly to moderately disturbed condition. For the purpose of this assessment, farm dams have therefore been classified as being measurably degraded ecosystems and the water guidelines for the protection of 90% of aquatic species adopted. The 90% protection values are designed to be applied to waterbodies where a functional yet modified ecosystem can be supported.

For a number of metals, the default ANZAST (2018) aquatic ecosystem protection values are specific to a water hardness level of 30 mg/L $CaCO_3$. It is recommended that these guidelines are corrected based on site-specific hardness data, as elevated levels of $CaCO_3$ hardness can limit metal bioavailability and therefore toxicity to aquatic organisms. The limited chemistry dataset provided to GHD at the time of reporting (Arrow Excel spreadsheets entitled *Chemistry_Result.xls* and *SPbk_WCM_CHem.xls*) indicated that the hardness of groundwater extracted from the aquifers surrounding the site and surrounding areas ranges from < 1 mg/L to 252 mg/L. Insufficient data was available to support the site-specific correction of the default ANZAST (2018) guidelines and therefore these were retained for the purpose of this assessment.

Although terrestrial and semi-terrestrial wildlife drinking water is not a community value currently covered by ANZAST (2018), it is generally considered that the guideline values for the protection of aquatic ecosystems will be sufficient to protect wildlife from detrimental effects associated with drinking contaminated water.

Specific considerations for TPH and PAH

TPH

ANZAST (2018) does not provide aquatic protection guidelines for TPH but Dutch regulators have adopted sediment and water guidelines to protect ecosystems from TPH exposures (Verbruggen, 2004) These guidelines provide risk limits split for various hydrocarbon fractions and types (i.e. aliphatic or aromatic). The risk limits have been derived using toxicity data for marine species (amphipods, echinoderms, bacteria) and freshwater species (including nematodes, amphipods, midges and mayfly). The freshwater taxons used are relevant to the water bodies expected to be impacted by the TPHs.

Toxicity data, reported as LC50[5], EC10[6], EC50[7] and NOEC[8] was used to derive Species Sensitivity Distribution (SSD) and calculate Maximum Permissible concentrations (MPC). MPC represent the concentrations at which 95% of the species are protected, which is an approach slightly more conservative than ANZECC 90% DGV adopted for the other chemicals, but calculated with the same method. Hence, MPC have been considerated adequate for the protection of freshwater ecosystems in the water bodies potentially impacted by TPHs.

The Dutch guidelines have been used to screen the impact in aquatic organisms as indicated in Table 4-1. In order to provide screening levels for the TPH fractions reported in the analytical results, several fraction guidelines have been added to derive a guideline for an equivalent fraction range.

PAHs

The screening levels for a number of PAH compounds, without applicable ANZAST (2018) values, have been sourced from the Canadian Environmental Water Quality Guidelines for PAH (CCME, 1999a).

4.2.4 Cultural and spiritual values

ANZAST (2018) does not provide screening values specifically for the protection of cultural and spiritual values. Instead, it is recommended that, in order to protect the cultural and spiritual values of waterways, consideration should be given to whether the screening levels applicable to other community values and the protection of aquatic ecosystems, can also support the protection of the water quality components of cultural and spiritual values. In this setting, screening levels have been developed for the range of potential groundwater use scenarios, including aquatic organism exposures. These screening levels are also likely to be adequately protective of the potential cultural and spiritual values of the groundwater.

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[5] Lethal concentration required to kill 50% of the population

[6] Effect concentration where 10% of test organisms exhibit an inhibition effect

[7] Effect concentration where 50% of test organisms exhibit an inhibition effect

[8] The highest tested concentration that has no observed effects on the test organisms

5. Background groundwater quality assessment

5.1 Introduction

ANZAST (2018) suggests that a referential approach can be used to derive locally relevant water quality guideline values, particularly for chemicals where background concentrations naturally exceed the published toxicity-based guidelines. In this approach, the natural range of values for key indicators at reference sites is used to provide a suitable baseline. Ideal reference sites are similar to assessment sites (e.g. similar climate, relief and geology) but are minimally impacted, have limited exposure to anthropogenic drivers, and have sufficient historical data to characterise water quality condition and variability.

5.2 Local bore data

Arrow provided GHD with a limited groundwater monitoring dataset, within the following documentation:

- *SPbk_Walloon Coal Measures_Chem.xls*: An excel file summarising the analytical results obtained in single groundwater monitoring events undertaken in a selection of four private (landholder-owned) groundwater bores installed within the Springbok Sandstone and 12 private groundwater installed within the Walloon Coal Measures bores installed within an approximately 20 km radius of the site. Groundwater chemistry data was also provided for hydrogeological monitoring bores installed at the site.
- *Chemistry_Results.xls*: An excel file summarising the analytical results obtained in multiple groundwater monitoring events undertaken in a selection of site monitoring bores.
- *20200402_chem request_GHD.xls*: An excel file summarising the analytical results obtained for metals in single groundwater monitoring events undertaken in four private (landholder-owned) groundwater bores installed within the Springbok Sandstone and 16 private groundwater bores installed within the Walloon Coal Measures within an approximately 20 km radius of the site. Two rounds of data were provided for one of the Springbok Sandstone bores and eight of the Walloon Coal Measure bores.

The data in these files has been reviewed, to provide an indication of the background water quality in the Springbok Sandstone and Walloon Coal measure aquifers underlying the site.

GHD was also supplied with a number of site-specific reports, including the Arrow (2019) *Hopeland environmental authority groundwater characteristics monitoring program annual report* and Arrow (2018) *Conceptual groundwater model and assessment* but these documents did not include chemistry datasets pertaining to the chemicals of interest to this HHERA and therefore have not been included in the background groundwater quality data set.

A summary of the range of concentrations identified in the provided datasets for the chemicals of interest to this HHERA is presented in Table 5-1.

Table 5-1 Summary of CoPC concentrations reported in onsite boundary monitoring wells

Chemical	Concentrations reported in private landholder bores (mg/L)	
	Springbok Sandstone	Walloon Coal Measures
Metals		
Arsenic (Total)	<LoR (0/4)*	<LoR (0/16)*
Arsenic (Dissolved)	<LoR – 0.002 (1/4)*	<LoR (0/16)*
Barium (Total)	0.28 – 3.43 (4/4)*	0.11 – 6.7 (16/16)*
Barium (Dissolved)	0.27 – 3.22 (4/4)*	0.09 – 5.7 (16/16)*
Beryllium (Total)	<LoR (0/4)*	<LoR (0/16)*
Beryllium (Dissolved)	<LoR (0/4)*	<LoR (0/16)*
Boron (Total)	0.21 – 0.44 (4/4)*	0.12 – 1.1 (16/16)*
Boron (Dissolved)	0.24 – 0.39 (4/4)*	0.15 – 1.1 (16/16)*
Cadmium (Total)	<LoR (0/4)*	<LoR – 0.002 (1/16)*
Cadmium (dissolved)	<LoR (0/4)*	<LoR (0/16)*
Chromium (VI) (Total)	<LoR (0/4)*	No data provided
Chromium (VI) (dissolved)	No data provided	<LoR
Chromium (total) (Total)	<LoR (0/4)*	<LoR – 0.002 (1/16)*
Chromium (total) (Dissolved)	<LoR – 0.001 (1/4)*	<LoR
Cobalt (Total)	<LoR (0/4)*	<LoR (0/16)*
Cobalt (Dissolved)	<LoR (0/4)*	<LoR (0/16)*
Copper (Total)	<LoR – 0.07 (2/4)*	<LoR – 0.06 (9/16)*
Copper (Dissolved)	<LoR – 0.008 (1/4)*	<LoR – 0.006 (3/16)*
Mercury (Total)	<LoR (0/4)*	<LoR (0/16)*
Mercury (Dissolved)	<LoR (0/4)*	<LoR (0/16)*
Manganese (Total)	0.01 – 0.64 (4/4)*	<LoR – 0.036 (15/16)*
Manganese (dissolved)	0.01 0.53 (4/4)*	<LoR – 0.27 (16/16)*
Nickel (Total)	<LoR (0/4)*	<LoR (0/16)*
Nickel (Dissolved)	<LoR – 0.003 (1/4)*	<LoR (0/16)*
Lead (Total)	<LoR – 0.01 (1/4)*	<LoR – 0.02 (5/16)*
Lead (Dissolved)	<LoR – 0.003 (1/4)*	<LoR – 0.005 (2/16)*
Selenium (Total)	<LoR (0/4)*	<LoR (0/16)*
Selenium (Dissolved)	<LoR (0/4)*	<LoR (0/16)*
Vanadium (Total)	<LoR (0/4)*	<LoR – 0.0004 (1/16)*
Vanadium (Dissolved)	<LoR (0/4)*	<LoR (0/16)*
Zinc (Total)	<LoR – 0.044 (3/4)*	<LoR – 1.7 (14/16)*
Zinc (Dissolved)	<LoR – 0.103 (3/4)*	<LoR – 0.27 (9/16)*
Phenolic compounds*		
No data provided		
Total petroleum hydrocarbons		
No data provided		
Polycyclic aromatic hydrocarbons		
No data provided		
BTEX		
Benzene	<LoR (0/4)*	<LoR (0/12)*
Toluene	<LoR (0/4)*	<LoR – 0.010 (2/12)*

Chemical	Concentrations reported in private landholder bores (mg/L)	
	Springbok Sandstone	Walloon Coal Measures
Ethylbenzene	<LoR (0/4)*	<LoR (0/12)*
Xylenes	<LoR (0/4*)	<LoR (0/12)*
** (Number of bores with detections/Number of bores with data provided)*		

Under the EPP Water, the management intent for groundwaters is that there should be ‘no change’ to existing water quality, i.e. no change in the natural range of values. No change is deemed to have occurred if there are no detectable changes to the 20th, 50th and 80th percentiles of the natural distribution of values.

5.3 Scientific studies

Organic compounds, such TPH, PAH and BTEX can leach from coal *in situ* as a result of natural processes (Taulis & Stearman, 2015). Scientific studies evaluating the impact of natural processes on the concentrations of these CoPC in the Springbok Sandstone and Wallon Coal Measures aquifers in the Surat Basin have been evaluated, to assess whether the screening levels presented in Section 4 may be below naturally occurring background levels.

The identification of the range of naturally occurring hydrocarbons in the Surat Basin, where coal seam gas is commercially extracted, has been assessed by the Commonwealth Scientific and Industrial research Organisation (CSIRO) (Schinteie, et al., 2018). This study incorporated a review of groundwater quality data collected from within the Surat Cumulative Management Area (CMA) between 2009 and 2013.

Out of a total of 106 individual water samples collected from the Walloon Coal Measures, 46 reported detectable hydrocarbon concentrations, as follows:

- TPH C_6-C_{40} was detected in 46 samples, with concentrations ranging from 0.00004 mg/L to 0.0036 mg/L
- Toluene was detected in 6 samples, with concentrations ranging from 0.002 to 0.003 mg/L. Benzene concentrations were at or below the laboratory limit of reporting (0.002 mg/L in these samples)

The study author also referenced limited samples collected from within the Springbok Sandstone in the Surat Basin in 2014. Concentrations of TPH>C_{10}-C_{40} of up to 0.009 mg/L were noted.

Stearman *et al.* (2014) reviewed government-held CSG water-quality data from the Surat Basin and identified detection of PAHs in 13 of the 47 CSG water samples collected from the Walloon Coal Measures in the eastern Surat Basin. Naphthalene and phenanthrene (with a maximum concentration of 0.000046 mg/L and 0.00002 mg/L, respectively) were the most commonly detected PAHs, identified in seven samples.

Both study authors noted that concentrations of these detections were not surprising, as hydrocarbons are a natural constituent of coal.

6. Site specific target levels

The focus of this HHERA is the development of SSTV for sixteen total and dissolved metals, phenolic compounds, PAHs, TPH, TRH and BTEX in groundwater around the boundary of the site within the Springbok Sandstone aquifer and Walloon Coal Measures. GHD understands that the SSTV will be used to support an application by Arrow to reassess the groundwater quality triggers defined in EA0001401.

6.1 Methodology

The final SSTV have be selected, taking into account that the groundwater triggers should protect the human, agricultural and environmental users of groundwater from increases in toxicant concentrations attributed to CSG activities and not natural processes.

For each compound, separate published groundwater quality screening levels have been identified in Section 4 for each of the following scenarios:

- ***Risk-based standards (human health):*** the levels of contaminants that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to human users of extracted groundwater
- ***Risk-based standards (agricultural):*** the levels of contaminants that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to livestock or crop plants exposed to extracted groundwater
- ***Risk-based standards (environmental):*** the levels of contaminants that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to aquatic organisms and aquaculture species exposed to extracted groundwater.

The lowest of the range of screening levels for each CoPC has been selected as the SSTV. For each CoPC, consideration has also been given to the background CoPC concentration reported in Section 5, with the 95% percentile of the reported background concentrations adopted as the SSTV, when this is a higher concentration that the guidelines identified in Section 4. This approach has been used so that the SSTVs are not below the levels that may be associated with natural processes.

6.2 Recommended site specific target levels

The final recommended SSTV are summarised in Table 6-1.

It is noted that, at the time of reporting, the dataset on the concentrations of metals that are naturally occurring in the Springbok Sandstone and Walloon Coal Measures aquifers was relatively limited, incorporating one to two rounds of data collection in a selection of the private wells surrounding the site. . It is therefore recommended that the SSTV for metals are reassessed as additional baseline data is collected from within PLA 253.

Table 6-1 Recommended risk-based trigger levels

Chemical	SSTV (mg/L)	Source
Metals		
Arsenic	*0.042*	Aquatic species water quality guideline (90% protection) [#]
Barium	*3.1 / 2.7*	80th percentile of the background dataset [#,]
Beryllium	*0.06*	Livestock watering quality guideline [#,1]
Boron	*0. 5 / 1.0*	Irrigation water quality guideline / 80th percentile of the background dataset [#,]
Cadmium	*0.004*	Aquatic species water quality guideline (90% protection) [#]
Chromium (VI)	*0.006*	Aquatic species water quality guideline (90% protection) [#]
Chromium (total)	Not applicable	Cr (III) is of relatively low toxicity
Cobalt	*0.0014*	Aquatic species water quality guideline
Copper	*0.005*	80th percentile of the background dataset
Mercury	*0.00006*	Aquatic species water quality guideline (99% protection) [#]
Manganese	*0.2*	Irrigation water quality guideline [#]
Nickel	*0.013*	Aquatic species water quality guideline (95% protection) [#]
Lead	*0.0056*	Aquatic species water quality guideline (90% protection) [#]
Selenium	*0.005*	Aquatic species water quality guideline (99% protection) [#]
Vanadium	*0.006*	Aquatic species water quality guideline [#]
Zinc	*0.09 / 0.2*	80th percentile of the background dataset [#,]
Phenolic compounds*		
Phenol	0.6	Aquatic species water quality guideline (90% protection)
Cresols (sum)	1.5	Livestock watering quality guideline [#,1]
2,4-dimethylphenol	0.002	Aquatic species water quality guideline (90% protection)
Total petroleum hydrocarbons		
TPH>C_{10}–C_{16}	Aromatic – 0.056 Aliphatic – Solubility limit, based on sheen formation	Aquatic species water quality guideline*
TPH>C_{16}–C_{34}	Solubility limit, based on sheen formation	The solubility limit in water is low and therefore exposure is limited irrespective of the criterion nominated
TPH>C_{34}–C_{40}		
Polycyclic aromatic hydrocarbons		
Anthracene	0.0015	Aquatic species water quality guideline (90% protection)*
Acenaphthene	0.058	Aquatic species water quality guideline*
Acenaphthylene	-	Appropriate published criteria not identified
Fluorene	0.003	Aquatic species water quality guideline*
Naphthalene	0.02	Non-potable water quality guideline*
Phenanthrene	0.0006	Aquatic species water quality guideline (99% protection)*[2]
BTEX		
Benzene	0.01	Non-potable water quality guideline*
Toluene	0.23	Aquatic species water quality guideline (90% protection)*
Ethylbenzene	0.11	Aquatic species water quality guideline (90% protection)*
Xylenes	0.10	Aquatic species water quality guideline (90% protection)*

* Higher than the range of concentrations reported in local bore data and scientific studies undertaken to identify naturally occurring hydrocarbons in the Surat Basin aquifers

Springbok Sandstone SSTV / Walloon Coal Measures SSTV

[1] Note: Does not incorporate an aquatic species water quality guideline, in the absence of sufficient published ecotoxicity data

[2] Note: Does not incorporate a non-potable human use or livestock watering guideline, in the absence of sufficient published toxicity data

EA0001401 requires that monitoring is undertaken for both total and dissolved metals concentration in the Springbok Sandstone and Walloon Coal Measures. For the majority of the SSTV, the risk-driving exposure scenario (i.e. the exposure scenario associated with the lowest screening level) was the protection of aquatic species. ANZAST (2018) recommends that consideration is given to dissolved rather than total metal concentrations when considering risk to aquatic receptors and it is therefore recommended that primary consideration is given to the dissolved rather than total metal concentrations measured in ongoing monitoring activities.

Livestock watering and irrigation uses are the risk-driving exposure pathways for a limited number of the metal CoPC. There are also a number of metal CoPC, for which the non-potable human use screening levels identified are of a similar order of magnitude to the screening levels recommended for the protection of aquatic species. It is also recommended that primary consideration is given to the dissolved rather than total concentrations measured for these metals, as the identified receptors for onsite groundwater impacts are offsite users of groundwater. The total metals analysis incorporates metals that are bound to particulate matter and therefore are not very mobile in the environment, whereas the application of a filtration process to the groundwater samples focuses the analysis on the more highly mobile fraction.

6.3 Uncertainty analysis

The Uncertainty Analysis identifies the key assumptions and data gaps associated with the HHERA.

The SSTVs identified in this HHERA err on the side of the overestimation of potential health and ecological risks. Health and ecologically conservative assumptions applied in the identification of SSTV include:

- Selection of conservative published screening levels, intended to be well below any threshold for adverse health effects (based on no-observed-adverse-effect levels, with a number of safety factors applied to account for issues such as variability within populations).
- Selection of a wide range of potential exposure scenarios, including a number (e.g. the use of groundwater within dams, to provide long-term habit for a variety of aquatic species) that may be unlikely to be realised in full.

GHD also notes that the SSTVs are designed to be applied across PLA 253, to provide early notification of any changes in groundwater quality that may occur in response to CSG extraction. It is anticipated that if the CSG extraction activities across PLA 253 were to result in the migration of onsite groundwater impacts offsite and towards the identified groundwater users, that this would first be identified in the onsite boundary wells (HSMB1D, HSMB1S, HSMB2D, HSMB2S, HSMB3D1, HSMB3D2, HSMB3S1, HSMB3S2, HSMB4D, HSMB4S, HSMB5D) and Arrow’s newly installed offsite boundary monitoring wells. Exceedances of the SSTVs in the boundary monitoring wells should allow Arrow to implement measures to reduce the further migration of CoPC, prior to offsite groundwater extraction wells being impacted.

There is a level of uncertainty associated with the dataset provided by Arrow, in that a portion of the data was provided in Excel format, without a robust supporting quality assurance/quality control (QA/QC) information. The Excel dataset was primarily used to identify the individual PAH and phenolic CoPC and to define the range of naturally occurring concentrations of CoPC that may be present in the Springbok Sandstone and Walloon Coal Measures. As such, this Excel dataset did not fundamentally influence the SSTV and this uncertainty is not considered to limit the potential application of the values.

7. Conclusions

This HHERA has focused on the development of Site SSTV for groundwater quality within the Springbok Sandstone aquifer and Walloon Coal Measures, to support an application to reassess the groundwater quality triggers defined in the EA0001401. The SSTVs are designed to be applied across PLA 253, to provide early indication of potential risks to human, agricultural and environmental users of groundwater from increases in toxicant concentrations attributed to CSG activities and not natural processes. The CoPC identified in EA0001401 include sixteen total and dissolved metals, phenolic compounds, PAHs, TPH, and BTEX.

For each CoPC referenced in EA0001401, separate published groundwater screening levels have been identified for each of the following scenarios:

- ***Risk-based standards (human health):*** the levels of CoPC that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to human users of extracted groundwater
- ***Risk-based standards (agricultural):*** the levels of CoPC that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to livestock or crop plants exposed to extracted groundwater
- ***Risk-based standards (environmental):*** the levels of CoPC that could be present within the Springbok Sandstone aquifer and Walloon Coal Measures in the area surrounding the site without representing a risk to aquatic organisms and aquaculture species exposed to extracted groundwater
- ***Background concentrations:*** Concentrations that are representative of naturally-occurring conditions in the Springbok Sandstone and Walloon Coal Measure aquifers

The lowest of the range of screening levels identified for each CoPC was selected as the SSTV. For the phenolic compounds, PAHs, TPH and BTEX, the SSTV selected were above the levels that, based on background water quality data, may be associated with natural processes.

A relatively limited dataset was available at the time of reporting regarding the naturally occurring metals concentrations in the aquifers underlying the site. The metal SSTV should therefore be reconsidered as additional locally relevant background water quality data becomes available.

For the metal CoPC, it is recommended that primary consideration is given to the results of analysis undertaken on filtered rather than total groundwater samples, as the filtered samples more accurately reflect the metal concentrations that are likely to be mobile in the aquifers and to be more bioavailable to offsite water users.

The proposed SSTV for the site are as follows:

Chemical	SSTV (mg/L)
Metals	
Arsenic	*0.042*
Barium	*3.1 (Springbok Sandstone) / 2.7 (Walloon Coal Measures)*
Beryllium	*0.06*
Boron	*0.5*
Cadmium	*0.004*
Chromium (VI)	*0.006*
Chromium (total)	Not applicable
Cobalt	*0.0014*
Copper	*0.005*
Mercury	*0.00006*
Manganese	*0.2*
Nickel	*0.013*
Lead	*0.0056*
Selenium	*0.005*
Vanadium	*0.006*
Zinc	*0.09 (Springbok Sandstone) / 0.2 (Walloon Coal Measures)*
Phenolic compounds	
Phenol	0.6
Cresols (sum)	1.5
2,4-dimethylphenol	0.002
Petroleum hydrocarbons	
TPH>C_{10}–C_{16}	Aromatic – 0.056 Aliphatic – Solubility limit, based on sheen formation
TPH>C_{16}–C_{34}	Solubility limit, based on sheen formation
TPH>C_{34}–C_{40}	
Polycyclic aromatic hydrocarbons	
Anthracene	0.0015
Acenaphthene	0.058
Acenaphthylene	-
Fluorene	0.003
Naphthalene	0.02
Phenanthrene	0.0006
BTEXN	
Benzene	0.01
Toluene	0.23
Ethylbenzene	0.11
Xylenes	0.10

8. References

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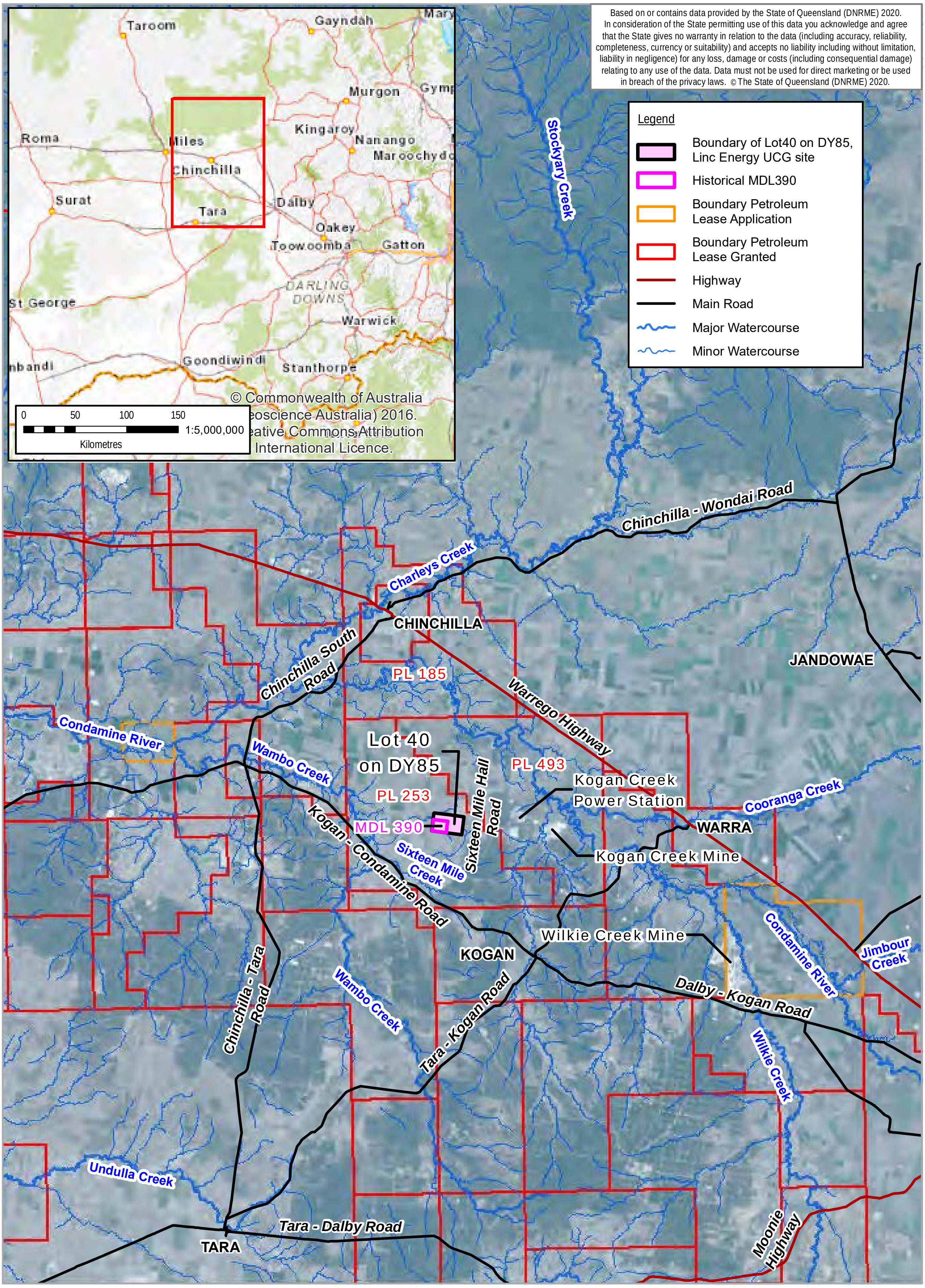
Appendices

Appendix A – Figures



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Kilometres

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Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Arrow HHERA

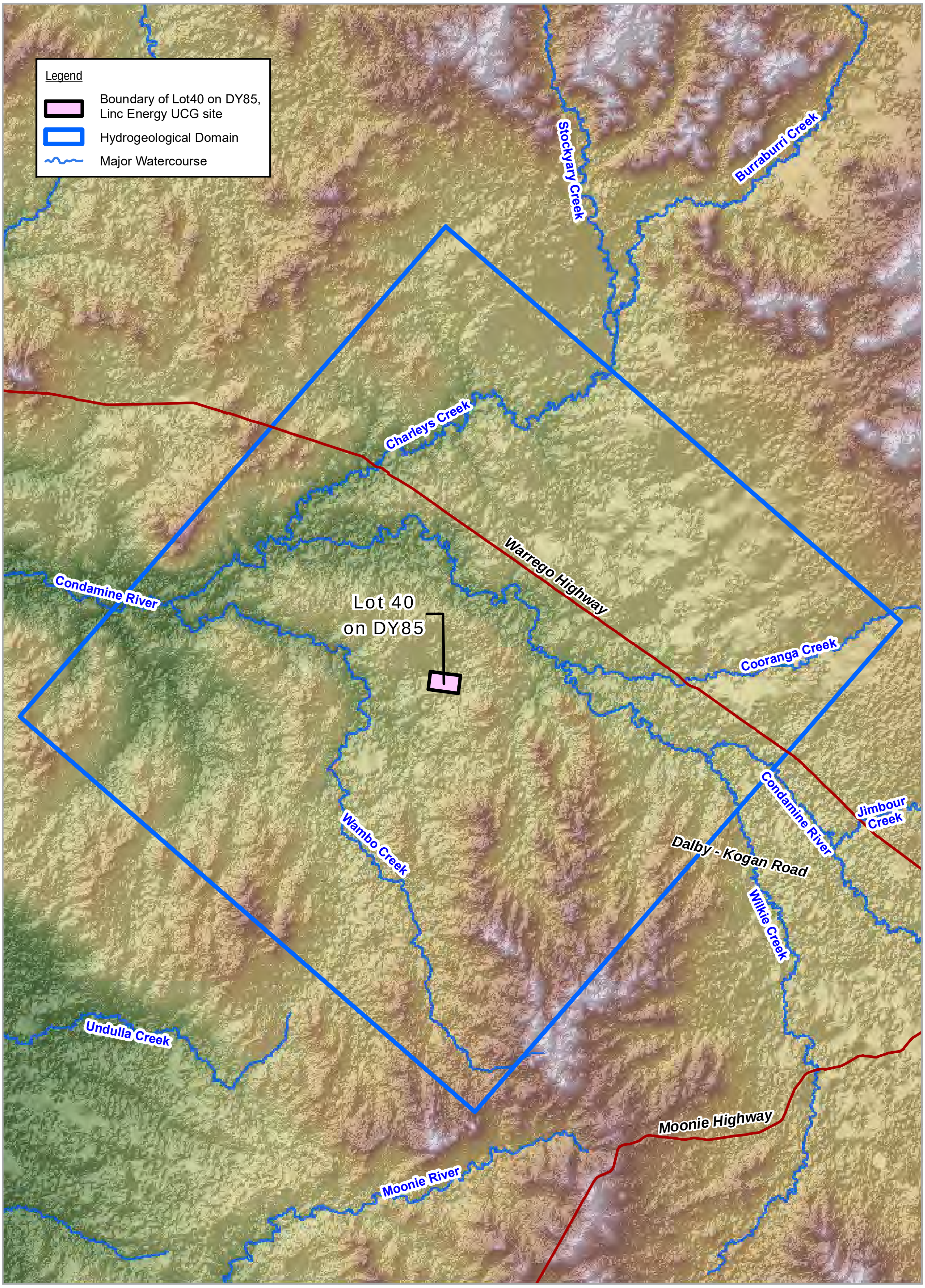
Locality Map

Project No.	12524316
Revision No.	A
Date	14/04/2020

FIGURE 1

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-12524616-01_locality_revA.mxd
Print date: 15 Apr 2020

Data source: DNRME: roads, watercourses, Petroleum Leases, Planning Cadastre (2019), imagery QldBase (2019), topo base map (2019). Created by: JVanCooten



1:500,000 (Paper Size A4)

0 5 10 15 20

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Arrow Energy Pty Ltd
Arrow HHERA

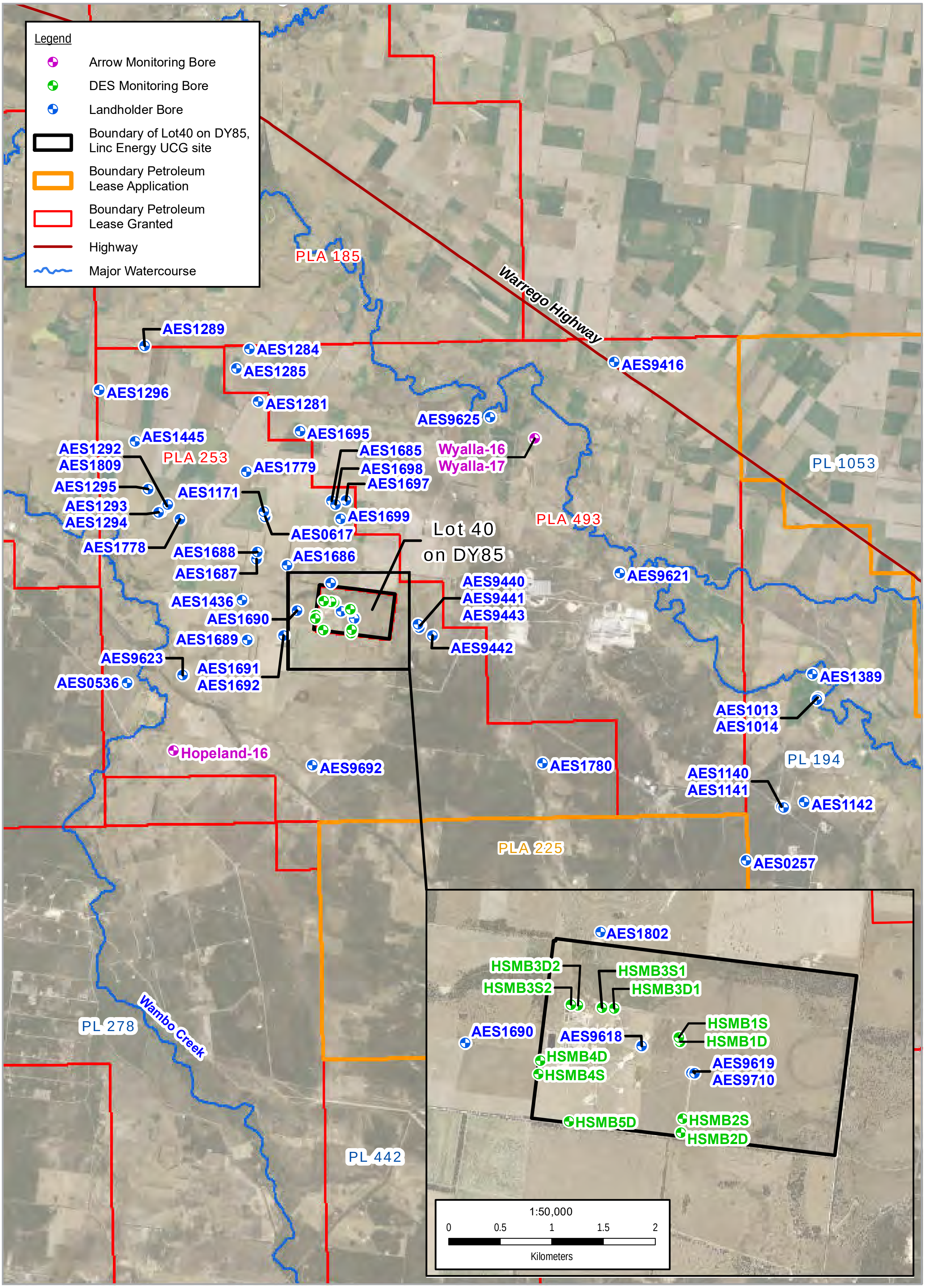
Topography and Drainage

Project No.	12524316
Revision No.	A
Date	14/04/2020

FIGURE 2

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-12524616-02_topoAndDrainage_revA.mxd
Print date: 15 Apr 2020

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: JVanCooten



1:200,000 (Paper Size A4)

0 2 4 6 8

Kilometers

N

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

GHD

Arrow Energy Pty Ltd
Arrow HHERA

Groundwater Bore Locations

Project No.	12524316
Revision No.	A
Date	14/04/2020

FIGURE 3

G:\41\32187\GIS\Maps\MXD\02_Hopeland GW\41-12524616-03_GWboreLocs_revA.mxd
Print date: 15 Apr 2020

Data source: DNRME: CSG Wells, Registered Bores, Roads, Water Courses, Petroleum Leases, Planning Cadastre (2017); Google Earth: Imagery (June 2017, extracted June 2018); Created by: JVanCooten

Appendix B – Groundwater bore summary

Groundwater Bores - Hydrocarbon Data

RN	Arrow Bore ID	AECOM Bore ID	Longitude	Latitude	Location	Ownership	Aquifer Accessed	Status	Utilisation	Bore Depth (mbgl)	Sample Date	pH	EC	TDS	Benzene	Toluene	Ethylbenze	o_Xylene	m_Xylene	Xylene
37177	AES0257		150.834542	-27.014967	Offsite - within 20 km	Landholder	Walloon Coal Measures	Existing			10/04/2018	7.52	3640	2370	<1	10	<2	<2	<2	<2
119965	AES0536		150.594361	-26.949067	Offsite - within 10 km			Existing	Water Supply											
10678	AES0617		150.64935	-26.891871	Offsite - within 5 km		Injune Creek Group	Functional	Stock and Domestic	114.6										
	AES1013		150.86363	-26.95848	Offsite - within 20 km	Landholder	Condamine Alluvium				29/08/2012	7.15	3142	1870	<1	<1	<1	<2	<2	
	AES1014		150.86317	-26.95932	Offsite - within 20 km	Landholder					30/08/2012	7.57	3987	2580	<1	<1	<1	<2	<2	
94039	AES1140		150.84874	-26.99641	Offsite - within 20 km	Landholder	Hutton Sandstone	Existing			12/04/2018	8.25	7780	5060	<1	3	<2			<2
107800	AES1141		150.84955	-26.99671	Offsite - within 20 km	Landholder	Hutton Sandstone				18/12/2012	8.45	3673	2660	<1	<1	<1	<2	<2	
66146	AES1142		150.85759	-26.99489	Offsite - within 20 km	Landholder					13/04/2018	8.69	14500	9420	<1	<2	<2	<2	<2	<2
107868	AES1171		150.64893	-26.89019	Offsite - within 5 km	Landholder	Walloon Coal Measures	Functional	Stock and Domestic	110	20/08/2018	8.25	10700	6960						
19988	AES1281		150.64746	-26.85153	Offsite - within 10 km	Landholder	Walloon Coal Measures				8/07/2013	8.52	3470	1990	<0.05	<0.5	<0.05	<0.05	<0.05	<0.05
10898	AES1284		150.64452	-26.83318	Offsite - within 20 km	Landholder	Walloon Coal Measures				1/02/2018	8.81	3880	2520	<1	<2	<2	<2	<2	<2
	AES1285		150.63931	-26.83999	Offsite - within 20 km	Landholder	Walloon Coal Measures				31/01/2018	8.88	4120	2680	<1	<2	<2	<2	<2	<2
119484	AES1289		150.603623	-26.83138	Offsite - 20 km+	Landholder	Walloon Coal Measures				1/06/2016	8.61	3780	2460	<1	<2	<2	<2	<2	<2
107739	AES1292		150.61118	-26.8875	Offsite - within 10 km				SI											
107698	AES1293		150.60883	-26.88935	Offsite - within 10 km				SI											
147177	AES1294		150.60782	-26.88957	Offsite - within 10 km				SI											
24467	AES1295		150.60394	-26.88148	Offsite - within 10 km	Landholder	Walloon Coal Measures		SI		3/09/2014	8.56	2780	1810						
38191	AES1296		150.58569	-26.84655	Offsite - 20 km+	Landholder	Walloon Coal Measures				12/07/2013	8.48	2880	1700	<1	<2	<2	<2	<2	<2
119075	AES1389		150.8617	-26.9502	Offsite - within 20 km	Landholder	Walloon Coal Measures				24/10/2013	8.03	2990	1690	<1	<2	<2	<2	<2	<2
33553	AES1436		150.639697	-26.920875	Offsite - within 5 km	Landholder	Springbok Sandstone	Functional	Stock and Domestic	111.6	15/08/2019	8.14	7760	5040	<1	<2	<2	<2	<2	<2
24469	AES1445		150.599206	-26.864802	Offsite - within 20 km	Landholder	Walloon Coal Measures				12/12/2016	7.81	12400	8060	<1	<2	<2	<2	<2	<2
24485	AES1685		150.675415	-26.88679	Offsite - within 5 km			Functional	OTH/Stock and Domestic											
10790	AES1686		150.65757	-26.90889	Offsite - within 5 km		Walloon Coal Measures	Functional	ST/Stock and Domestic	165.8										
107857	AES1687		150.64561	-26.90659	Offsite - within 5 km	Landholder	Springbok Sandstone	Functional	ST	102	24/09/2019	7.93	9220	5990	<1	<2	<2	<2	<2	<2
71483	AES1688		150.64616	-26.904158	Offsite - within 5 km			Functional	OTH/Stock and Domestic	97.5										
24466	AES1689		150.64154	-26.93487	Offsite - within 5 km	Landholder	Walloon Coal Measures	Functional	ST/Stock and Domestic	161.5	2/04/2018	8.55	2500	1620	<1	<2	<2	<2	<2	<2
15811	AES1690		150.66116	-26.92495	Offsite - within 5 km	Landholder		Functional	ST/Stock and Domestic	152.4	14/08/2018	8.88	2550	1660						
147607	AES1691		150.65568	-26.93346	Offsite - within 5 km	Landholder	Walloon Coal Measures	Functional	IR/Stock and Domestic	150	5/04/2018	8.58	2230	1450	<1	<2	<2	<2	<2	<2
19982	AES1692		150.65567	-26.93344	Offsite - within 5 km			Decommissioned	OTH											
147001	AES1695		150.66356	-26.86221	Offsite - within 20 km	Landholder	Walloon Coal Measures				5/02/2018	8.6	10400	6760	<1	2	<2	<2	<2	<2
15832	AES1697		150.68108	-26.88667	Offsite - within 5 km		Injune Creek Group	Functional	OTH	134.1										
17322	AES1698		150.676916	-26.888047	Offsite - within 5 km			Functional	OTH	170.6										
34262	AES1699		150.67881	-26.893169	Offsite - within 5 km			Decommissioned	OTH											
24479	AES1778		150.61624	-26.89222	Offsite - within 10 km	Landholder	Walloon Coal Measures		OTH		12/11/2018	8.97	3300	2140	<1	<2	<2	<2	<2	<2
24504	AES1779		150.64243	-26.8761	Offsite - within 10 km				ST											
86623	AES1780		150.75585	-26.97976	Offsite - within 20 km				DO											
15868	AES1802		150.674548	-26.915497	Offsite - within 5 km	Landholder	Walloon Coal Measures	Functional	ST/Stock and Domestic	170.7	16/11/2018	8.17	6410	4170	<1	<2	<2	<2	<2	<2
172327	AES1809		150.61149	-26.88699	Offsite - within 10 km	Landholder	Hutton Sandstone		ST		5/12/2017	8.41	3180	2070	<1	<2	<2	<2	<2	<2
13878	AES9416		150.786564	-26.840029	Offsite - within 20 km	Landholder	Hutton Sandstone				4/07/2018	8.41	8670	5640	<1	<2	<2	<2	<2	<2
66757	AES9440		150.709156	-26.93085	Offsite - within 5 km				Stock and Domestic											
	AES9441		150.70877	-26.93169	Offsite - within 5 km				DO											
15812	AES9442		150.713713	-26.934474	Offsite - within 5 km		Kumbarilla Beds	Functional	Stock and Domestic	73.2										
147004	AES9443		150.70826	-26.93048	Offsite - within 5 km	Landholder	Springbok Sandstone	Functional	ST/Water Supply	80.5	23/08/2018	8.01	11400	7410	<1	<2	<2	<2	<2	<2
17301	AES9618		150.678358	-26.925498	Onsite		Injune Creek Group / Mulgildie Coal Measures	Functional	Stock and Domestic	152.4										
66152	AES9619		150.68318	-26.92793	Offsite - within 5 km				Stock and Domestic											
87436	AES9621		150.78727	-26.91385	Offsite - within 20 km	Landholder	Hutton Sandstone				19/03/2019	8.62	3080	2000	<1	<2	<2	<2	<2	<2
87897	AES9623		150.61607	-26.94677	Offsite - within 10 km	Landholder	Springbok Sandstone		SD		21/03/2019	8.56	3770	2450	<1	<2	<2	<2	<2	<2
	AES9625		150.73774	-26.85846	Offsite - within 10 km	Landholder					22/03/2019	8.28	4380	2850	<1	<2	<2	<2	<2	<2
87505	AES9692		150.66604	-26.97902	Offsite - within 10 km				ST											
137990	AES9710		150.68348	-26.92796	Onsite				Stock and Domestic	96										
	Hopeland-16		150.611942	-26.973009	Onsite	Arrow	Kumbarilla Beds		Monitoring Bore		23/05/2019	0	42300	0	<1	<2	<2	<2	<2	<2
	Wyalla-16		150.75502	-26.866198	Onsite	Arrow	Condamine Alluvium		Monitoring Bore		10/05/2019	0	0	0						
	Wyalla-17		150.754992	-26.866326	Onsite	Arrow	Precipice Sandstone		Monitoring Bore		8/10/2018	0	0	0						
147941			150.6853	-26.9167	Offsite - within 5 km		Walloon Coal Measures	Functional	Sub-artesian Monitoring	151										
3426			150.6789	-26.8932	Offsite - within 5 km		-	Decommissioned	Unknown											
160139			150.6715	-26.9261	Offsite - within 5 km			Functional	Unknown	80										
160137			150.6715	-26.9275	Offsite - within 5 km			Functional	Unknown	80										
160138			150.6717	-26.9261	Offsite - within 5 km			Functional	Unknown	100										
160055			150.6759	-26.9278	Offsite - within 5 km			Functional	Unknown	124										
6675			150.7093	-26.9308	Offsite - within 5 km		Unknown	Functional	Stock and Domestic											
160059			150.6769	-26.9261	Offsite - within 5 km			Functional	Unknown	114										

160058			150.6753	-26.9278	Offsite - within 5 km			Functional	Unknown	124										
160142			150.6843	-26.8941	Offsite - within 5 km			Functional	Unknown	85.8										
160141			150.6703	-26.9261	Offsite - within 5 km			Functional	Unknown	100										
160057			150.6753	-26.9278	Offsite - within 5 km			Functional	Unknown	90										
160140			150.6703	-26.9264	Offsite - within 5 km			Functional	Unknown	80										
160056			150.6759	-26.9278	Offsite - within 5 km			Functional	Unknown	90										
160109			150.6767	-26.9316	Offsite - within 5 km			Functional	Unknown	135										
160108			150.6767	-26.9316	Offsite - within 5 km			Functional	Unknown	115.7										
172602			150.668492	-26.926596	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	156.34										
172603			150.671161	-26.931938	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	162.3										
160105			150.6755	-26.9261	Offsite - within 5 km			Functional	Unknown	115										
160104			150.6749	-26.9261	Offsite - within 5 km			Functional	Unknown	80										
24492			150.6927	-26.8886	Offsite - within 5 km			Functional	Stock and Domestic											
160107			150.6767	-26.9316	Offsite - within 5 km			Functional	Unknown	80										
160106			150.6755	-26.9261	Offsite - within 5 km			Functional	Unknown	132.5										
172604			150.68204	-26.933119	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	164.47										
172605			150.671551	-26.921774	Offsite - within 5 km		Springbok Sandstone	Functional	Unknown	139.54										
160149			150.6517	-26.9638	Offsite - within 5 km			Decommissioned	Unknown	190										
160155			150.6843	-26.8942	Offsite - within 5 km			Functional	Unknown	58										
160157			150.6377	-26.9312	Offsite - within 5 km			Functional	Unknown	176										
160080			150.6733	-26.9294	Offsite - within 5 km			Functional	Unknown	80										
160081			150.6759	-26.9247	Offsite - within 5 km			Functional	Unknown	115										
172601			150.672244	-26.921848	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	163.22										
160082			150.6759	-26.9247	Offsite - within 5 km			Functional	Unknown	80										
160083			150.6789	-26.925	Offsite - within 5 km			Functional	Unknown	115										
160084			150.6789	-26.925	Offsite - within 5 km			Functional	Unknown	80										
160085			150.6789	-26.925	Offsite - within 5 km			Functional	Unknown	128.7										
160111			150.6765	-26.926	Offsite - within 5 km			Functional	Unknown	133										
160112			150.6775	-26.9276	Offsite - within 5 km			Functional	Unknown	136										
160086			150.6761	-26.9264	Offsite - within 5 km			Functional	Unknown	132										
160113			150.6787	-26.9276	Offsite - within 5 km			Functional	Unknown	132.5										
160110			150.6775	-26.9258	Offsite - within 5 km			Functional	Unknown	132										
172595			150.668286	-26.927766	Offsite - within 5 km		Springbok Sandstone	Functional	Unknown	124.39										
172596			150.682236	-26.931904	Offsite - within 5 km		Springbok Sandstone	Functional	Unknown	127.54										
172599			150.67577	-26.922195	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	148.25										
172600			150.674575	-26.922058	Offsite - within 5 km		Springbok Sandstone	Functional	Unknown	133.46										
172597			150.682019	-26.924816	Offsite - within 5 km		Springbok Sandstone	Functional	Unknown	123.4										
6615			150.6885	-26.9262	Offsite - within 5 km			Functional	Stock and Domestic											
172598			150.682112	-26.925169	Offsite - within 5 km		Walloon Coal Measures (Macalister Seam)	Functional	Unknown	162.1										
160079			150.6773	-26.9272	Offsite - within 5 km			Functional	Unknown	132										
160078			150.6715	-26.9275	Offsite - within 5 km			Functional	Unknown	80										
160077			150.6695	-26.9258	Offsite - within 5 km			Functional	Unknown	6										
160076			150.6691	-26.9249	Offsite - within 5 km			Functional	Unknown	7										
160075			150.6697	-26.924	Offsite - within 5 km			Functional	Unknown	6.2										
160074			150.6715	-26.9253	Offsite - within 5 km			Functional	Unknown	9										
160073			150.6715	-26.9228	Offsite - within 5 km			Functional	Unknown	6.5										
160072			150.6715	-26.9223	Offsite - within 5 km			Functional	Unknown	7.5										
160071			150.6713	-26.922	Offsite - within 5 km			Functional	Unknown	8										
160070			150.6709	-26.9222	Offsite - within 5 km			Functional	Unknown	6.5										
160068			150.6733	-26.9294	Offsite - within 5 km			Functional	Unknown	115										
160067			150.6769	-26.9269	Offsite - within 5 km			Functional	Unknown	82										
160069			150.6733	-26.9294	Offsite - within 5 km			Functional	Unknown	135.5										
160064			150.6773	-26.9286	Offsite - within 5 km			Functional	Unknown	78										
160134			150.6695	-26.9275	Offsite - within 5 km			Functional	Unknown	80										
160063			150.6773	-26.9286	Offsite - within 5 km			Functional	Unknown	114										
160066			150.6789	-26.9275	Offsite - within 5 km			Functional	Unknown	80										
160136			150.6711	-26.9275	Offsite - within 5 km			Functional	Unknown	100										
160065			150.6789	-26.9275	Offsite - within 5 km			Functional	Unknown	115										
160135			150.6695	-26.9278	Offsite - within 5 km			Functional	Unknown	100										
160060			150.6769	-26.9261	Offsite - within 5 km			Functional	Unknown	79										
160062			150.6759	-26.9269	Offsite - within 5 km			Functional	Unknown	80										
160061			150.6759	-26.9269	Offsite - within 5 km			Functional	Unknown	114										
8642			150.6725	-26.8812	Offsite - within 5 km			Functional	Unknown	145.7										

1012464		HSMB1D	150.682102	-26.925169	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	160.18	5/06/2018		20100		225	28	<2	<2		2
					Onsite - boundary			Functional			28/06/2018		19200		153	23	<2	<2		<2
					Onsite - boundary			Functional			12/09/2018		17200		77	12	<2	<2		<2
1012463		HSMB1S	150.682019	-26.924816	Onsite - boundary	DES	Springbok Sandstone	Functional	Monitoring Bore	124.4	12/06/2018		18500		755	124	8	5		12
					Onsite - boundary			Functional			26/06/2018		15900		652	82	5	3		7
					Onsite - boundary			Functional			26/06/2018		15500		666	101	6	4		10
					Onsite - boundary			Functional			12/09/2018		13500		547	83	5	3		8
1012470		HSMB2D	150.68203	-26.933127	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	165.86	6/06/2018		9300		30	9	<2	<2		<2
					Onsite - boundary			Functional			6/06/2018		9300		34	10	<2	<2		<2
					Onsite - boundary			Functional			28/06/2018		9100		49	10	<2	<2		<2
					Onsite - boundary			Functional			12/09/2018		8900		32	8	<2	<2		<2
					Onsite - boundary			Functional			7/05/2019		9300		27	4	<2	<2		<2
1012462		HSMB2S	150.682236	-26.931913	Onsite - boundary	DES	Springbok Sandstone	Functional	Monitoring Bore	129.26	6/06/2018		6560		1020	238	33	14		42
					Onsite - boundary			Functional			28/06/2018		6420		684	126	13	6		18
					Onsite - boundary			Functional			17/09/2018		5990		681	136	14	6		19
1012465		HSMB3D1	150.67577	-26.922195	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	149.8	5/06/2018		7600		95	12	<2	<2		2
					Onsite - boundary			Functional			5/06/2018		7540		102	13	<2	<2		2
					Onsite - boundary			Functional			27/06/2018		6760		78	12	<2	<2		3
					Onsite - boundary			Functional			12/09/2018		6500		69	10	<2	<2		3
					Onsite - boundary			Functional			11/12/2018		5880		64	9	<2	<2		3
					Onsite - boundary			Functional			19/12/2018		5760		44	4	<2	<2		<2
					Onsite - boundary			Functional			19/12/2018		3440		1	<2	<2	<2		<2
					Onsite - boundary			Functional			19/12/2018		2760		16	<2	<2	<2		<2
					Onsite - boundary			Functional			19/12/2018		2770		16	<2	<2	<2		<2
					Onsite - boundary			Functional			18/01/2019		2770		21	<2	<2	<2		<2
					Onsite - boundary			Functional			18/01/2019		2770		20	<2	<2	<2		<2
					Onsite - boundary			Functional			18/01/2019		2850		23	3	<2	<2		<2
1012467		HSMB3D2	150.672234	-26.921848	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	164.89	5/06/2018		7670		35	6	<2	<2		<2
					Onsite - boundary			Functional			25/06/2018		6380		26	4	<2	<2		<2
					Onsite - boundary			Functional			10/09/2018		3850		18	3	<2	<2		<2
					Onsite - boundary			Functional			7/05/2019		3760		7	2	<2	<2		<2
1012466		HSMB3S1	150.674575	-26.922067	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	131.91	5/06/2018		18600		96	8	<2	<2		<2
					Onsite - boundary			Functional			28/06/2018		17400		71	10	<2	<2		<2
					Onsite - boundary			Functional			28/06/2018		17300		92	11	<2	<2		<2
					Onsite - boundary			Functional			12/09/2018		16000		69	9	<2	<2		<2
					Onsite - boundary			Functional			11/12/2018		16500		78	9	<2	<2		<2
					Onsite - boundary			Functional			13/12/2018		15100		12	<2	<2	<2		<2
					Onsite - boundary			Functional			19/12/2018		20200		<1	<2	<2	<2		<2
					Onsite - boundary			Functional			18/01/2019		14700		4	<2	<2	<2		<2
					Onsite - boundary			Functional			18/01/2019		14600		4	<2	<2	<2		<2
					Onsite - boundary			Functional			7/05/2019		13500		5	<2	<2	<2		<2
					Onsite - boundary			Functional			7/05/2019		13400		6	<2	<2	<2		<2
1012471		HSMB3S2	150.671541	-26.921774	Onsite - boundary	DES	Springbok Sandstone	Functional	Monitoring Bore	140.65	5/06/2018		54000		77	28	5	3		9
					Onsite - boundary			Functional			28/06/2018		47800		1490	271	22	13		40
					Onsite - boundary			Functional			17/09/2018		44800		1330	273	23	13		41
1012468		HSMB4D	150.668482	-26.926596	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	156.34	6/06/2018		25400		79	13	<2	<2		<2
					Onsite - boundary			Functional			27/06/2018		24700		86	23	<2	<2		<2
					Onsite - boundary			Functional			10/09/2018		25200		91	20	<2	<2		<2
1012461		HSMB4S	150.668286	-26.927766	Onsite - boundary	DES	Springbok Sandstone	Functional	Monitoring Bore	123.26	6/06/2018		14400		1060	139	9	4		12
					Onsite - boundary			Functional			25/06/2018		15000		959	153	10	4		13
					Onsite - boundary			Functional			12/09/2018		15200		1010	126	8	4		11
					Onsite - boundary			Functional			12/09/2018		15100		984	126	8	4		11
1012469		HSMB5D	150.67115	-26.931947	Onsite - boundary	DES	Macalister Coal Seams	Functional	Monitoring Bore	163.83	12/06/2018		6890		106	15	<2	<2		<2
					Onsite - boundary			Functional			27/06/2018		5110		100	13	<2	<2		<2
					Onsite - boundary			Functional			10/09/2018		4260		64	9	<2	<2		<2
					Onsite - boundary			Functional			10/09/2018		4260		83	10	<2	<2		<2
					Onsite - boundary			Functional			10/09/2018		4240		73	10	<2	<2		<2

Groundwater Bores - Metal Data

Data_Source	Station	RN_MP	Sample_Date	Latitude	Longitude	Formation _Name	Barium	Barium _Dissolved	Beryllium	Beryllium _Dissolved	Boron	Boron _Dissolved	Cadmium	Cadmium _Dissolved
Landholder	AES1445	24469	12/12/2016	-26.8648019	150.5992061	WCM	6.68	5.71	<0.001	<0.001	0.32	0.29	0.0018	<0.0001
Landholder	AES1778	24479	11/12/2018	-26.89222	150.61624	WCM	0.38	0.33	<0	<0	0.32	0.33	<0	<0
Landholder	AES1691	147607	10/27/2016	-26.93346	150.65568	WCM	0.105	0.102	<0.001	<0.001	0.33	0.33	<0.0001	<0.0001
Landholder	AES1691	147607	4/05/2018	-26.93346	150.65568	WCM	0.113	0.089	<0.001	<0.001	0.31	0.37	<0.0001	<0.0001
Landholder	AES1281	19988	7/08/2013	-26.85153	150.64746	WCM	0.368	0.363	<0.0001	<0.0001	0.497	0.466	<5e-005	<5e-005
Landholder	AES1389	119075	10/24/2013	-26.9502	150.8617	WCM	0.307	0.296	<0.001	<0.001	0.12	0.15	<0.0001	<0.0001
Landholder	AES1284	10898	7/09/2013	-26.83318	150.64452	WCM		0.7		<0.0001		0.508		<5e-005
Landholder	AES1284	10898	2/01/2018	-26.83318	150.64452	WCM	0.592	0.592	<0.001	<0.001	0.5	0.49	<0.0001	<0.0001
Landholder	AES1289	119484	07/17/2013	-26.8313795	150.6036232	WCM	0.551	0.515	<0.001	<0.001	1.04	1.07	<0.0001	<0.0001
Landholder	AES1289	119484	6/01/2016	-26.8313795	150.6036232	WCM	0.443	0.468	<0.001	<0.001	1.13	1.12	<0.0001	<0.0001
Landholder	AES1171	107868	02/19/2013	-26.89019	150.64893	WCM	2.73	2.42	<0.0001	<0.0001	0.36	0.3	<0.0001	<0.0001
Landholder	AES1171	107868	08/20/2018	-26.89019	150.64893	WCM	2.68	2.79	<0.001	<0.001	0.24	0.24	<0.0001	<0.0001
Landholder	AES1802	15868	11/16/2018	-26.915497	150.674548	WCM	1.8	1.7	<0	<0	0.3	0.3	<0	<0
Landholder	AES1802	15868	08/23/2018	-26.915497	150.674548	WCM	2.47	2.52	<0	<0	0.31	0.32	<0	<0
Landholder	AES1689	24466	4/02/2018	-26.93487	150.64154	WCM	0.107	0.101	<0.001	<0.001	0.36	0.35	<0.0001	<0.0001
Landholder	AES1285		7/09/2013	-26.83999	150.63931	WCM		0.478		<0.0001		0.454		<5e-005
Landholder	AES1285		01/31/2018	-26.83999	150.63931	WCM	0.481	0.456	<0.001	<0.001	0.52	0.53	<0.0001	<0.0001
Landholder	AES1296	38191	7/12/2013	-26.84655	150.58569	WCM	0.329	0.326	<0.001	<0.001	0.44	0.36	<0.0001	<0.0001
Landholder	AES1687	107857	09/24/2019	-26.90659	150.64561	SBK	2.45	2.31	<0	<0	0.34	0.32	<0	<0
Landholder	AES1695	147001	04/27/2016	-26.86221	150.66356	WCM	1.9	1.84	<0.001	<0.001	0.31	0.29	<0.0001	<0.0001
Landholder	AES1695	147001	2/05/2018	-26.86221	150.66356	WCM	2.21	2	<0.001	<0.001	0.24	0.2	<0.0001	<0.0001
Landholder	AES1690	15811	08/14/2018	-26.92495	150.66116	WCM	0.139	0.12	<0.001	<0.001	0.31	0.32	<0.0001	<0.0001
Landholder	AES1295	24467	7/11/2013	-26.88148	150.60394	WCM	0.468	0.417	<0.001	<0.001	0.4	0.28	<0.0001	<0.0001
Landholder	AES1295	24467	9/03/2014	-26.88148	150.60394	WCM		0.324		<0.001		0.41		<0.0001
Landholder	AES1436	33553	08/15/2019	-26.920875	150.639697	SBK	1.38	1.39	<0	<0	0.21	0.39	<0	<0
Landholder	AES1436	33553	01/16/2014	-26.920875	150.639697	SBK	3.43	2.69	<0.001	<0.001	0.36	0.24	<0.0001	0.0001
Landholder	AES0257	37177	4/10/2018	-27.0149667	150.8345421	WCM	0.305	0.298	<0.001	<0.001	0.26	0.27	<0.0001	<0.0001
Landholder	AES9443	147004	08/23/2018	-26.93048	150.70826	SBK	3.14	3.22	<0	<0	0.4	0.39	<0	<0
Landholder	AES9623	87897	03/21/2019	-26.94677	150.61607	SBK	0.28	0.27	<0	<0	0.44	0.39	<0	<0

Groundwater Bores - Metal Data

Data_Source	Station	RN_MP	Sample_Date	Formation _Name	Chromium	Chromium _Dissolved	Cobalt	Cobalt _Dissolved	Copper _Dissolved	Lead	Lead _Dissolved	Manganese	Manganese _Dissolved	Mercury	Mercury _Dissolved
Landholder	AES1445	24469	12/12/2016	WCM	0.002	<0.001	<0.001	<0.001	<0.001	0.022	<0.001	0.088	0.048	<0.0001	<0.0001
Landholder	AES1778	24479	11/12/2018	WCM	<0	<0	<0	<0	<0	<0	<0	0.01	0.01	<0	<0
Landholder	AES1691	147607	10/27/2016	WCM	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.0001	<0.0001
Landholder	AES1691	147607	4/05/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.0001	<0.0001
Landholder	AES1281	19988	7/08/2013	WCM	<0.0002	<0.0002		<0.0001	<0.0005	<0.0001	<0.0001	0.0014	0.001	<0.0001	<0.0001
Landholder	AES1389	119075	10/24/2013	WCM	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	0.042	0.043	<0.0001	<0.0001
Landholder	AES1284	10898	7/09/2013	WCM		<0.0002		<0.0001	<0.0005		<0.0001		0.0031	<0.0001	<0.0001
Landholder	AES1284	10898	2/01/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.027	0.004	<0.0001	<0.0001
Landholder	AES1289	119484	07/17/2013	WCM	0.001	<0.001		<0.001	<0.001	0.005	<0.001	0.007	0.003	<0.0001	<0.0001
Landholder	AES1289	119484	6/01/2016	WCM	<0.001	<0.001	<0.001	<0.001	0.006	0.006	0.005	<0.001	<0.001	<0.0001	<0.0001
Landholder	AES1171	107868	02/19/2013	WCM	0.0006	<0.0005		<0.0001	<0.0005	0.0015	<0.0001	0.0075	0.0059	<0.0001	<0.0001
Landholder	AES1171	107868	08/20/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.009	<0.0001	<0.0001
Landholder	AES1802	15868	11/16/2018	WCM	<0	<0	<0	<0	<0	0	<0	0.01	0.01	<0	<0
Landholder	AES1802	15868	08/23/2018	WCM	<0	<0	<0	<0	0	0	<0	0.03	0.03	<0	<0
Landholder	AES1689	24466	4/02/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<1	<0.001	0.005	0.004	<0.0001	<0.0001
Landholder	AES1285		7/09/2013	WCM		<0.0002		<0.0001	0.0011		0.0009		0.0048	<0.0001	<0.0001
Landholder	AES1285		01/31/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.002	0.001	<0.0001	<0.0001
Landholder	AES1296	38191	7/12/2013	WCM	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.0001	<0.0001
Landholder	AES1687	107857	09/24/2019	SBK	<0	<0	<0	<0	0	0.01	<0	0.02	0.02	<0	<0
Landholder	AES1695	147001	04/27/2016	WCM	<0.001	<0.001		<0.001	0.004	0.002	<0.001	0.003	0.003	<0.0001	<0.0001
Landholder	AES1695	147001	2/05/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.004	<0.0001	<0.0001
Landholder	AES1690	15811	08/14/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.032	0.017	<0.0001	<0.0001
Landholder	AES1295	24467	7/11/2013	WCM	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	0.007	0.006	<0.0001	<0.0001
Landholder	AES1295	24467	9/03/2014	WCM		<0.001		<0.001	<0.001		<0.001		0.004		
Landholder	AES1436	33553	08/15/2019	SBK	<0	<0	<0	<0	<0	<0	<0	0.04	0.04	<0	<0
Landholder	AES1436	33553	01/16/2014	SBK	<0.001	0.001		<0.001	0.008	<0.001	0.003	0.638	0.534	<0.0001	<0.0001
Landholder	AES0257	37177	4/10/2018	WCM	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.07	0.055	<0.0001	<0.0001
Landholder	AES9443	147004	08/23/2018	SBK	<0	<0	<0	<0	<0	<0	0	0.01	0.07	<0	<0
Landholder	AES9623	87897	03/21/2019	SBK	<0	<0	<0	<0	<0	<0	<0	0.01	0.01	<0	<0

Groundwater Bores - Metal Data

Data_Source	Station	RN_MP	Sample_Date	Formation _Name	Nickel	Nickel_ Dissolved	Selenium	Selenium _Dissolved	Vanadium	Vanadium _Dissolved	Zinc	Zinc _Dissolved
Landholder	AES1445	24469	12/12/2016	WCM	0.003	<0.001	<0.01	<0.01	<0.01	<0.01	1.66	0.171
Landholder	AES1778	24479	11/12/2018	WCM	<0	<0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Landholder	AES1691	147607	10/27/2016	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	<0.005	<0.005
Landholder	AES1691	147607	4/05/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	<0.005	<0.005
Landholder	AES1281	19988	7/08/2013	WCM	<0.0005	<0.0005	<0.0002	<0.0002	<0.0002	<0.0002	0.009	0.002
Landholder	AES1389	119075	10/24/2013	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.006	<0.005
Landholder	AES1284	10898	7/09/2013	WCM		<0.0005		<0.0002		0.0002		0.053
Landholder	AES1284	10898	2/01/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.098	0.098
Landholder	AES1289	119484	07/17/2013	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.304	0.044
Landholder	AES1289	119484	6/01/2016	WCM		<0.001	<0.01	<0.01	<0.01	<0.01	0.338	0.265
Landholder	AES1171	107868	02/19/2013	WCM	0.0003	0.0001	<0.0005	<0.0005	0.0004	<0.0001	0.149	0.0518
Landholder	AES1171	107868	08/20/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.072	0.048
Landholder	AES1802	15868	11/16/2018	WCM	<0	<0	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Landholder	AES1802	15868	08/23/2018	WCM	<0	<0	<0.01	<0.01	<0.01	<0.01	0.05	0.01
Landholder	AES1689	24466	4/02/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.085	<0.005
Landholder	AES1285		7/09/2013	WCM		<0.0005		<0.0002		<0.0002		0.116
Landholder	AES1285		01/31/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.172	0.07
Landholder	AES1296	38191	7/12/2013	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.005	<0.005
Landholder	AES1687	107857	09/24/2019	SBK	<0	<0	<0.01	<0.01	<0.01	<0.01	0.1	0.02
Landholder	AES1695	147001	04/27/2016	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.18	0.135
Landholder	AES1695	147001	2/05/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.148	0.108
Landholder	AES1690	15811	08/14/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.009	<0.005
Landholder	AES1295	24467	7/11/2013	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.025	0.009
Landholder	AES1295	24467	9/03/2014	WCM		<0.001				<0.01		0.03
Landholder	AES1436	33553	08/15/2019	SBK	<0	<0	<0.01	<0.01	<0.01	<0.01	0.01	0.01
Landholder	AES1436	33553	01/16/2014	SBK	<0.001	0.003	<0.01	<0.01	<0.01	<0.01	0.044	0.103
Landholder	AES0257	37177	4/10/2018	WCM	<0.001	<0.001	<0.01	<0.01	<0.01	<0.01	0.024	0.009
Landholder	AES9443	147004	08/23/2018	SBK	<0	<0	<0.01	<0.01	<0.01	<0.01	0.01	0.01
Landholder	AES9623	87897	03/21/2019	SBK	<0	<0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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Document Status

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