Far North Prescribed Wells Area Groundwater Model

Volume 3 – Hydraulic parameterisation

Department for Environment and Water
September, 2023

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Government of South Australia
Department for Environment and Water

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

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Contribution, steering committee oversight or review of the report was provided by:

- project technical lead Mark Keppel, Principal Hydrogeologist, Department for Environment and Water (DEW)
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- project groundwater modelling technical lead Juliette Woods, Principal Groundwater Modeller, DEW
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The following people provided external review of the report:

- project Independent expert technical advisor, Hugh Middlemis, Principal Groundwater Engineer, HydroGeoLogic.
- Paul Howe, Principal Hydrogeologist, CDM Smith Pty Ltd
- Keith Phillipson, Principal Modeller, Australasian Groundwater and Environmental Consultants Pty Ltd.

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- Dominic Pepicelli, Principal Reservoir Engineer, DEM, for advice on petroleum, well test data.

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Executive Summary

The documentation for the Far North Prescribed Wells Area Groundwater Model is presented over several volumes. The purpose of these reports is to provide an overview of the study area, provide scientific evidence for the conceptual hydrogeological model used as the basis for the decisions and assumptions made during model construction and history matching. This volume (Volume 3) provides a compilation, analysis, results, and interpretations of hydraulic parameters used to develop the conceptual hydrogeological model and inform construction of the numerical model.

Hydraulic data was compiled from published and unpublished information and reports from: SA Geodata, oil and gas industry records, previous models for the Great Artesian Basin (GAB) hydrogeological super-basin, and models of adjacent basins within the study area, such as the Cooper, Pedirka and Arckaringa basins. Hydraulic aquifer parameters were collated for individual hydrostratigraphic units.

As well as literature and previous modelling, two data collation, interpretation and conversion studies were conducted specifically for this study. The first study involved the calculation of apparent transmissivity (*T*) data from pumping test and flow data collected during routine water well monitoring. Transmissivity is described as 'apparent' because values were not corrected for salinity or temperature. A hydraulic conductivity (*K*) could then be estimated using this apparent *T* data. From this study, *K* and *T* were found to vary considerably across the mapped area. Estimated apparent *T* values ranged from 1.21 m^2/d to 22,900 m^2/d (Figure 1). This large range of values may be due to factors like variability in local hydraulic characteristics, measurement errors, equipment malfunction and equipment not being properly calibrated. Results at the higher end of the scale are thought to be more impacted by error or local factors. Resultant values of *K* for the J-K aquifer vary between 0.1 and 250 m/d, with an average of 22 m/d. The median, arithmetic mean and geometric mean of estimated *T* are 134 m^2/d, 790 m^2/d and 143 m^2/d, respectively.

The second study involved the collation of core porosity and air permeability data from industry-sourced core-plug analysis for several Eromanga Basin stratigraphic units in the Cooper Basin region. These required conversion to an ideal fluid permeability before use in modelling. Permeability values were also obtained from existing Drill Stem Tests (DST) and Repeat Formation Tests (RFT) conducted over reservoir intervals with good shows of petroleum hydrocarbons. Swanson mean permeability values varied between 2.851 millidarcies (mD) (Murta Formation) and 2,523 mD (Namur Sandstone). Estimated Swanson mean liquid brine hydraulic conductivity (*K*) calculated from these permeabilities range from approximately 2.2 x 10^{-4} m/d for the Murta Formation to 2.05 x 10^{-1} m/d for the Hutton Formation, whilst equivalent arithmetic means range from 5.43 x 10^{-3} to 2.1 x 10^{-1} m/d (Figure 1).

Specific yield (S_y) and specific storage (S_s) values for aquifer and aquitard units have initial values derived from literature but will also be subject to modification during model calibration. However, the tolerance with which such parameters can be modified is subject to review to ensure consistency with the current understanding of system hydraulics. For example, recent work by Rau et al. (2018) indicates that S_s is limited to $2.3 \times 10^{-7}\ m^{-1} \leq S_s \leq 1.3 \times 10^{-5}\ m^{-1}$. Rau et al. (2018) argue that parameterization of S_s for unconsolidated materials should therefore not exceed the physical upper limit of approximately 1.3 x 10^{-5} m^{-1}.

A summary of horizontal (K_h) and vertical (K_v) hydraulic conductivity values either collected or calculated during this study are presented in Tables 1 and 2, while a summary of S_y and S_s data is provided in Table 3. Regions covered by these tables include the Eromanga, Cooper, Simpson, Pedirka, Arckaringa, Warburton and Arrowie basins and the Stuart Shelf.

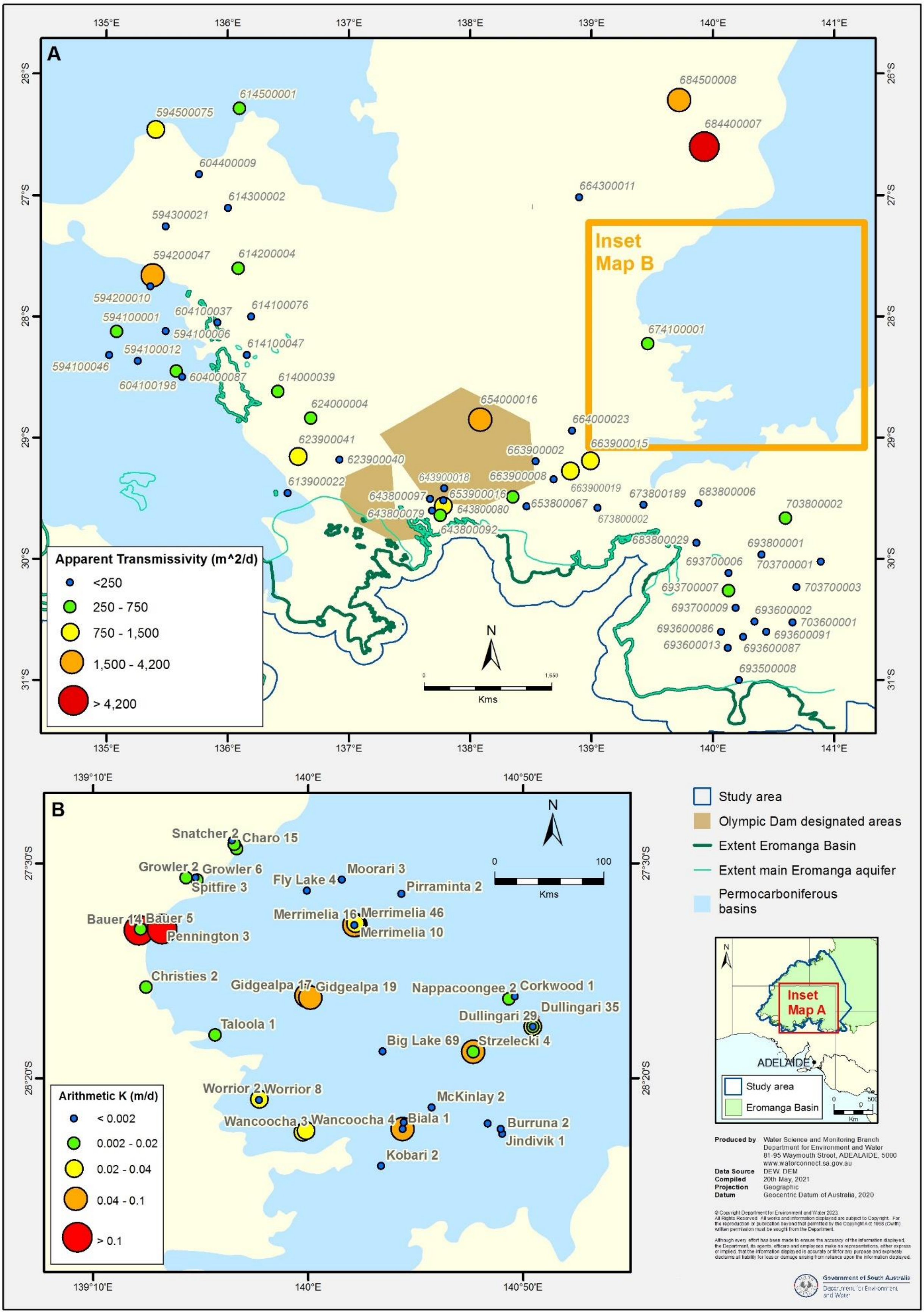


Figure 1: Distribution of transmissivity results from shut-in tests and mean arithmetic conductivity results from core-derived air permeability

During this study, several limitations were determined. These limitations include:

- Porosity and permeability (*k*) data obtained from core plugs may not be representative of the bulk formation because of sampling bias. Sampling bias occurs because sampling tends to favour sections of strata that are the more productive units, which are generally obtained from depth. Consequently, the resultant porosity and permeability values may be exaggerated because of depressurisation from the removal of overburden pressure.
- Similarly, the hydraulic property estimates obtained from drill stem tests (DST), Modular Formation Dynamics Testing (MDT) and pumping tests may not be strictly representative of the formation because they were obtained from restricted vertical intervals. These intervals may be considerably smaller than the thickness of the unit in question. Further, like core plug data, pump test data undertaken for hydrogeological assessment may also favour the more highly conductive units, as it is less likely that wells will be completed in the less conductive zones.

Table 1: Summary of horizontal hydraulic conductivities (m/d)

Formation	Region (defined by the basins underlying the Eromanga basin)					
	Simpson	Cooper	Arckaringa	Pedirka	Stuart Shelf	Min. to Max.
Cadna-owie Fm		$8 \times 10 \times 10^{-2}$	20.0	7.0		0.1 to 100
Murta Fm		$1.44 \times 10 \times 10^{-8}$ to 4.43				
McKinlay Mbr		$1.44 \times 10 \times 10^{-8}$ to 6.34				
Algebuckina Sst	22.1				22.1	0.1 to 100
Namur Sst		$1.18 \times 10 \times 10^{-4}$ to 5.48				
Hooray Sst		0.12				<18.7
Westbourne Fm		0.1				
Adori Sst		0.77				10 (mean)
Birkhead Fm		$1.44 \times 10 \times 10^{-8}$ to 1.85				
Hutton Sst Poolowanna Fm		1.5×10^{-4} to 4.35				<170
Mt Toondina Fm			9×10^{-5} to 5.0			
Stuart Range Fm			3.46×10^{-8} to 1×10^{-4}			
Boorthanna Fm			0.2 to 2.53			
Purni Fm				2.5×10^{-4} to 6		
Crown Point Fm				0.1 to 2.3		
Cuddapan Fm		1.7×10^{-2}				
Tinchoo Fm		0.28				
Wimma Sst		1.0×10^{-2}				
Paning Mbr		2.1×10^{-2}				
Callamura Mbr		6.7×10^{-3}				
Toolache Fm		3.6×10^{-2}				
Daralinge Fm		4.3×10^{-3}				
Epsilon Fm		7.3×10^{-3}				
Patchawarra Fm		1.0×10^{-2}				
Tirrawarra Sst		1.7×10^{-2}				
Merrimelia Fm		1.2×10^{-3}				

Formation	Region (defined by the basins underlying the Eromanga basin)					
	Simpson	Cooper	Arckaringa	Pedirka	Stuart Shelf	Min. to Max.
Andamooka Lmst					5	
Arcoona Qtz.					0.05	
Tent Hill Fm.					1×10^{-2}	
Tregolana Sh					1×10^{-4}	
Generic Basement						1×10^{-4} to 0.3

Table 2: Summary of estimated vertical hydraulic conductivity K_v values (m/d)

Collective term	Region	Hydrostratigraphic unit	K_v (m/d)
Main confining unit		Rolling Downs Group	3.46×10^{-9} to 8.64×10^{-4}
Main Eromanga Aquifer Sequence	Cooper Basin	Cadna-owie Fm	0.7 to 2
		Murta Fm	
		Namur-Algebuckina Sandstone Aquifer	0.7 to 2
		Birkhead Formation	4.31×10^{-5}
		Hutton-Poolowanna Aquifer	
Pre-Jurassic Basement	Generic Pre-Jurassic Basement	Generic Pre-Jurassic Basement	4.15×10^{-8} to 2
	Arckaringa Basin	Mt Toondina Fm	4.15×10^{-8} to 3.46×10^{-5}
		Stuart Range Fm	
		Boorthanna Fm	
	Pedirka Basin	Purni Formation	0.05
		Crown Point Fm	
	Warburton Basin	Generic Warburton Basin	0.19
	Arrowie Basin	Stuart Shelf (Tent Hill Fm)	8×10^{-4}

Table 3: Summary of estimated specific yield S_y and storage S_s values

Collective term	Region	Hydrostratigraphic unit	S_s (1/m)	S_y (-)
Main confining unit		Rolling Downs Group	4.3×10^{-6} to 1×10^{-3}	
Main Eromanga Aquifer Sequence	Cooper Basin	Cadna-owie Fm	1.75×10^{-6} to 1.9×10^{-3}	8×10^{-6} to 7
		Murta Fm		
		Namur–Algebuckina Sandstone Aquifer	3×10^{-7} to 1.9×10^{-3}	0.1 to 0.3*
		Birkhead Fm	5.8×10^{-7}	
		Hutton–Poolowanna Aquifer		0.05 to 0.25*
Pre-Jurassic Basement		Generic Pre-Jurassic Basement	1×10^{-5}	
	Arckaringa Basin	Mt Toondina Fm	1×10^{-5}	
		Stuart Range Fm		
		Boorthanna Fm		
	Pedirka Basin	Purni Fm	1.1^{-6} to 1×10^{-4}	0.04 to 0.32*
		Crown Point Fm		0.11 to 0.32*
	Arrowie Basin	Stuart Shelf	4×10^{-5} to 0.02	

*Estimated based on effective porosity.

1 Introduction

Groundwater in the Far North Prescribed Wells Area (FNPWA) is vital for the success of the mining, energy, pastoral and tourism industries, and the provision of community water supplies in the Landscape SA South Australian Arid Lands (LSA SAAL) Management Region (Figure 1.1). The continued success and expansion of these industries is dependent on balancing the needs of existing users and the environment. Of particular environmental importance are the spring wetland communities in the discharge areas of the Great Artesian Basin hydrogeological super-basin (GAB) which are listed under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. Protection of these environments is regulated and managed at a State level through the Far North Water Allocation Plan (FNWAP), through the description and implementation of spring buffer zones, water management zones and drawdown triggers at state borders. Further, the South Australian Government also has regulatory responsibilities over water management under the *Roxby Downs (Indenture Ratification) Act 1982*.

With demand for groundwater expected to grow in the mining and energy industries, a new numerical groundwater flow model is required to evaluate current knowledge and determine key knowledge gaps. This model will also be a tool to inform management of groundwater resources, both ongoing and for future major developments.

1.1 The Far North Prescribed Wells Area (FNPWA)

Groundwater in the FNPWA is managed under the FNWAP; a key principle being to manage groundwater resources by pressure (head) and to allocate by volume. The FNPWA was prescribed on 27 March 2003, and the first WAP was adopted on 16 February 2009. The 2021 FNWAP was adopted on the 27 February 2021.

Currently, the total groundwater allocation is 176 ML/d (2018–2019 data) (Figure 1.2), with the majority (approximately 76% or 134 ML/d) sourced from the GAB hydrogeological super-basin aquifers (Figure 1.3). These allocations are made up of mining, industrial and human requirement supplies, co-produced water (water extracted with petroleum hydrocarbons), stock and domestic use, bore-fed wetlands and other amounts. Demand on the groundwater resources is expected to grow, particularly in response to growth in the mineral and energy industries.

1.2 Previous modelling

Although several groundwater models cover part of the western margin of the GAB hydrogeological super-basin, they are subject to one or more of the following limitations in terms of suitability for cumulative impact assessment to inform management of aquifers within South Australia (SA).

- a small or constrained geographical extent
- an over-simplified or limited aquifer system representation
- proprietary ownership by private companies that prohibits use for regulatory water resource assessments
- being based on outdated hydrogeological conceptualisations that do not reflect the current understanding of basin structure and groundwater processes including recharge and discharge
- not taking into account other interconnected basins that form important water resources in the FNPWA
- not being designed to consider the cumulative impacts of multiple groundwater users.

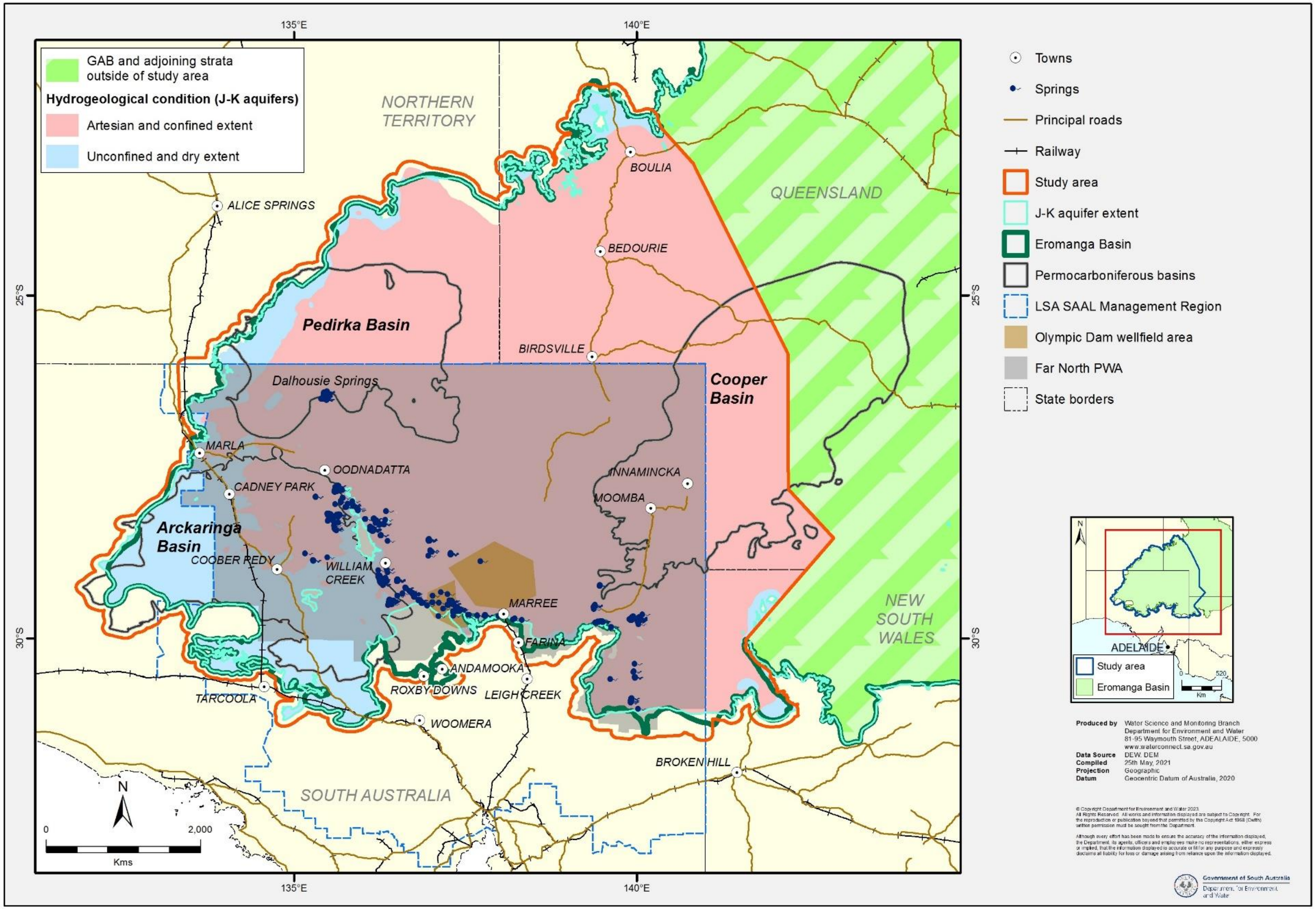


Figure 1.1: Location map of the Far North Prescribed Wells Area and study area

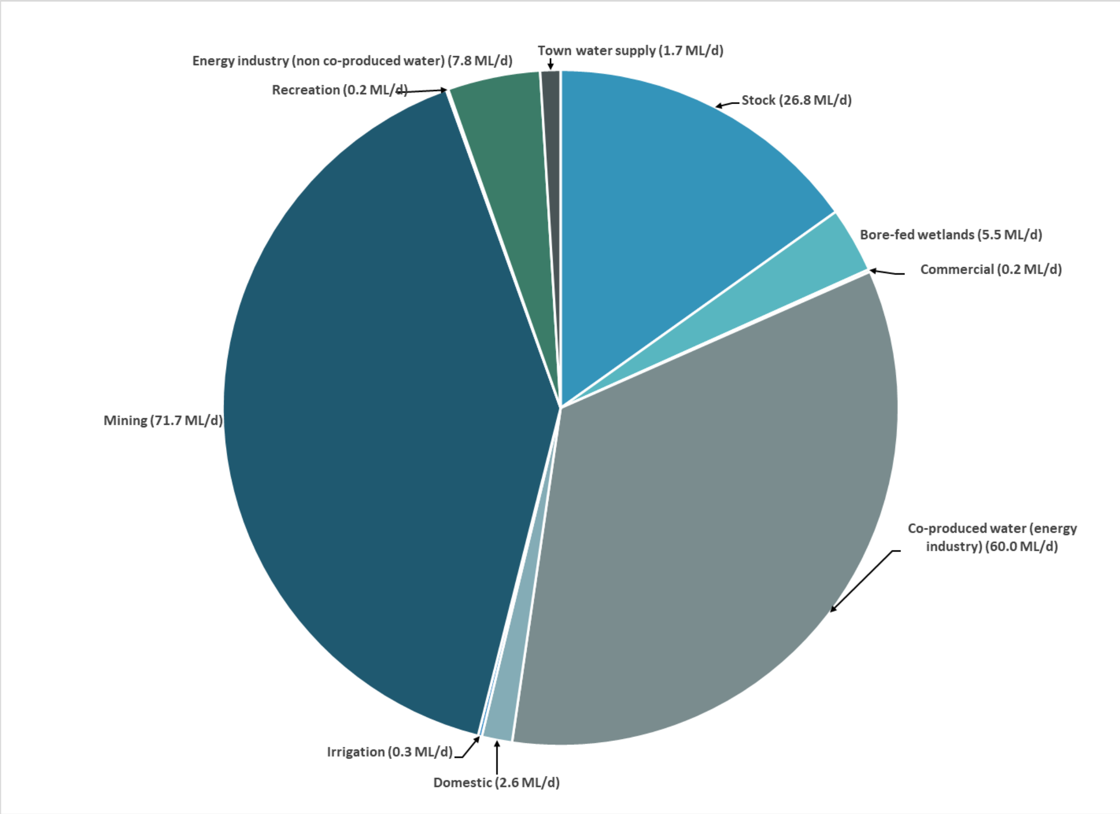


Figure 1.2: Total licensed volume (176 ML/d) presented by licence purpose description, FNPWA.

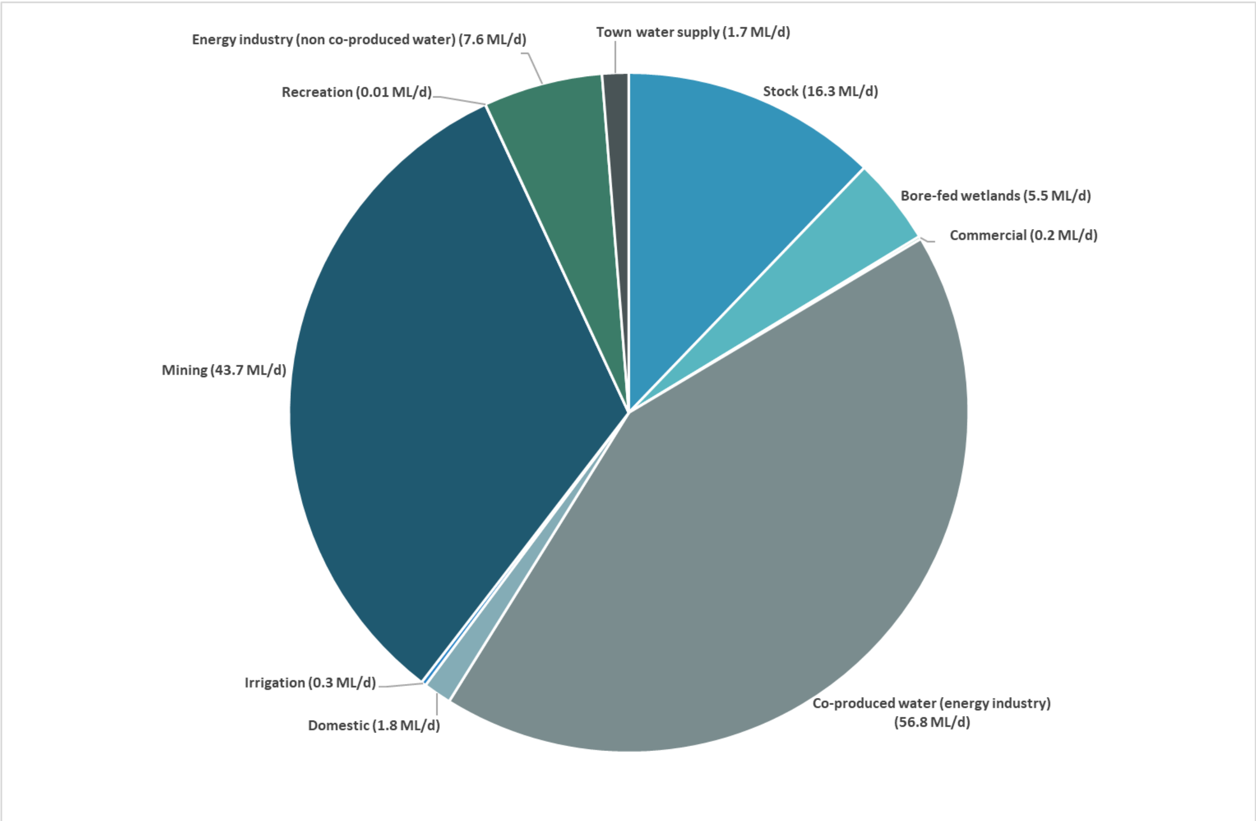


Figure 1.3: Licensed volume sourced from the GAB hydrogeological super-basin (134 ML/d) presented by licence purpose description, FNPWA.

DEW has developed a numerical groundwater flow model to address the gaps identified in the existing models and to provide a tool to inform management of groundwater resources in the FNPWA. This model is consistent with the latest science and knowledge and can updated in the future, providing a quantitative and predictive tool for development assessments and to inform management decisions. Further discussion of previous modelling is provided in Volume 8 of this report.

1.3 The study area

To cover an area of sufficient extent to achieve the model objectives, the study area (Figure 1.1) encompasses portions of the Eromanga Basin in Queensland (QLD) and New South Wales (NSW), part of the Cooper Basin in Queensland, and the entirety of the following administrative areas and features of hydrogeological significance:

- Eromanga Bain in SA and the Northern Territory (NT)
- Cooper Basin in SA
- Pedirka Basin
- Arckaringa Basin
- the Far North Prescribed Wells Area (PWA).

The initial model design is to simulate groundwater flow within the Main Eromanga Aquifer Sequence, with a focus on the Far North PWA in SA. Future modelling programs may involve extensions to other groundwater flow systems, such as the Cooper, Arckaringa and Pedirka Basins.

The study area (Figure 1.1) covers a total area of about 721,370 km^2. A 10 km-wide external buffer encompassing the features described in the above dot points extends beyond the southern, western and northern perimeters of the study area. The eastern boundary extends: between 245 km and 420 km from the NT border into QLD; between 125 km and 190 km from the SA border into Queensland; and between 60 km and 140 km into NSW from the SA border. The eastern boundary is designed to allow for lateral inflow of groundwater to the study area in some areas and no flow in others, consistent with the groundwater flow system contours interpreted during this project. The spatial extent of the eastern boundary was selected to provide a sufficient distance away from the areas of interest in SA, so that the hydraulic conditions along the boundary do not materially influence simulation results.

1.4 Reporting structure

Given the size and multi-faceted nature of the investigation supporting model development, reporting occurs over several volumes:

1. Simplified technical summary
2. Hydrogeological framework
3. Hydraulic parametrisation
4. Groundwater flow system dynamics
5. Time series data
6. Recharge and discharge processes
7. Water use and balance estimations
8. Model construction and history matching

1.5 Volume objective

Central to any numerical groundwater model are the hydraulic data used to describe and control the flow of groundwater through the various simulated layers. This volume (Volume 3) provides a compilation, analysis, results and interpretations of hydraulic parameters used to develop the conceptual hydrogeological model for the Far North numerical groundwater model. There are two sources of hydraulic parametrisation data.

The first are data derived from literature and past modelling works relevant to this study. An objective of this volume is to collate, discuss and summarise these literature values so they can provide a convenient reference to future modelling works.

The second source of hydraulic parametrisation are data from core analysis and historical pump tests. These data form an important new source of hydraulic parametrisation information unique to this study. Consequently, another important objective of this volume is to describe the source of these new data and the methodology used to determine the parameter values.

A final objective of this volume is to summarise the collated data to inform the initial parameter conditions to be employed in model construction and the variations possible during the history-matching phase of model development.

1.6 Hydrostratigraphy

Table 1.1 and Figure 1.4, which have been taken from Volume 2, summarise the key stratigraphic, hydrostratigraphic and model layer nomenclature used during this study. The terms discussed below are used throughout this and other volumes.

The study area covers a sizable portion of the Mesozoic Eromanga Basin, including its entire occurrence in SA and the NT. The Eromanga Basin is the largest volumetric component of the GAB hydrogeological super-basin (Krieg 1995) and can be described as having a bowl shape that is partly defined and modified by faulting (Figure 1.4).

In the SA part of the Eromanga Basin, the most important strata sequence is the Cadna-owie Formation, the Algebuckina Sandstone, and their lateral equivalents (primarily the Namur Sandstone and Adori Sandstone). The collective hydrostratigraphic terminology commonly used in SA for aquifers and partial aquifers within these chronostratigraphically and lithologically connected extensive units is the 'J-K aquifer' (Table 1.1). It should be noted that within this general hydrostratigraphic nomenclature, there can exist sub-regional scale lithological variation or structural deformation that may promote the development of sub-basinal groundwater flow systems.

The other important aquifer grouping is found in the deeper parts of the Eromanga Basin near the Cooper Basin and is associated with the Hutton Sandstone and the Poolowanna Formation. In the Cooper Basin region, these aquifer and partial aquifer units are separated from one another by a series of finer grained confining units such as such as the Birkhead, Murta and Westbourne formations (Table 1.1).

The initial design of the model is to primarily simulate groundwater flow within the sequence of strata defined by the top of the Cadna-owie Formation, called the 'C Horizon', to the base of Mesozoic sediments (Base of the Poolowanna Formation), or the top of the pre-Jurassic units, called the 'J-Horizon'. Collectively, this package of aquifers and confining units is called the 'Main Eromanga Aquifer Sequence' (Table 1.1). It is essentially the combination of the extensive J-K aquifer and the sub-basinal Hutton–Poolowanna aquifer, including intervening confining units.

The Main Eromanga Aquifer Sequence is overlain by a confining unit composed of shaly mudstone units of low permeability that are collectively part of the Rolling Downs Group (Vine and Day. 1965). The main elements of this group are the Bulldog Shale and Oodnadatta Formations which outcrop extensively near the western margin of the GAB hydrogeological super-basin, whereas the Wallumbilla Formation and Allaru Mudstone occur at depth in the central portions of the basin near the borders of SA and Qld.

Of the strata underlying the Main Eromanga Aquifer Sequence, the most important are the sedimentary rocks of the Permo-Carboniferous Arckaringa, Pedirka and Cooper basins. Not only do the sandstones, siltstones, shales, diamictites and coal beds in these basin sediments contain aquifers themselves, but also significant oil, gas and coal resources under varying degrees of development. Outside of the Permo-Carboniferous basins, metasedimentary rocks of the early Paleozoic Warburton Basin, Precambrian rocks of the Adelaide Geosyncline and crystalline Archaean rock may also be found.

For model construction, the Main Eromanga Aquifer Sequence was discretised into 5 model layers based on regional scale hydrostratigraphy (Figure 1.4). These included the Cadna-owie Formation Aquifer/leaky aquitard, the Murta Formation confining layer, the Namur–Algebuckina Sandstone Aquifer, the Birkhead Formation confining layer and the Hutton–Poolowanna aquifer. Underlying these is a layer of nominal thickness representative of the Pre-Jurassic Basement.

Table 1.1: Summary of hydrostratigraphic unit nomenclature and relationship to model layer design.

Collective term	Western study area					Cooper Basin region, study area					Whole of study area	
	Stratigraphic unit	Hydrostratigraphic unit	Model layer name	Hydrogeological characteristic	Qualitative permeability	Stratigraphic unit	Hydrostratigraphic unit	Model layer name	Hydrogeological characteristic	Qualitative permeability	[a]Max. thick. (m)	[a]Ave. thick. (m)
Main confining units	Rolling Downs Group	Main confining unit		Confining unit	Low	Rolling Downs Group	Main confining units		Confining unit	Low	NA	NA
'C' Horizon												
Main Eromanga Aquifer Sequence	Cadna-owie Formation (and lateral equivalents)	J-K aquifer	Cadna-owie Formation (Layer 1)	Partial aquifer/aquifer	Medium	Cadna-owie Formation	Intra-sequence confining unit	Cadna-owie Formation (Layer 1)	Leaky aquitard	Low	689[b]	42
	Algebuckina Sandstone		Namur Algebuckina Sandstone aquifer, (Layer 3)	Aquifer	High	Murta Formation and McKinlay Member	Intra-sequence confining unit	Murta Formation confining unit (Layer 2)	Low permeability confining unit. McKinlay Member included initially as conservative option; however, an alternative conceptualisation to include within layer 3 is an option.	Low	122	49
						Adori Sandstone, Westbourne Formation, Namur Sandstone	J-K aquifer	Namur–Algebuckina Sandstone aquifer (Layer 3)	Aquifer	High	1259	211
						Birkhead Formation	Intra-sequence confining unit	Birkhead Formation confining unit (Layer 4)	Low-permeability confining unit	Low	225	72
						Hutton Sandstone and Poolowanna Formation	Hutton–Poolowanna aquifer	Hutton–Poolowanna aquifer (Layer 5)	Aquifer	Medium	855	256
'J' Horizon												
Basement	Pre-Jurassic	Basement	Pre-Jurassic Basement (Layer 6)	Partial aquifer. A designated thickness specified below Layer 3 with variable boundary conditions to allow for broad upward or downward leakage. Base of layer 6 is a no-flow boundary	Variable	Pre-Jurassic	Basement	Pre-Jurassic Basement (Layer 6)	A designated thickness specified below layer 5 with variable boundary conditions to allow for broad upward or downward leakage. Base of layer 6 is a no-flow boundary	Variable	NA	User defined

Note: Table shading reflects hydrogeological properties of model layers. [a] Depths based on isopach interpolation. [b] Maximum thickness was interpolated in close vicinity to a mapped fault but cannot be confirmed. Confirmed thickness of 357 m based on intersection found in Well Unit no. 684200195.

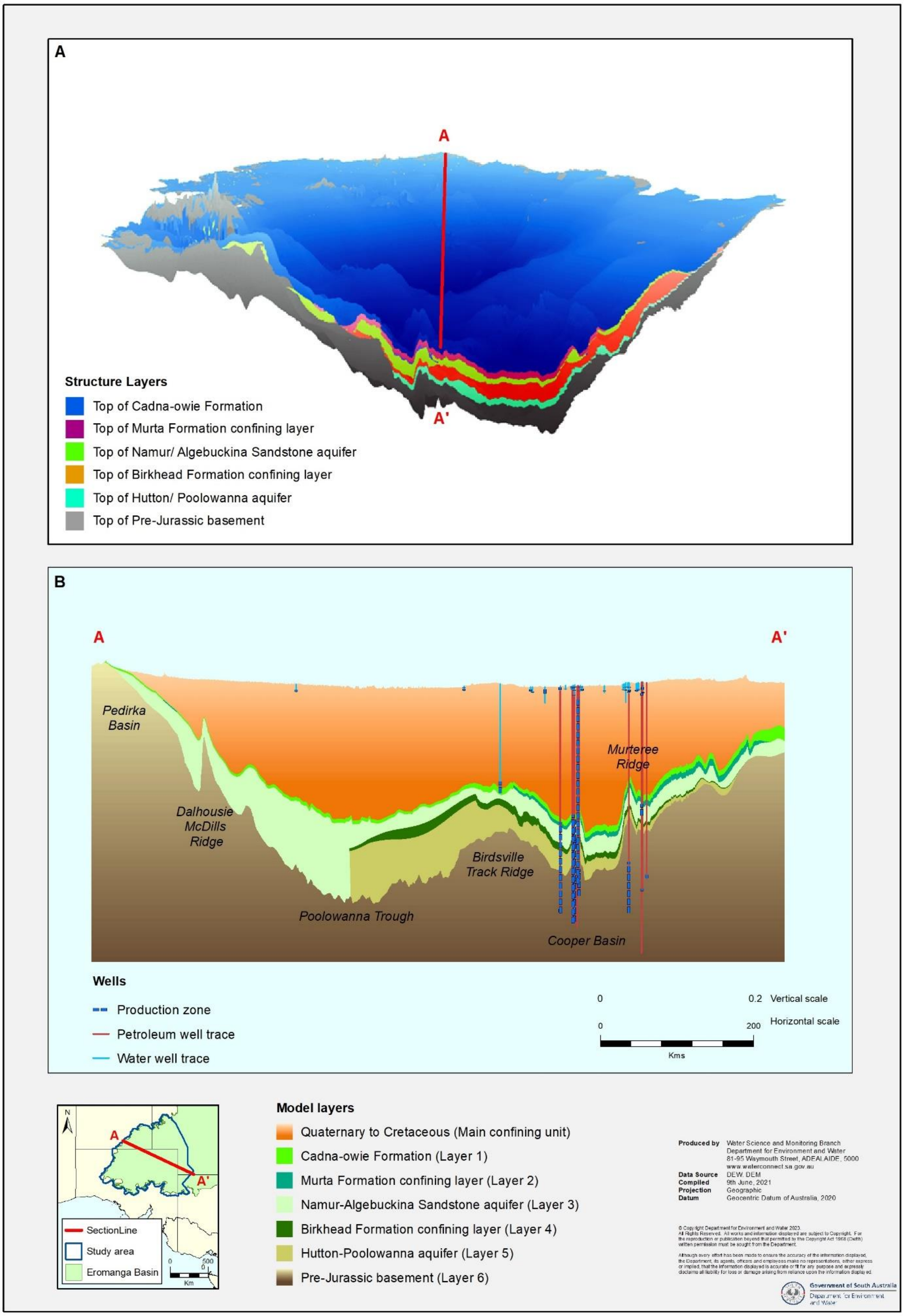


Figure 1.4: A) 3D projection of structure surface used in numerical model. B) Cross section through study area showing model layers and key structures.

2 Prior estimations from literature

Hydraulic property data was sought for horizontal (K_h) and vertical (K_v) hydraulic conductivity, transmissivity (T), specific storage (or storativity) (S_s) and specific yield (S_y). Data derived and presented in this section include those from previous modelling studies, as well as published reports from government and industry. A primary source of hydraulic property data is previously published aquifer pumping tests and artesian monitoring studies. With respect to industry sources, the Energy Industry operating in the region was a particularly important source of information. Parameter data from previously published reports is provided in Table 2.1.

An important source of data is previous modelling of the GAB hydrogeological super-basin, as well as other basins located within the study area, such as the Cooper, Pedirka and Arckaringa basins. Previous models that overlap with this study area that were examined include GAB95 (Berry and Armstrong 1995), GABFLOW (Welsh 2000), ODEX5 (Berry 2005), GABTRAN (Welsh 2006), ODEX6 (BHP Billiton 2014), and ODGAB (Golder Associates 2015) models. Parameter data from reviewed models is provided in Table 2.2.

Literature and industry-derived hydraulic parameter values for key Permo-Carboniferous units underlying the Main Eromanga Aquifer Sequence have been compiled and presented in Table 2.3 and Table 2.4 (Cooper Basin specifically). Such values are important with respect to the construction of layer 6 (Table 1.1) in key areas of the model, such as the Cooper Basin region and the south-western corner (Figure 1.1).

2.1 Previous core-plug-based porosity and permeability studies

Petrophysics is the study of physical and chemical properties of rocks and their interaction with fluids. Petrophysics can be used to describe lithology, porosity, water saturation, permeability and density. Given many of these properties are important in hydrogeology as well, petrophysical studies can also be very useful in understanding groundwater flow systems.

Gravestock and Alexander (1986, 1988 and 1989) study the petrophysical properties of key Eromanga Basin reservoirs against core-derived porosity and permeability data, to develop tools to assess reservoir (rocks with relatively higher porosity and permeability) and cap rock (rocks with relatively lower porosity and permeability) quality. A total of 270 m of core was logged and 638 plugs were sampled over a range of grain sizes and facies (Cotton et al. 2007). These were subjected to a variety of routine and special core analyses. Key results of the study, summarised from Gravestock and Alexander (1988) are: the porosity–permeability trends are controlled by grain size, and two trends can be readily identified – the RES trend for good to excellent quality reservoir rocks (highly porous and permeable rocks) and the CAP trend for poorer quality reservoir rock and capping rock (caprock) (Figure 2.1).

Gravestock and Alexander (1986, 1988 and 1989) consider the petrophysical properties of the Murta and Birkhead formations as well as the Namur and Hutton sandstones and the McKinlay Member for the purpose of calculating porosity and permeability. With respect to gross porosity and permeability, Gravestock and Alexander (1988) classify Namur and Hutton Sandstones as good quality reservoir rocks and Murta and Birkhead formations as poorer quality reservoir rocks and cap rocks. However, petrophysical methods available at the time to measure porosity, such as corrected sonic and corrected density log porosity, at best only yield an order of magnitude correlation with permeability and tend to work best when core porosities are higher than 10%. Further, hole conditions (the evenness and variability of the hole diameter and walls) are found to impact on the quality of correlation (density log porosity) or required correction using gamma ray data to account for transit time (sonic log porosity).

Table 2.1: Selected parameter values from previous test analysis and modelling found in literature for the main GAB aquifer sequence, with an emphasis on the J-K aquifer and main confining unit

Parameter	Main Eromanga Aquifer Sequence – J-K aquifer	Bulldog Shale and Oodnadatta Formation
Transmissivity	Berry and Armstrong (1995): 5 m^2/d to 380 m^2/d Habermehl (1980): 1 m^2/d to 2,000 m^2/d, with a predominance of recorded values in the range of 10 m^2/d to 20 m^2/d Fulton et al. (2015): 1,190 and 2,260 m^2/d (cumulative) Fulton et al. (2013): 2470 to 2600 m^2/d	Between 1.7 and 79.1 m^2/d for an interpreted fracture zone aquifer near Mount Willoughby (Smith 1976)
Storage coefficient values	Audibert (1976): Mean of 2.5 x 10^{-4} for whole basin Berry and Armstrong (1995): 3 x 10^{-6} Seidel (1978, 1980): 2.75 x 10^{-6} Fulton et al. (2015): 1 x 10^{-3} and 1.9 x 10^{-3} Fulton (2012) 6 x 10^{-4} to 1.2 x 10^{-3} KCB (2015): 1 x 10^{-5} (Cadna-owie Formation), 5 x 10^{-6} (Hutton Sandstone) Jiang (2014): 5.95×10^{-7} (Westbourne Fm) 5.8 ×10^{-7} (Birkhead Fm)	Berry and Armstrong (1995): 1 x 10^{-3} (Bulldog Shale to Cadna-owie Formation) 1 x 10^{-2} (Wellfield A region) Harrington et al. (2013): : 8×10^{-6} to 6×10^{-6} for the Bulldog Shale and 1×10^{-5} for the Oodnadatta Formation Smerdon et al. (2014): 4.3×10^{-6}
Hydraulic conductivity	Habermehl (1980): 01 to 10 m/d (J-K aquifer, mostly Cadna-owie Formation) Armstrong and Berry (1997): 0.5 m/d to 22 m/d, mean 7.0 m/d Berry and Armstrong (1995): Measured Permeability 1.6 m/d to 18.5 m/d, mean of 8.9 m/d. Most measurements in 5 to 15 m/d range (Algebuckina Sandstone). K_h 2.5 to 12.5 m/d (steady state modelling calibration). Rust PPK (1994): 1 m/d to 13 m/d, mean of 6.3 m/d (Longsight Sandstone) Audibert (1976): 0.02 m/d to 82 m/d Fulton et al. (2015): 15 to 25 m/d Kellett et al. (1999): 0.5 to 1 m/d (estimated) Fulton (2012): 11 m/d KCB (2015): K_h: 2 x 10^{-2} to 1 m/d (Cadna-owie Fm), 1 x 10^{-2} to 1 m/d (Hutton Sst), K_v 1 x 10^{-4} m/d Jiang (2014): K_h: 1.16 to 18.7 m/d (Cadna-owie Fm – Hooray Sst), 0 to 170 m/d (Hutton, Evergreen and Precipice Sst), 1 x 10^{-6} to 0.1 (Birkhead Fm), 10 m/d (mean (Adori Sst), K_v: 2.17×10^{-5} m/d (Westbourne Fm), 4.31×10^{-5} m/d. (Birkhead Fm).	Aquitard Kinhill Stearns (1984): 2.7 x 10^{-4} m/d Smerdon et al. (2014): K_h 1.73 x 10^{-8} to 4.32 x 10^{-7}. Harrington et al. (2013): mean values from pore water pressure and chemistry K_v 8.12 x 10^{-9} to 2.16 x 10^{-6} m/d (9.4 x 10^{-14} to 2.5 x 10^{-11} m/s) (Bulldog Shale) and 6.31 x 10^{-9} to 7.78 x 10^{-5} m/d (7.3 x 10^{-14} to 9.0 x 10^{-10} m/s) (Oodnadatta Formation). From Helium -4 (^{4}He) concentrations in shallow groundwater from a regional scale survey, with bores often coinciding with playa lakes: K_v 8.64 x 10^{-5} to 8.64 x 10^{-4} m/d (1×10^{-9} to 1×10^{-8} m/s). (Harrington et al. 2013) Jiang (2014) <1 x 10^{-5} m/d (Rolling Downs Group).

Parameter	Main Eromanga Aquifer Sequence – J-K aquifer	Bulldog Shale and Oodnadatta Formation
Porosity	Audibert (1976): Mean of 21% for whole basin New (1988): >20% Kellett et al. (1999): 5% estimate (effective) Radke et al. (2000): 10 to 29 % with an average porosity of 23 % Ransley and Smerdon (2012): 15% (Cadna-owie Formation), 16% (Hooray Sandstone), 14% Westbourne Formation), 22% (Adori Sandstone), 14% (Birkhead Formation), 17% (Hutton Sandstone) DMER, (1997): 13% Poolowana Formation), 5-25% (Hutton Sandstone)	Harrington et al. (2013): 37% for Bulldog Shale, 42% for Oodnadatta Formation

Table 2.2: Hydraulic parameters used in published modelling.

Formation	ODGAB (Golder 2015)					ODEX6 (BHP Billiton 2014)					GABTRANS (Welsh 2006)					Pedirka Basin model (Peat and Yan 2015)					Arckaringa Basin model (Purczel 2015)				
	K_x m/d	K_y m/d	K_v m/d	S_s 1/m	S_y	K_x m/d	K_y m/d	K_v m/d	S_s 1/m	S_y	K_x m/d	K_y m/d	K_v m/d	S_s 1/m	S_y	K_x m/d	K_y m/d	K_v m/d	S_s 1/m	S_y	K_x m/d	K_y m/d	K_v m/d	S_s 1/m	S_y
Algebuckina Sandstone	0.1 to 100			3×10^{-7} to 4.4×10^{-6}		0.5 to 2.5	0.5 to 2.5		1.75×10^{-6}																
Basement										1×10^{-4}						0.01	0.01	0.001	1×10^{-5}		0.3	0.3	5×10^{-4}	1×10^{-5}	
Boorthanna Formation																					1.25	1.25	1×10^{-4}	1×10^{-5}	
Bulldog Shale			1×10^{-8} to 1×10^{-4}			0.01	0.01			2×10^{-4}											0.5	0.5	1×10^{-6}	1×10^{-5}	
Cadna-Owie Formation	0.1 to 100					0.5 to 2.5	0.5 to 2.5		1.75×10^{-6}																
Coorikiana Sandstone										0.1															
Crown Point Formation																1	1	0.1 to 2	1×10^{-5}						
J-K aquifer											0.1 to 20	0.1 to 20		5×10^{-6}	8×10^{-6} to 0.155	7	7	0.7 to 2	1×10^{-5}	7	20	20	2	1×10^{-5}	
Mackunda Formation			1×10^{-8} to 1×10^{-4}																						
Mount Toondina Formation																					5	5	1×10^{-3}	1×10^{-5}	
Purni Formation																0.5	0.5	0.05	1×10^{-5}						
Stuart Range Formation																					1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-5}	
Sturt Shelf																					5.00	5.00	1×10^{-4}	1×10^{-5}	
Triassic Strata																1×10^{-7}	1×10^{-7}	1×10^{-7}	1×10^{-5}						
Winton Formation			1×10^{-8} to 1×10^{-4}																						

Note: No Parameter values specifically for the Adori Sandstone, Birkhead Formation, Hooray Sandstone, Hutton Sandstone, McKinlay Member, Murta Formation, Namur Sandstone, Oodnadatta Formation, Patchawarra Formation, Poolowanna Formation, surficial sediments, Toolachee Formation, Westbourne Formation, and Wyandra Sandstone

Table 2.3: Hydraulic properties for underlying Permo-Carboniferous strata derived from literature.

Region	Porosity	Transmissivity	Storage Co-efficient	Permeability (k) /Hydraulic conductivity (K) (1mD=1.27 x 10^{-3} m/d (OGIA 2016)
Cooper Basin	See Table 2.4	Green Rock Energy (2010) reported transmissivities for a combined Patchawarra Formation and Tirrawarra Sandstone reservoir as 0.15 to 3.15 m^2/d (115 to 2,428 mD.m).		See Table 2.4
Arckaringa Basin	Mount Toondina Formation: 4–36.6% (summary from Wohling et al. 2013) Stuart Range Formation: 12.1–26% (summary from Wohling et al. 2013) Boorthanna Formation: 3.6–25% (summary from Wohling et al. 2013) Kellett et al. (1999) suggests that secondary porosity development is important in assessing the unit's viability as a reliable groundwater supply.	Mount Toondina Formation: 0.073 (coal seam) to 38.14 m^2/d (clastic sediments) (AGC, 1975) Boorthanna Formation: 2 to 150 m^2/d (SKM 2009); <5-180 m^2/d (Howe et al. 2008)	See Table 6.3	(*K*) Mount Toondina Formation, sedimentary beds: 9 x 10^{-4} – 9 x 10^{-5} m/d (Coffey and Partners 1983) (*k*) 3.8 x 10^{-4} to 0.19 m/d. (Based on 0.3 to 152 mD) (Linc Energy 2010a) (*k*) 1.3 x 10^{-4} to 1.79 m/d. (Based on 0.1 to 1,408.3 mD) (Linc Energy, 2010b) Mount Toondina Formation, coal seams: K_h: 0.9^{-9} x 10^{-3} m/d (Coffey and Partners 1983). Stuart Range Formation: Laboratory analysis: (K_v) 3.46 x 10^{-8} to 3.46 x 10^{-5} m/d, median of 3.9 x 10^{-7} m/d. One-dimensional (1D) analytical modelling: (K_v) (4.15 x 10^{-8} to 4.6 x 10^{-7} m/d) (possible) (Kleinig et al. 2015) Boorthanna Formation: K_h: 0.2 m/d (estimated) (Kellett et al. 1999) (*k*) 0.38 to 2.53 m/d. (Based on 300–1,996 mD) (Tucker 1997).
Pedirka Basin	Purni Formation: Porosity ranges from 4–32% (16 25% for core analysis) (summary from Wohling et al., 2013; Fulton et al., 2015) Crown Point Formation: Porosity ranges from 3 30% (11–32% for core analysis) (summary from Wohling et al., 2013; Fulton et al., 2015)	Purni Formation: between 176 and 264 m^2/d (Fulton et al. 2015) Crown Point Formation: estimated at 14 m^2/d (Fulton et al. 2015)	Purni Formation: between 5 x 10^{-5} and 1 x 10^{-4} (Fulton et al. 2015)	Purni Formation (siliceous sediment): (*K*) 4 to 6 m/d (Fulton et al. 2015). (*k*) 0.8 to 3.2 m/d. (Based on 632 to 2,529 mD) (Amerada Petroleum 1966) (*k*) 0.17 to 0.24 m/d. (Based on 135 to 187 mD) (Amerada Petroleum, 1965) (*k*) 2.5 x 10^{-3} m/d. (Based on 2 mD) (Delhi International 1978) Purni Formation (coal measures): (*k*) 2.5 x 10^{-4} to 0.12 m/d. (Based on 0.2 to 96 mD) (Central Petroleum 2008) (*k*) 0.047 m/d. (Based on 36.7 mD) (Central Petroleum 2009) (*k*) 2.5 x 10^{-4} to 0.085 m/d (Based on 0.2 to 66.7 mD) (Questa 1990) Crown Point Formation: (*K*) 0.2 to 2.3 m/d (Fulton et al. 2015) (*k*) 0.74 to 1.06 m/d. (Based on 582 to 836 mD) (Amerada Petroleum (1965) (*k*) 0.7 m/d. (Based on 557 mD) (French Petroleum 1964) (*k*) 0.1 to 2.5 m/d (Based on 91 to 1998 mD) (New, 1988; Alexander and Jensen-Schmidt, 1995)

Region	Porosity	Transmissivity	Storage co-efficient	Permeability/ Hydraulic conductivity
Simpson Basin	Peera Formation: maximum measured porosity of 7.4% (Goldstein et al. 2011) in vicinity of Poolowanna Trough			
Stuart Shelf/ Arrowrie Basin	Andamooka Limestone (inc. surficial regolith): 2% (effective porosity, estimated value) (Kellett et al. 1999) Approximately 3% (laboratory analysis, core of fresh material) (BHP 2009a) 7 to 7.9% (Abstraction-based calculation, shallower weathered zone) (BHP 2009a) High secondary porosity and permeability associated with karst development north of Olympic Dam	Andamooka Limestone (north of Olympic Dam): 100 to 4,000 m^2/d (BHP 2009a) Andamooka Limestone (Southern margin of unit): 4 to 120 m^2/d) (BHP 2009a) Tent Hill Formation: 1 to 640 m^2/d. Higher value associated with Mashers Fault Zone (REM 2007)	Andamooka Limestone (north of Olympic Dam): 10^{-4} – 10^{-2} (BHP 2009a) 8 x 10^{-5} to 0.02 (around Olympic Dam) (BHP 2009a) Tent Hill Formation: 4 x 10^{-5} to 6 x 10^{-3} (REM, 2007)	Andamooka Limestone (inc. surficial regolith): (K) 0.2 m/d (estimated value) (Kellett et al. 1999) Arcoona Quartzite and Corraberra Sandstone (K): 0.05 m/d (Kellett et al. 1999) Tent Hill Formation: (K) 10^{-2} to 20 m/d. Higher value associated with Mashers Fault Zone (REM 2007; summary BHP 2009a) 10^{-3} to 1 m/d (K) (summary BHP 2009a) 10^{-3} to 2 m/d (K) (BHP, 2009a) Tregolana Shale: K_h 1 x 10^{-4} to 0.02 m/d (BHP, 2009a) K_v: 8 x 10^{-4} m/d (BHP 2009a)
Warburton Basin		Sheard (1982) undertook pumping tests of wells partially completed in a Paleozoic aquifer (as well as the overlying GAB) that may be Warburton Basin rocks. Transmissivity ranges from 9.7 to 18.7 m^2/d.	Morris et al. (1989) assumes a value of 10^{-5}	K_h values are unknown. Sheard (1982) provided a K_v of 0.19 m/d from well 564300053, but suggested permeability varied vertically.
Adelaidean	Porosity is predominantly secondary, with structure-related fracturing of importance. (Gravestock and Zang 1996) interpreted primary porosity destruction through cementation and compaction due to burial. Etina Formation sandstone: 9.6% (Gravestock and Zang 1996)	Ajax Limestone: 36 to 3,800 m^2/d and >5,000 m^2/d (dewatering tests – early results) 2 to 100 m^2/d (effective transmissivity) (Eggleston 2007) Ajax Limestone: 10 m^2/d (Read 1981) Parara Limestone: 24.3 to 82.5 m^2/d (Costar and Howles 2011) Wataru Gneiss: 18 to,73 m^2/d (Dodds and Clarke 2003)	Ajax Limestone: 1.6 x 10^{-6} – 0.013 (dewatering tests – early results) (Eggleston, 2007) Ajax Limestone: 6 x 10^{-4} (Read, 1981) Parara Limestone: 1.48 x 10^{-3} – 3.05 x 10^{-3} (Costar and Howles 2011)	Etina Formation sandstone k_h: 2.54 x 10^{-5} m/d (based on 0.02 mD) (Gravestock and Zang 1996)

Table 2.4: Summary of porosity and permeability values for the Cooper Basin[a]

Form.	No. meas.	Sample depth (m)			Porosity (%)			Permeability (mD) [Equivalent K_h[b] (m/d)]		
		Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.
Cuddapan Formation	22	2,658	2,667	2,663	0.0	17.6	9.20	0.0 [0.0]	3,674 [4.67]	1.58 [2.01 x 10^{-3}]
Tinchoo Formation	56	2,489	2,506	2,497	0.2	19.3	11.9	0.008 [1.02 x 10^{-5}]	1,985 [2.52]	26.1 [3.31 x 10^{-2}]
Wimma Sandstone Member	32	2,130	2,164	2,157	2.5	22.9	10.0	0.05 [6.35 x 10^{-5}]	865 [1.10]	0.926 [1.18 x 10^{-3}]
Paning Member	202	2,125	2,505	,2173	1.2	22.9	11.6	0.01 [1.27 x 10^{-5}]	865 [1.10]	1.98 [2.51 x 10^{-3}]
Callamurra Member	96	2,086	2,859	2,465	1.4	21.1	9.7	0.1 [1.27 x 10^{-4}]	296 [3.76 x 10^{-1}]	0.62 [7.87 x 10^{-4}]
Toolachee Formation	993	1,867	3,234	2,180	0.1	25.3	12.4	0.001 [1.27 x 10^{-6}]	1,995 [2.53]	3.363 [4.27 x 10^{-3}]
Daralingie Formation	173	2,331	2,509	2,424	0.4	20.4	9.7	0.004 [5.08 x 10^{-6}]	414 [5.26 x 10^{-1}]	0.397 [5.04 x 10^{-4}]
Epsilon Formation	238	1,952	3,114	2,409	0.9	21.0	9.1	0.007 [8.89 x 10^{-6}]	407 [5.17 x 10^{-1}]	0.68 [8.64 x 10^{-4}]
Patchawarra Formation	846	1,764	3,547	2,463	0.2	23.8	10.5	0.005 [6.35^{-6}]	2,503 [3.18]	0.933 [1.18 x 10^{-3}]
Tirrawarra Sandstone	718	2,208	3,114	2,643	1.7	18.8	11.1	0.007 [8.89 x 10^{-6}]	329 [4.18 x 10^{-1}]	1.59 [2.02 x 10^{-3}]
Merrimelia Formation	59	1,952	3,148	2,990	0.4	16.5	7.7	0.002 [2.54 x 10^{-6}]	30 [3.81 x 10^{-2}]	0.109 [1.38 x 10^{-4}]

[a] after Gravestock et al., 1998

[b] A conversion factor of 1.27 x 10^{-3} (OGIA, 2016) was used to convert mD to m/d.

Based on the porosity–permeability trends identified by Gravestock and Alexander (1988), a mathematical relationship between permeability and porosity for cap rocks and reservoir rocks could be established. Equations 1 and 2 are averages of combined data representing samples from various formations and localities; data from each formation were not analyzed separately. These formulae are:

$$k_{res} = 120750\emptyset^{2.86} \qquad 1$$

and

$$k_{cap} = (-0.6\ln(1 - 5.16\emptyset))^{3.33} \qquad 2$$

Where k_{res} is the permeability (mD) of a reservoir rock, k_{cap} is the permeability (mD) of a cap rock and Ø is core porosity (−). Equations 1 and 2 are specific and applicable to only Eromanga Basin reservoir and cap rock strata. The cap rock trend behavior is found mainly in the Birkhead Formation and at the interface sequence between Birkhead and Hutton and between the Namur Sandstone and Murta Formation.

The porosity–permeability trends of Equations 1 and 2 are related to visually estimated grain size variations, although diagenetic factors, which were not studied by Gravestock and Alexander (1988), may contribute. Equation 2 indicates that permeability is sensitive to minor variations in porosity and that the trend follows a continuum from fine-grained sandstone (potentially good aquifer) through siltstone to mud-rock dominated lithologies. The sensitivity of the cap rock trend in permeability necessitates accurate determination of porosity.

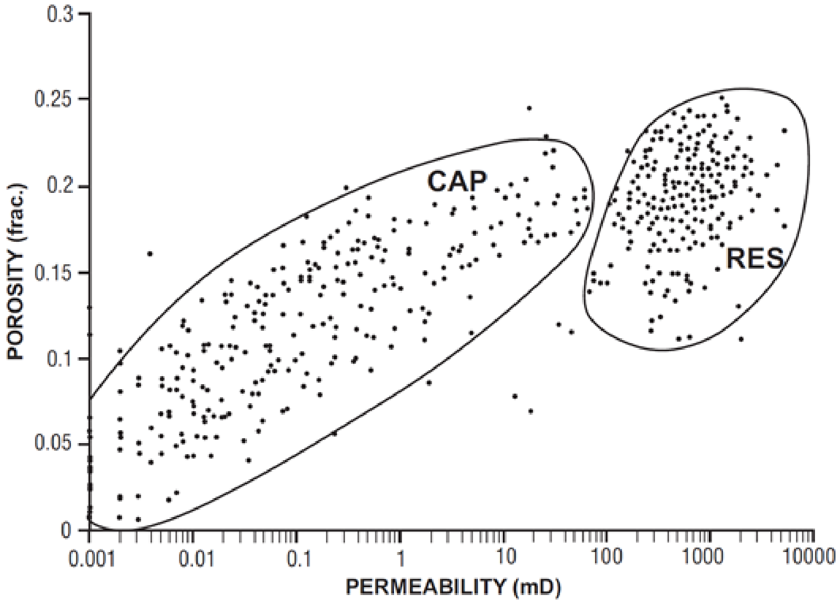


Figure 2.1: Porosity–permeability trend of key Eromanga Basin Reservoirs)

Further, as evident from Figure 2.1 (after Gravestock and Alexander, 1986), there is a difficulty in selecting which equation to use to estimate permeability in the porosity range between 0.1 and 0.20, since any porosity within this range could result in two estimated permeability's that are several orders of magnitude apart. To clarify this, Gravestock and Alexander (1988) established a criterion to determine which of the trend equations is applicable for a given lithology. The method employs gamma ray logging to determine whether a sample was more likely to be a high (reservoir rock) or a low (cap rock) permeability unit so the correct permeability derivation formula could be applied. Gravestock and Alexander (1988) found the gamma ray method to be a useful indicator of permeability as the relationship between gamma ray value in American Petroleum Institute (API) units and core porosity could be used to demarcate samples of permeability greater or less than 1 mD using a line defined by the trigonometric relationship:

$$\tan(\theta) = \frac{860(0.25 - \varnothing)}{178 - GR} \qquad 3$$

Where *GR* is the gamma ray value (API). For a known *GR* and porosity values, Equation 3 could be used to estimate *tan(θ)*. Where *tan(θ)* was less than one, in most instances the permeability was found to be greater than 1 mD, with the converse also true (Figure 2.2, from Gravestock and Alexander, 1988).

A summary of porosity and permeability data derived from core samples by Gravestock and Alexander (1986, 1988 and 1989) is provided in Table 2.5.

Table 2.5: Summary of Eromanga Basin porosity and permeability data[a]

Formation	Statistic	Depth (m)	AKHC (mD)	AKHC (m/d) *	APHC (fraction)	OKHC (mD)	OKHC (m/d) *	OPHC (fraction)
Murta Formation and McKinlay Member (214 samples)	Average	1,447.5	28.20	3.58×10^{-2}	0.22	21.03	2.67×10^{-2}	0.13
	Maximum	1,804.7	999.0	1.27	0.251	661.0	8.39×10^{-1}	0.245
	Minimum	1,199.4	0.007	8.89×10^{-6}	0.045	0.0	0	0.008
Namur Sandstone (128 samples)	Average	1,499.3	884.0	1.12×10^{-3}	0.20	601.0	7.63×10^{-1}	0.19
	Maximum	1,615.4	10,000	1.27×10^{1}	0.28	4,300.0	5.46	0.239
	Minimum	1,242.2	0.011	1.40×10^{-5}	0.1	0.003	3.81×10^{-6}	0.085
Birkhead Formation (119 samples)	Average	1,667.4	252.0	3.20×10^{-1}	0.14	200.0	2.54×10^{-1}	0.13
	Maximum	2,167.4	7,620.0	9.68	0.258	4,950.0	6.29	0.251
	Minimum	1,559.8	0.008	1.02×10^{-5}	0.024	0.001	1.27×10^{-6}	0.005
Hutton Sandstone (118 samples)	Average	1,801.4	1,308.0	1.66	0.21	897.0	1.14	0.19
	Maximum	1,882.3	9,780	1.24×10^{1}	0.273	5130	6.52	0.244
	Minimum	1,685.4	0.321	4.08×10^{-4}	0.083	0.02	2.54×10^{-5}	0.066
Poolowanna Formation (133[#] samples)	Average	2,310.7	423.0	5.37×10^{-1}	0.13	364#	4.62×10^{-1}	0.08#
	Maximum	2,667.5	3674	4.67	0.219	1,917#	2.43	0.15#
	Minimum	1,806.4	0.001	1.27×10^{-6}	0	0.002#	1.35×10^{-5}	0#

[a]Gravestock and Alexander (1986 , 1988, 1989))

[b] 1mD=1.27×10^{-3} m/d (OGIA 2016). AKHC = Permeability (ambient pressure); APHC = porosity (ambient pressure); OKHC = permeability (reservoir or overburden pressure); OPHC = porosity (reservoir or overburden pressure); # Indicates 29 samples were measured at overburden pressure.

In addition to the work of Gravestock and Alexander (1986, 1988, 1989), Dillinger et al. (2013) and Arouri et al. (2004) also examined petrophysical data with respect to determining porosity and permeability characteristics of Eromanga and Cooper basin stratigraphy. The purpose of the study by Dillinger et al. (2013) was to better characterise the petrophysical and petrological properties as well as the diagenesis processes occurring within the Hutton Sandstone, (Cooper–Eromanga Basin, SA). A significant amount of data from drill cuttings and cores retrieved from existing stratigraphic and petroleum exploration wells (Celsius-1, Della-2, Merrimelia-19, Strzelecki-17, Packsaddle-1, Acrasia 1 and Tantanna 3) was examined. Combined porosity-permeability analyses were performed on cores from Hutton Sandstone under ambient conditions for over 449 samples in 22 wells.

Porosities plotted against permeabilities showed that the porosity of the Hutton Sandstone ranges mainly between 12 and 25% while the permeability span is from 100 mD to 5,000 mD. High permeabilities combined with low stress sensitivities suggest a stiff formation behaviour that is usually related to tightly cemented sandstones.

Finally, Arouri et al. (2004) collated porosity and permeability data from core samples from 9 oilfields and adjacent ridges in the Cooper Basin region in SA as part of a study to better resolve the oil accumulation histories in these fields. Included in their collation are overburden permeability and porosity values of the Murta Formation, McKinlay Member and Namur Sandstone, which were compiled from oil and gas well-completion reports and the Petroleum Exploration and Production System (PEPS) database currently managed by DEM. Porosity and permeability data collected as part of the study by Arouri et al. (2004) is provided in Table 2.6.

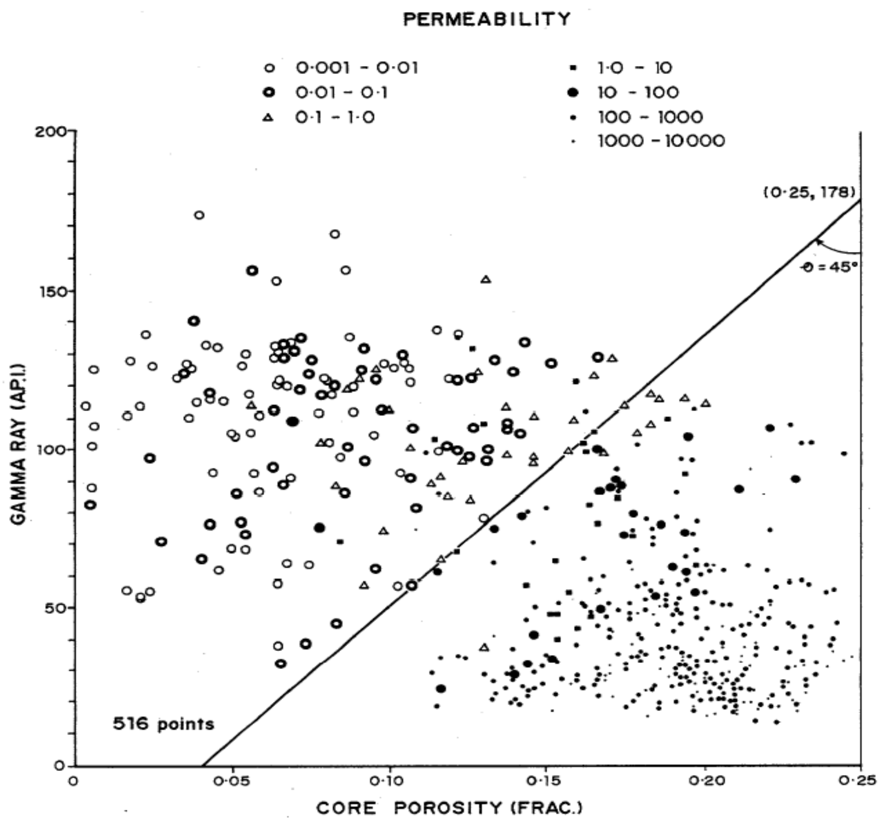


Figure 2.2: Gamma Ray versus overburden core porosity (excluding data Murteree Horst wells Line constructed from Equation 3.

Table 2.6: Data compiled from oil and gas well-completion and PEPS database

Field	Well	Formation	Depth (m) (DST)	Actual depth tested	Porosity (%)	Permeability, k_a (mD)	Permeability, k_b (m/d)
Biala	Biala-7	McKinlay	1,237.31	1,237.31	22.3	50	7.07×10^{-3}
		Namur	1,242.49	1,242.49	18.9	289	5.92×10^{-2}
Jena	Jena-6	Murta	1,119.21	1,119.21	18.7	7.4	6.99×10^{-4}
	Jena-11	Murta	1,183.16	1,183.16	22.2	63	9.36×10^{-3}
		McKinlay	1,223.95	1,223.95	25.6	154	2.76×10^{-2}
		Namur	1,236.62	1,236.62	25.5	1,938	5.94×10^{-1}
Limestone Creek	Limestone Creek-9	McKinlay	1,247.97	1,247.97	25.5	1,938	5.94×10^{-1}
		Namur	1,254.43	1,254.43	22.3	11	1.13×10^{-3}
Nungeroo	Nungeroo-1	Topmost Namur	1,262.79	1,263.35	23.7	334	7.06×10^{-2}
		Namur	1,267.05	1,266.93	20.7	227	4.42×10^{-2}
Ulandri	Ulandi-1	Namur	1,244.96	1,244.65	24.3	927	2.43×10^{-1}
	Ulandi-2	Murta	1,200.09	1,200.09	26.2	28	3.50×10^{-3}

3 Transmissivity from artesian wells

Transmissivity (T) estimates of the J-K aquifer were made using shut-in pressure data available in SA Geodata and collected during groundwater monitoring. In total, 103 datasets from 60 bores (Figure 3.1) were analysed to estimate aquifer transmissivity (Table 9.1, Appendix A). The pressure and flow data from shut-in-pressure tests that were chosen for compilation were all conducted in the J-K aquifer between 2011 and 2019. Data and information collected at each bore during these tests included shut-in pressure, time, stabilised flow rate, stable temperature, and field Electrical conductivity (EC) (Table 9.1, Appendix A). The data were analyzed to estimate aquifer T at each test site. The T was estimated from the gradient of a straight line from plots of build-up pressure against logarithm of build-up time and using the methodology described below. Semi-log plots of build-up against time are presented in Appendix B.

3.1 Methodology

Shut-in-pressure data can be analysed using the basic equation by Horner (1951) for a well that was shut-in after it had produced at rate Q for time t_o and the (bottom-hole) pressure p_w was recorded at times Δt:

$$p_w = p_o - \frac{2.30\mu Q}{4\pi k D} \log \left(\frac{t_o - \Delta t}{\Delta t}\right) \qquad 4$$

where p_w is pressure at the well bore at any time (kg/ms^2), p_o is undisturbed formation pressure (kg/ms^2), Q is flow or recovery rate (m^3/s^1), μ is dynamic viscosity (kg/ms), k is intrinsic permeability (m^2), D is thickness of tested interval (m), t_o is time of flowing or recovering (s), and Δt is elapsed time since the end of flow period (s).

For $\Delta t << t_o$, $(t_o + \Delta t) \approx t_o$ and

$$p_w \approx p_o - \frac{2.30\mu Q}{4\pi k D} \log \left(\frac{t_o}{\Delta t}\right) \qquad 5$$

A plot of p_w (build-up pressure) against $\log(\Delta t)$ (logarithm of build-up time) should give a straight line. Permeability (k) can then be calculated from the following equation:

$$\frac{kD}{\mu} = \frac{2.30Q}{4\pi \Delta p} \qquad 6$$

Where $\Delta p = \log(t_0 - \Delta t)/(p_0 - p_w)$ is pressure change per log cycle of time (gradient or slope of the semi-log straight line). It should be noted that:

$$k = \frac{\mu K}{\rho g} \qquad 7$$

Where K is hydraulic conductivity (m/s), ρ is fluid density (kg/m^3) and g is acceleration of gravity (m/s^2). Substituting Equation 7 into Equation 6 yields:

$$\frac{T}{\rho g} = \frac{0.183Q}{\Delta p} \qquad 8$$

For this study, Equation 8 is referred to as the 'apparent aquifer T equation'. The unit of Equation 8 is (m^{4}s/kg). Converting to T, Equation 8 becomes

$$T = \frac{0.183\rho g Q}{\Delta p} \qquad 9$$

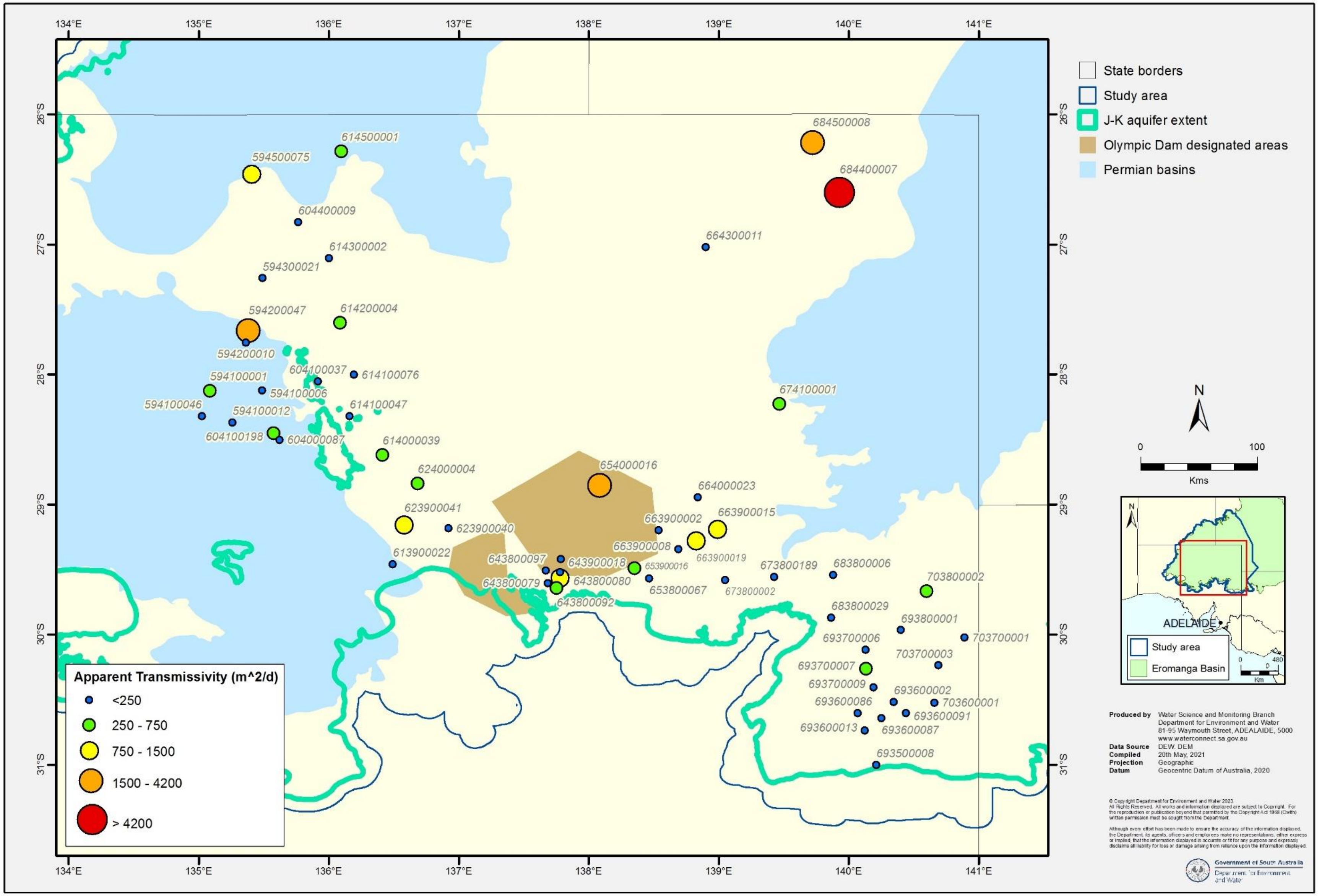


Figure 3.1: Transmissivity in the J-K aquifer.

Hydrostatic pressure in a liquid column can be calculated as $p=h\rho g$ and ρg is the specific weight of water. Equation 6 represents the true but uncorrected *T*. The unit of Equation 9 is m^2/s. Equation 9 is not corrected for the effects of salinity and temperature on the density of water, but instead assumes a constant specific weight and therefore is described as '*apparent T*'. Since the density of water can be affected by dissolved salts and temperature, the value of *T* estimated from Equation 9 is a function of dissolved salt (salinity) and temperature in hydrogeological environments like the GAB hydrogeological super-basin. A correction was not attempted because of lack of good understanding concerning the available temperature and salinity information that were recorded during the tests. The resultant a*pparent T* values were then used to estimate a hydraulic conductivity (K_h) where the thickness of the tested interval was reported or could be reasonably calculated. The validity of the estimated *apparent T* is limited by the following factors:

- Accuracy of the testing methods was not evaluated as part of this analysis.
- It is assumed that all the data were used as reported.

Finally, the estimated values can only be used as first (initial) guesses or estimates of *T* where no other information is available because:

- The system was not put under sufficient pumping stress during the data collection.
- Artesian flow is not the same as stressing the aquifer during an aquifer pumping test.
- Test duration was limited (5 to 60 minutes).
- The hydrogeological formation tested at each site was not provided in the dataset.

3.2 Results

Values are highly variable, ranging from 1.21 m^2/d to 22,868 m^2/d. This large range of values may be due to factors such as high variability in local hydraulic characteristics or measurement errors. Results at the higher end of the scale will be unrepresentative of regional values. The median, arithmetic mean and geometric mean of estimated transmissivity are 134 m^2/d, 790 m^2/d and 143 m^2/d, respectively. There are several bores which have two or more shut-in-pressure datasets obtained at different times; for this reason, data from one bore has the potential to overly influence the statistics (i.e., bias the data). The lower 95% confidence limit and the upper 95% confidence limit for the median were estimated as 102 m^2/d and 204 m^2/d, respectively.

A review of screened intervals and aquifer thickness (*B*) at each well location enables hydraulic conductivity to be estimated at each location (*T=K.B*). Resultant *K* values estimated from *apparent T* for the J-K aquifer vary considerably across the mapped area (Figure 3.1). Table 3.1 provides summary statistics.

Table 3.1: Estimated *K* from artesian well shut-in pressure monitoring tests, J-K aquifer.

Statistics	Hydraulic conductivity (m/d)
Maximum.	249
95th percentile (%)	107
Average	22.3
Geometric mean	5.7
Median	5.1
5th percentile (%)	0.6
Minimum	0.1

4 Permeability from Energy Industry drill hole test data

Many permeability values are derived from petroleum hydrocarbon geology and engineering studies. Typically, such data are derived either from well-based drill stem tests (DST), Modular Formation Dynamics Testing (MDT) or laboratory-based core analysis. DST and MDT are procedures for downhole testing of hydraulic pressure within an isolated geological formation (Earlougher 1977; Chaudhry 2004; Schlumberger 2002). The basic tools for these tests consist of packers, valves, and pressure recorders. In the testing period, the formation of interest is separated in the drill hole by one or two packers. Fluid flow from the formation to the drill stem can be controlled by opening or shutting valves and the pressure variations are recorded. Pressure variations recorded during the tests can be used to interpret the permeability of the tested formation by applying Equation 4 (Horner 1951) and using the same analysis methodology presented in Section 3.1.

4.1 Conversion of permability (mD) to hydraulic conductivity (m/d)

Fields of study associated with the energy industry normally express permeability (*k*) in Darcies (*D*) or *mD*. In practice, a medium with a permeability of 1 D allows a flow of 1 cm^3/s of a fluid with viscosity 1 centipoise (or 1 milli-Pascal second) under a pressure gradient of 1 atm/cm acting across an area of 1 cm^2.

In contrast, studies in hydrogeology usually use *K*, which is a property of the fluid (usually assumed to be water) in combination with the transmitting medium, rather than permeability, which is a property of the medium only. Further, *K* is normally expressed in units of length/time, typically metres per day (m/d). Consequently, a conversion is required before Energy industry-derived permeability data can be used in hydrogeological modelling. As this conversion needs to consider the particulars of the fluid density, conversion factors may vary slightly depending upon application. To convert permeability in *mD* to groundwater hydraulic conductivity in m/d, a conversion factor of 1.27×10^{-3} (OGIA, 2016) was used in this study. This conversion assumes an average temperature of groundwater in the study area of 32°C and a dynamic viscosity of 0.66 kg /(m s).

We note that Darcy units (*D*) may be converted to SI units (m^2) by use of the following relationship (Commonwealth of Australia 2018):

$$1D = 9.869233\ x\ 10^{-13} m^2 \quad (10)$$

and the following equation to calculate *K* (*m/d*):

$$K = \frac{k\rho g}{\mu} \quad (11)$$

Where *k* is the intrinsic permeability (m^2), ρ is the density of fluid (997.05 kg/m^3), *g* is gravitational acceleration (9.8 m/s^2) and μ is the viscosity (8.91×10^{-4} kg/ (m s)). For simplicity, this conversion assumes a density of fresh water at approximately 25°C and therefore a density of ≈1 centipoise.

Average estimated liquid brine *K* values for each formation examined from DST and MDT data from publicly available sources are presented in Table 4.1. Data provided in confidence by industry is not presented but is summarised in averaged data presented later in Chapter 6.

Table 4.1: Estimated liquid (brine) *K* from DST and MDT data

Formation	DST and MDT tests (Data source SA GEODATA) K (m/d)	QLD region of Eromanga Basin (Bradshaw et al. 2011) K (m/d)	Central Eromanga Basin (Ransley and Smerdon 2012) K (m/d)
Adori Formation		3.8×10^{-1}	7.7×10^{-1}
Birkhead Fm	9.98×10^{-4} to 2.08×10^{01}		0.12×10^{-1}
Cadna-owie Fm			9.0×10^{-2}
Hooray Sst		4.3×10^{-3}	1.2×10^{-1}
Hutton Sst	1.5×10^{-4} to 4.31	8.6×10^{-2}	4.3×10^{-1}
Murta Fm	8.58×10^{-1} to 4.43		
Patchawarra Fm	7.84×10^{-5} to 5.11×10^{-2}		
Lower Poolowanna Fm		6.1×10^{-3}	
Toolachee Fm	2.49×10^{-5} to 4.74×10^{-2}		
Westbourne Fm			1.0×10^{-1}
Wyandra Sst		3.8×10^{-4}	

Note: No parameters values specifically for the Algebuckina Sandstone, Boorthanna Formation, Bulldog Shale, Coorikiana Sandstone, Crown Point Formation, Mount Toondina Formation, Mackunda Formation, McKinlay Member, Namur Sandstone, Oodnadatta Formation, Purni Formation, Stuart Range Formation, Surficial Sediments, Triassic Sediments, Winton Formation

5 Porosity and permeability from core plugs

As well as DST and MDT, the energy industry also derive hydraulic property data using laboratory-based air permeability testing on core samples. Petroleum operators drilling wells in the SA portion of the Cooper and Eromanga basins routinely obtain whole-core or rotary-sidewall core samples for such purposes. Such testing is conducted under ambient and overburden (reservoir) conditions, but because these tests are not conducted inside wells, a conversion is required to convert an air-permeability measurement to a liquid permeability estimate. This section describes the origin of porosity and air permeability data from the SA portion of the Cooper and Eromanga basins, as well as the methods used to convert these results into a form useable in groundwater modelling.

Core plug samples collected for porosity and air permeability analysis are sealed and sent to laboratories in Australia (Amdel Core Services, Core Lab or Weatherford Laboratories) for Routine Core Analysis (RCA). Depending on the laboratory, a 1- or 1.5-inch diameter horizontal core plug is cut to measure grain density, bulk volume (mercury immersion), porosity and permeability (to air) at ambient and overburden (reservoir) conditions. These data normally accompany the Well Completion Report and are made publicly available after the confidentiality period lapses.

RCA samples representing all the major oil producing reservoirs in the Eromanga Basin were used in this data analysis. Table 5.1 provides a summary. This dataset contains more than 1,100 RCA results from 46 wells across the Cooper Basin region (Figure 5.1).

5.1 Methodology

5.1.1 Trend analysis

An attempt was made to establish correlation or any trend between core-derived porosity and air permeability data. Figure 5.2 to Figure 5.6 show the correlation between porosity and air permeability by formation at overburden conditions. Only open file porosity and air permeability data were selected, and analyses filtered so only those undertaken at overburden (reservoir) conditions were used. Data associated with vertical core plugs, seal failure or fractured plugs and all ambient data were excluded. The Cadna-owie, Westbourne and Poolowanna formations had limited ambient RCA data.

Table 5.1: Summary of the number of wells and samples from various reservoirs with RCA data

Formation	No. wells	No. samples
Murta Formation	13	245
McKinlay Member	11	161
Namur Sandstone	6	158
Birkhead Formation	13	455
Hutton Sandstone	3	137
Total	46	1,156

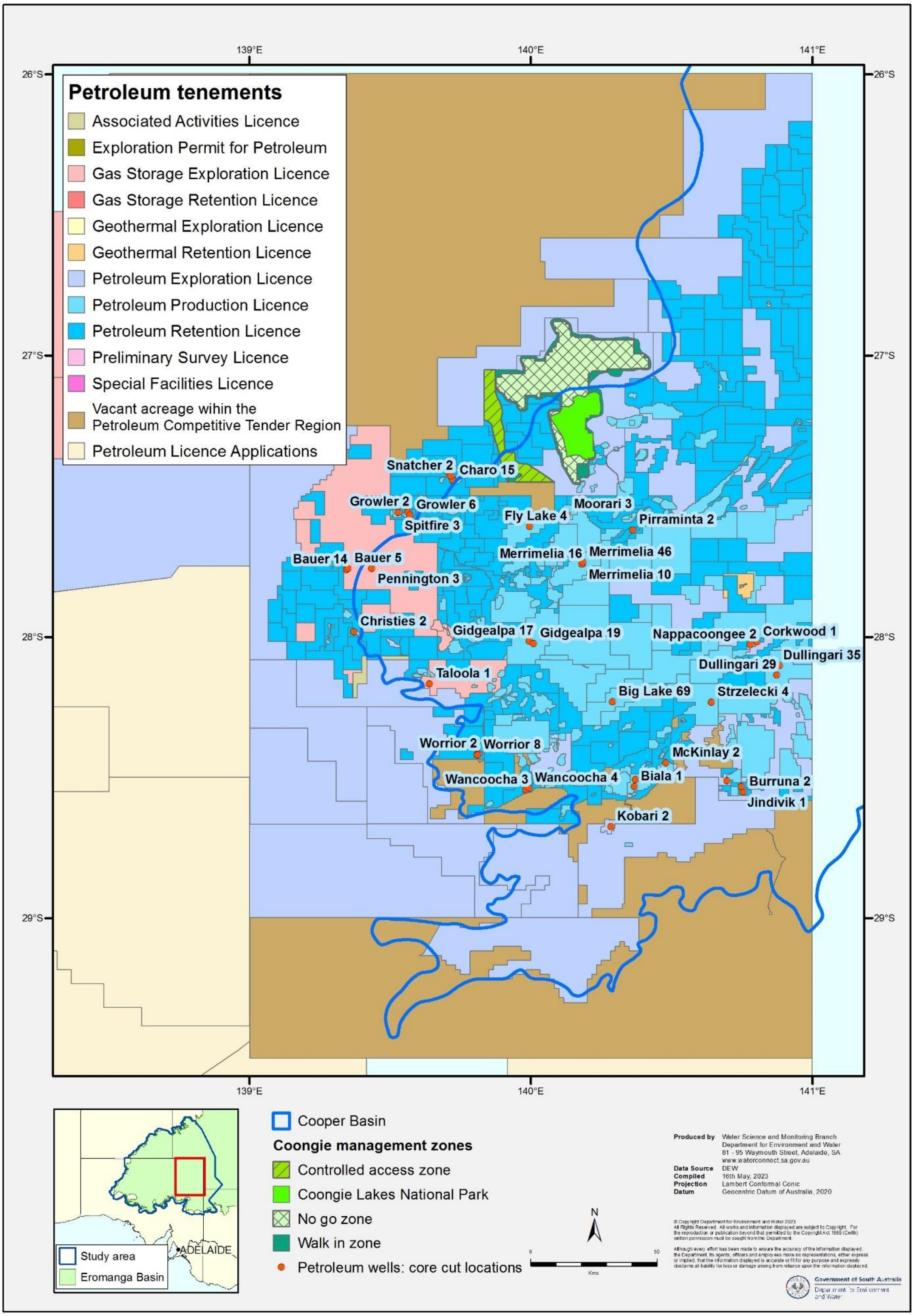


Figure 5.1: Petroleum well locations for routine core analysis

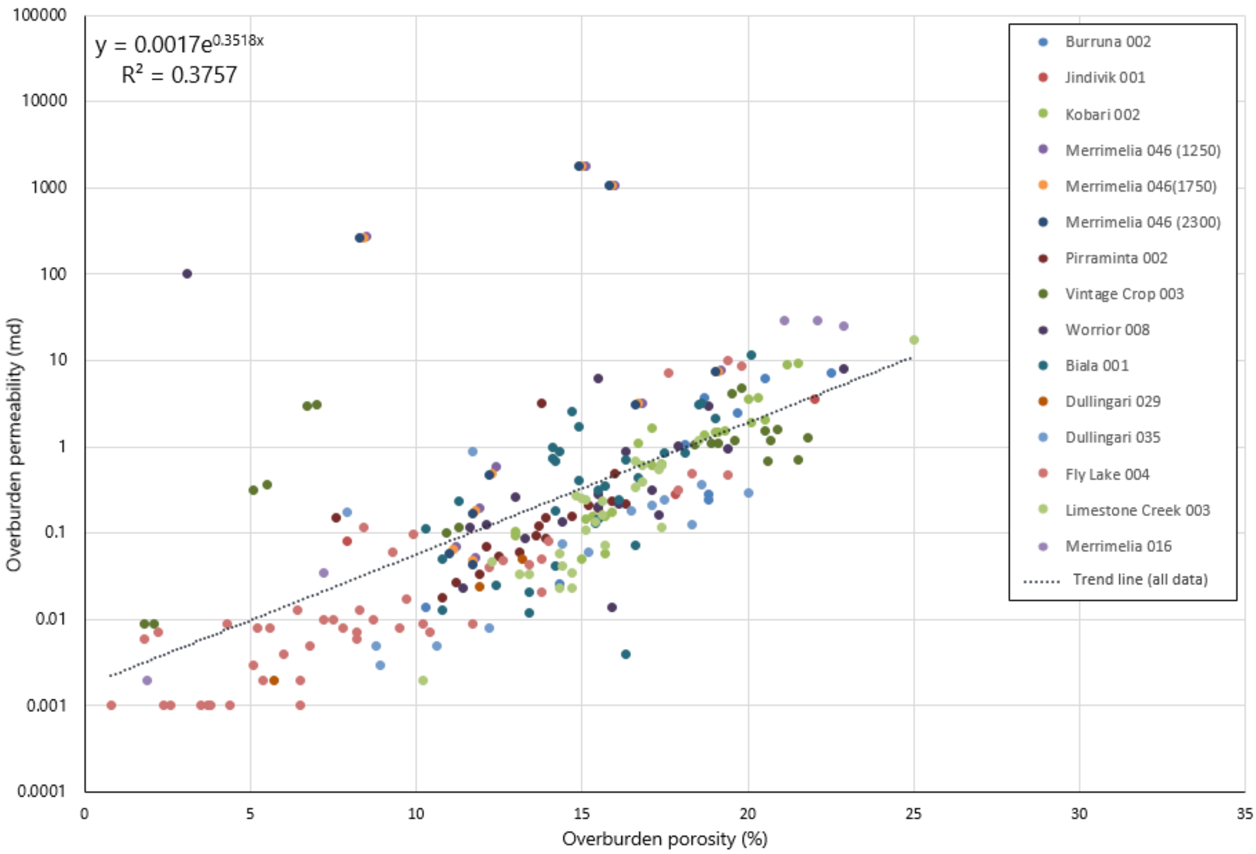


Figure 5.2: Porosity permeability cross plot – Murta Formation

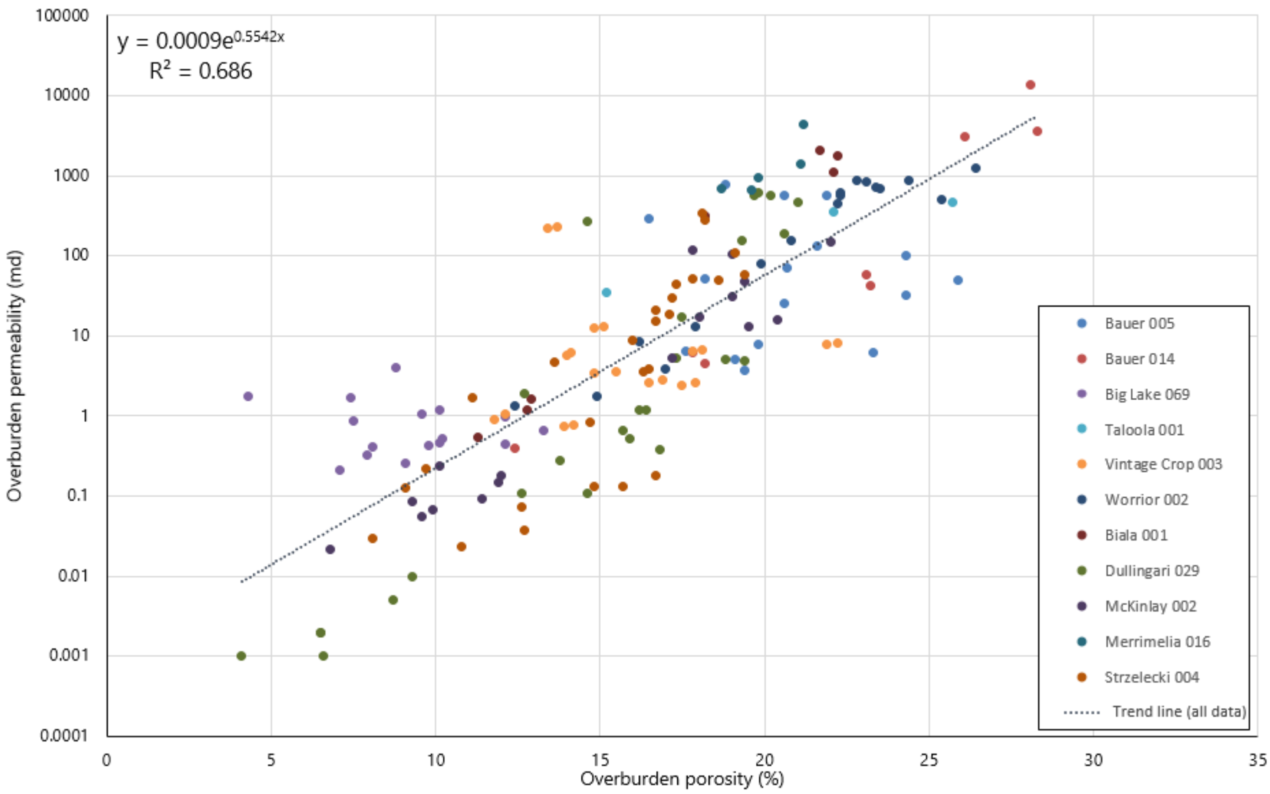


Figure 5.3: Porosity permeability cross plot – McKinlay Member

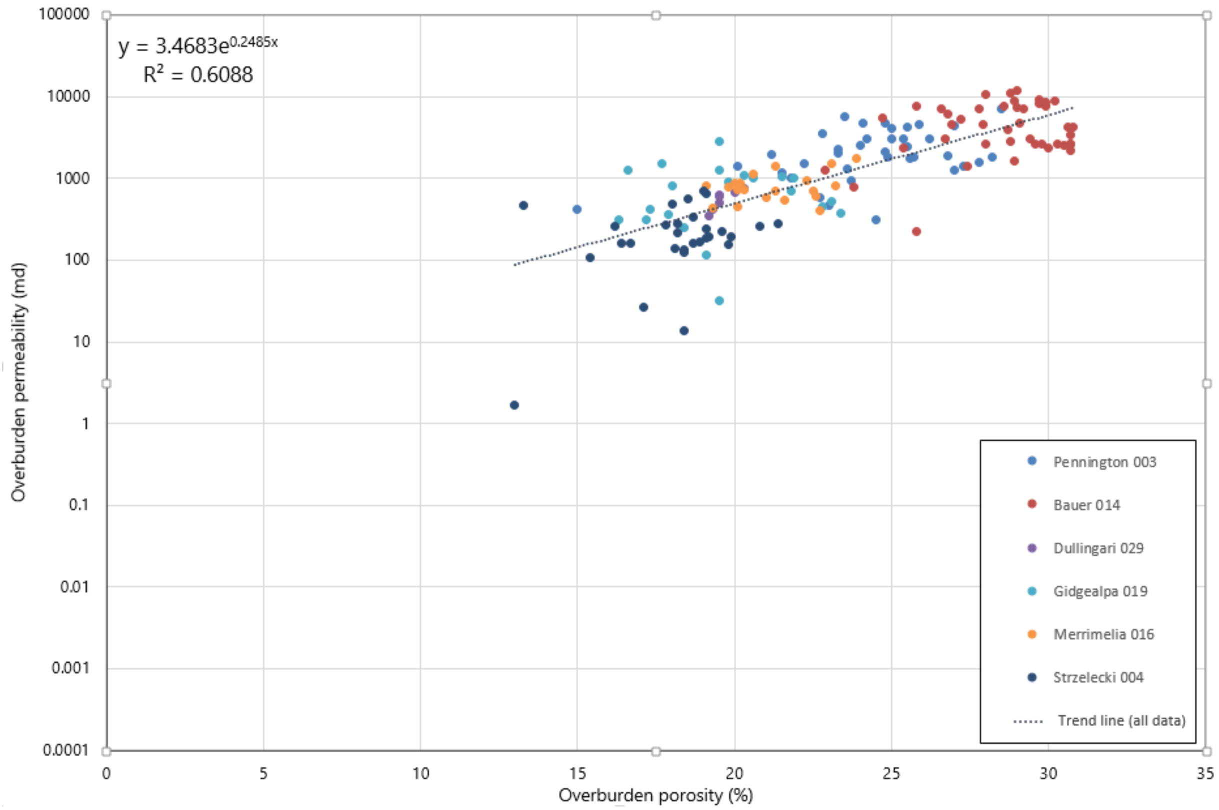


Figure 5.4: Porosity permeability cross plot – Namur Formation

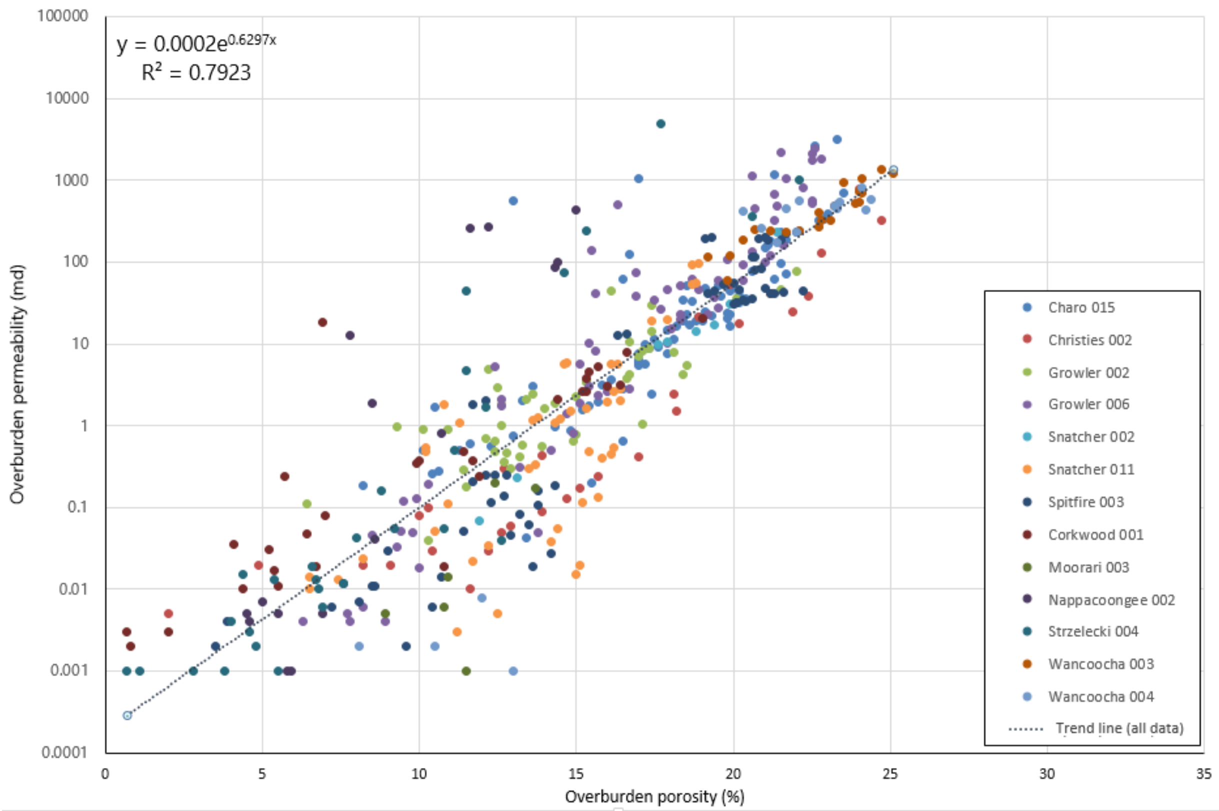


Figure 5.5: Porosity permeability cross plot – Birkhead Formation

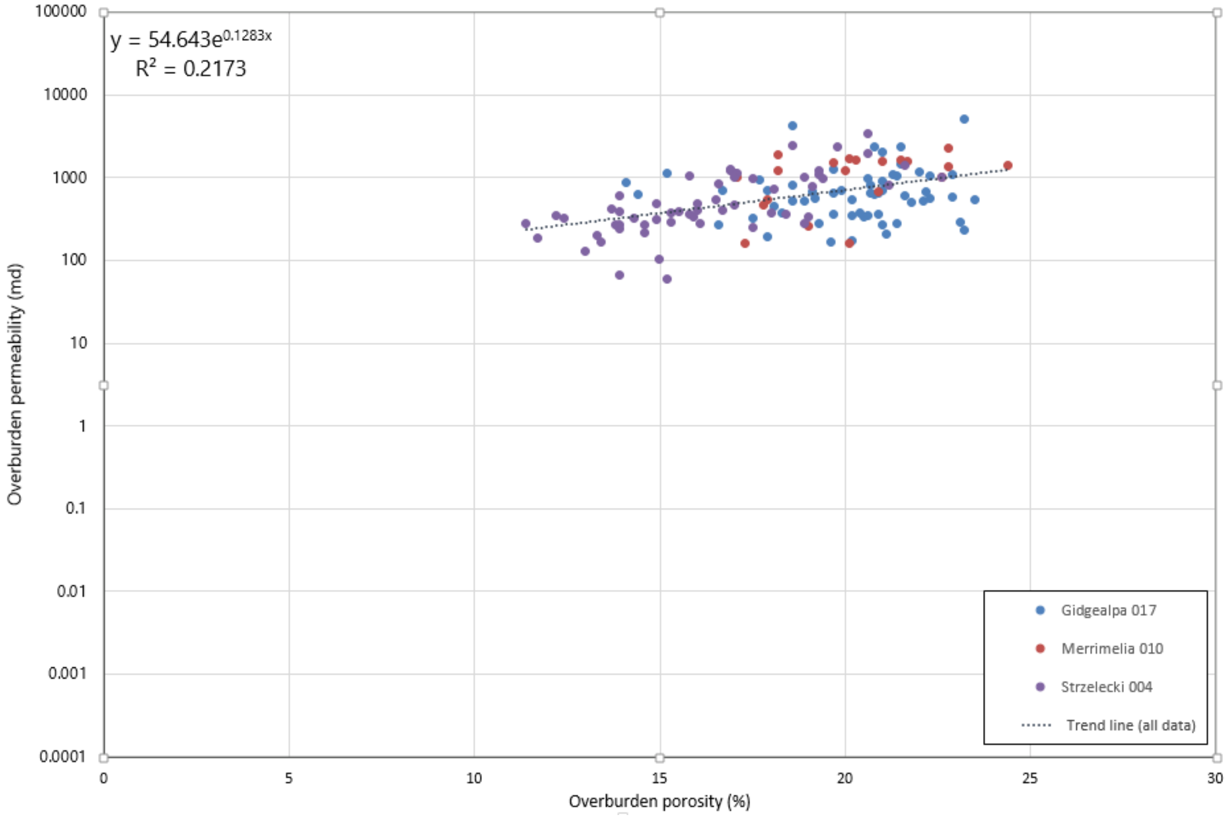


Figure 5.6: Porosity permeability cross plot – Hutton Sandstone

5.1.2 Method for converting air permeability estimates from core analysis to representative fluid permeability.

Before air permeability data can be used in groundwater studies, it must be converted to a liquid equivalent permeability. Klinkenberg (1941) determined through laboratory experiment that gas permeability (k_g) will generally be greater than liquid permeability (k_l) due to the reportable finite velocity of gas molecules at a grain's surface, referred to as 'slippage', as opposed to liquid molecules, which record no velocity. Klinkenberg (1941) described this relationship as:

$$k_g = k_l/(1 + \frac{b}{p}) \quad 12$$

Where *b*, known as the 'Klinkenberg constant', is constant for a particular gas in a given rock type, and *p* is the mean flowing pressure. The Klinkenberg constant *b* requires determination for each sample by conducting a flow test at a variety of pressures and then extrapolating to an infinite pressure.

The resultant value k_l is known as the 'Klinkenberg permeability' (Glover 2012) and represents the permeability of a gas if compressed by infinite pressure to become a near-perfect liquid that does not react with the wall rock. The value k_l does not consider any of the other factors important when considering permeability, such as the chemistry of an actual liquid. Chemistry is an important consideration with respect to permeability as it may alter wall rock mineralogy as well as change the viscosity of a fluid. Further, measurement may be complicated by the nature of porosity or consolidation. High confining or overburden pressures experienced by fractured or poorly consolidated rock may have the effect of closing pores and thus reducing permeability. In contrast, well consolidated rock may have less pressure-dependent porosity.

In general, applying a Klinkenberg correction becomes less important as the gas permeability increases and the surface area contact between grains and the migrating media decreases.

For results obtained from Santos, a Klinkenberg conversion factor was provided. However, we note that the bulk of results compiled by DEM were not accompanied with appropriate *b* or *p* values to allow correction. Further, although a small percentage of results were provided with a 'Klinkenberg permeability', this value was obtained by unsteady-state means directly from the measuring equipment, rather than being calculated using the k_g through steady-state series of measurements using increasing gas pressure. Consequently, these reported values are considered unreliable and were not used; Rushing et al. (2004) noted that unsteady-state Klinkenberg permeability values derived from two laboratories for tight sand samples were consistently overestimated when compared to the equivalent steady-state measurements.

Alternatively, several empirical methods have been developed to determine *b* that are limited within particular ranges of permeability and rock type (PetroWiki 2015). In the absence of a specifically derived Klinkenberg constant, the air to 'brine' (groundwater-equivalent term used in the energy industry) correction equation used by OGIA (2016) was applied:

$$k_b = 0.0487 k_a^{1.2114} \qquad 13$$

Where k_b is brine permeability (mD) and k_a is Klinkenberg corrected air permeability (mD).

5.2 Results from analysis of porosity and permeability from core plugs

Core-derived, overburden porosity and air permeability data were compiled from across the Far North PWA from both industry and DEM studies.

Following the methodology described above, the overburden porosity and air permeability data obtained from core samples were sorted from highest to lowest (by formation), then 'probit values' were calculated and plotted on a log scale. A probit value is the difference a unit change in the predictor makes in the cumulative normal probability of the outcome. P90, P50 and P10 numbers were determined so the Swanson's mean could be calculated. The Swanson's mean provides a better approximation of the dataset where sampling of the core plugs is generally biased towards the better reservoir, rather than simply taking the arithmetic mean. Using Swanson's 30-40-30 rule, the 10th Percentile, 50th Percentile and 90th Percentile of the data were assigned weights of 30%, 40% and 30%, respectively, and the mean was defined as $0.3P_{10} + 0.4P_{50} + 0.3P_{90}$, where P_{10}, P_{50} and P_{90} are the 10th, 50th and 90th percentiles. Consequently, P99 and P01 highlight the extreme end member (lowest and highest) range of the dataset, often orders of magnitude different to most of the data Figure 5.7.

Magliani (2019) calculated a median air permeability from existing DST and Repeat Formation Tests (RFT) conducted over reservoir intervals with good shows of hydrocarbons. Commonly, a DST is run across the McKinlay Member–Namur Sandstone interface or Birkhead Formation–Hutton Sandstone interface, which is why the calculated medians are presented across two formations. Table 5.2 presents a summary of the overburden core porosity values, whilst Table 5.3 presents these permeability numbers as a comparison to the core-plug-derived air permeability. The Murta and Birkhead formations are both regarded as oil reservoirs and seals and are therefore regarded as confining units in a hydrogeological sense. The calculated DST median reflects that the tests were run over appropriate reservoir intervals.

Overburden permeability was plotted against depth () to see if any Eromanga samples demonstrate permeability reduction because of diagenesis. None was noted in this dataset. Whilst there appears to be high permeability in the Nappamerri Trough, when McLeod 1 was perforated across sand units within the Namur Sandstone for a water supply for Habanero (geothermal well), there was no flow (A Hill, DEM 2019, personal Communication).

Table 5.2: Summary of the overburden core porosity values

							Overburden core porosity (%)		
Formation	**No.**	**P99**	**P90**	**P50**	**P10**	**P01**	**Arithmetic mean**	**Geometric mean**	**Swanson's mean**
Murta Formation	244	1.4	5.68	12.44	22.9	27.26	13.84	12.55	14.86
McKinlay Member	161	4.3	9.48	15.48	25.26	28.1	16.43	15.48	16.62
Namur Sandstone	158	13.3	17.55	22.64	29.21	30.7	23.07	22.64	23.08
Birkhead Formation	455	2	7.68	14.22	24.7	26.36	15.42	13.98	15.9
Hutton Sandstone	437	11.7	14.64	18.3	22.86	23.5	18.55	18.3	18.57

Table 5.3: Summary of the overburden air permeability values

							Overburden air permeability (k, [mD])			
Formation	**No.**	**P99**	**P90**	**P50**	**P10**	**P01**	**Arithmetic mean**	**Geometric mean**	**Swanson's mean**	**DST median**
Murta Formation	244	0.001	0.005	0.223	9.2	1,780	40.23	0.22	2.851	388
McKinlay Member	161	0.001	0.089	7.891	701.37	4,300	309.57	7.89	213.6	538
Namur Sandstone	158	13.6	168.5	1,071.44	6,812.9	11,005	2237.2	1,071.15	2523	538
Birkhead Formation	455	0.001	0.021	2.941	419.9	3,150	135.57	2.94	127.16	54.2
Hutton Sandstone	437	68	206.2	590.62	1,691.77	4,330	819.97	590.75	805.64	54.2

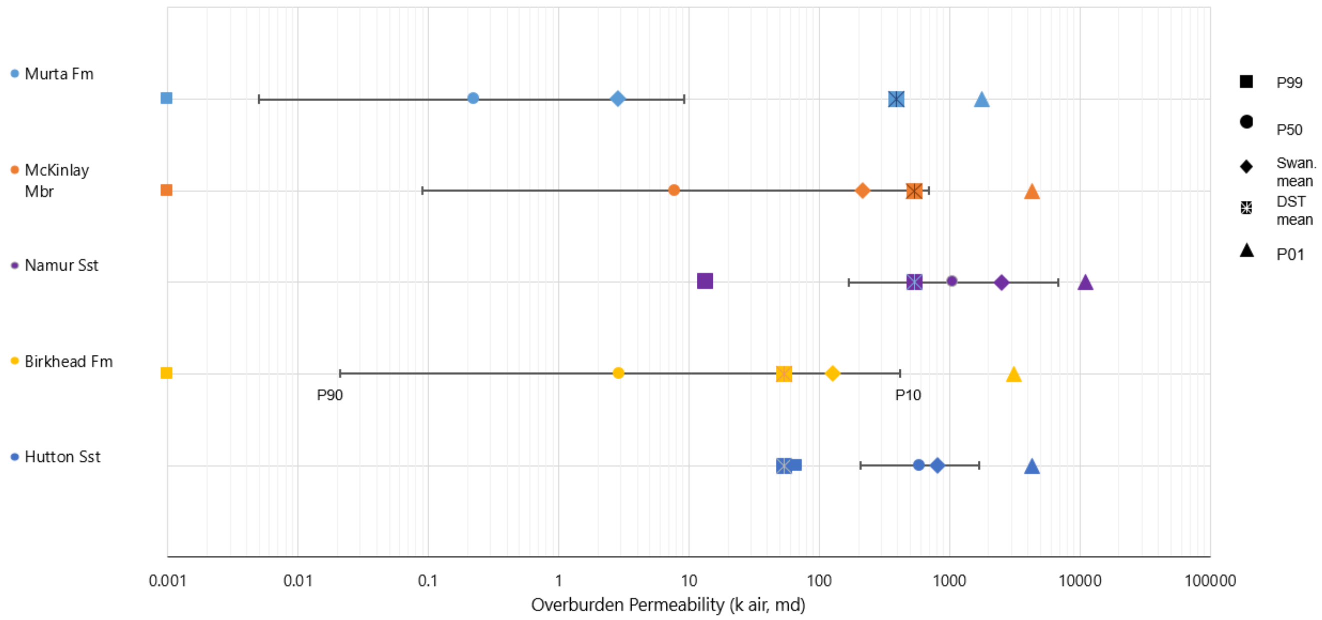


Figure 5.7: P99, P90, P50, P10, P01 Overburden permeability and Swanson's mean, summary by formation

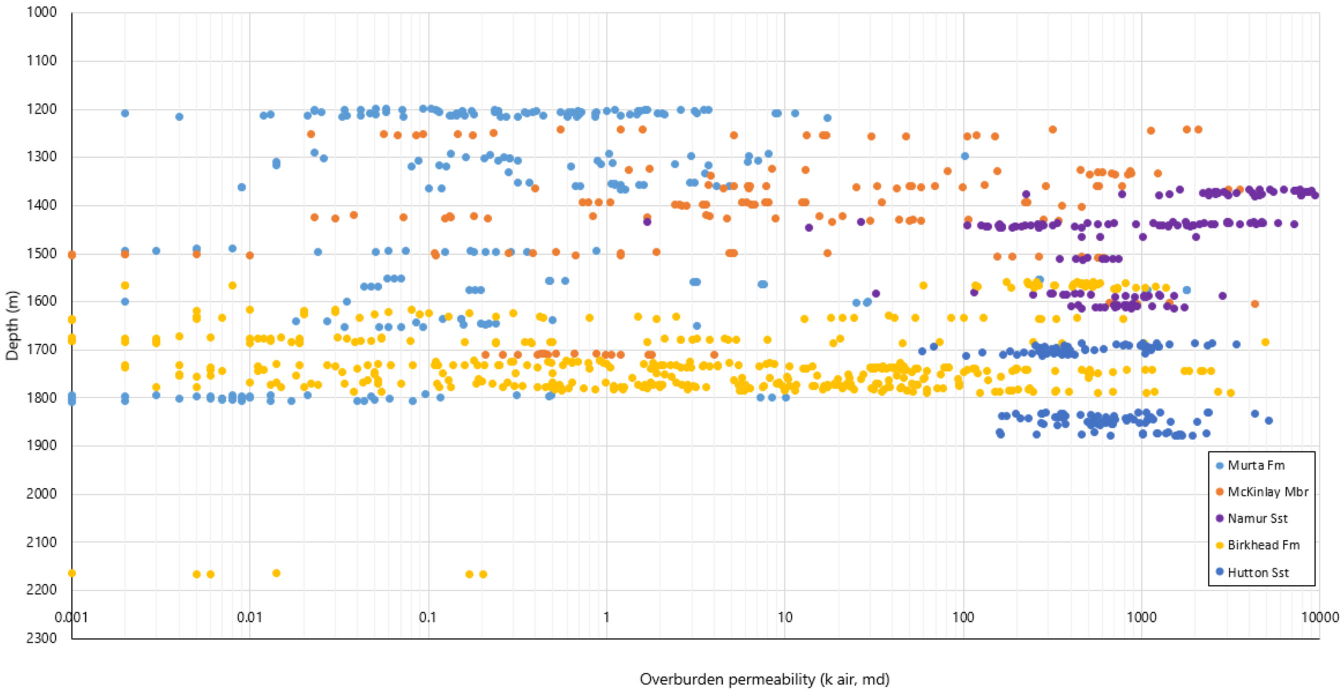


Figure 5.8: Overburden air permeability versus depth by formation

5.2.1 Representative fluid permeability from core-plug analysis (air permeability)

Table 5.4 presents summary results from analysis of porosity and the Klinkenberg permeability (brine) dataset from the DEM and Santos for various formations using Equations 12 and 13. The arithmetic mean *K* values vary from 5.43×10^{-3} m/d for the Murta Formation to 7.27×10^{-1} m/d for the Namur Sandstone. The spatial distribution of results is presented in Figure 5.9.

Table 5.4: Estimated liquid (brine) *K* from DEM dataset

Formation	No.	*K* (m/d) for brine		
		Arithmetic mean	Geometric mean	Swanson's mean
Murta Formation	244	5.43×10^{-3}	1.00×10^{-5}	2.20×10^{-4}
McKinlay Member	161	6.44×10^{-2}	7.55×10^{-4}	4.11×10^{-2}
Namur Sandstone	158	7.27×10^{-1}	2.90×10^{-1}	8.17×10^{-1}
Birkhead Formation	455	2.37×10^{-2}	2.28×10^{-4}	2.19×10^{-2}
Hutton Sandstone	437	2.10×10^{-1}	1.41×10^{-1}	2.05×10^{-1}

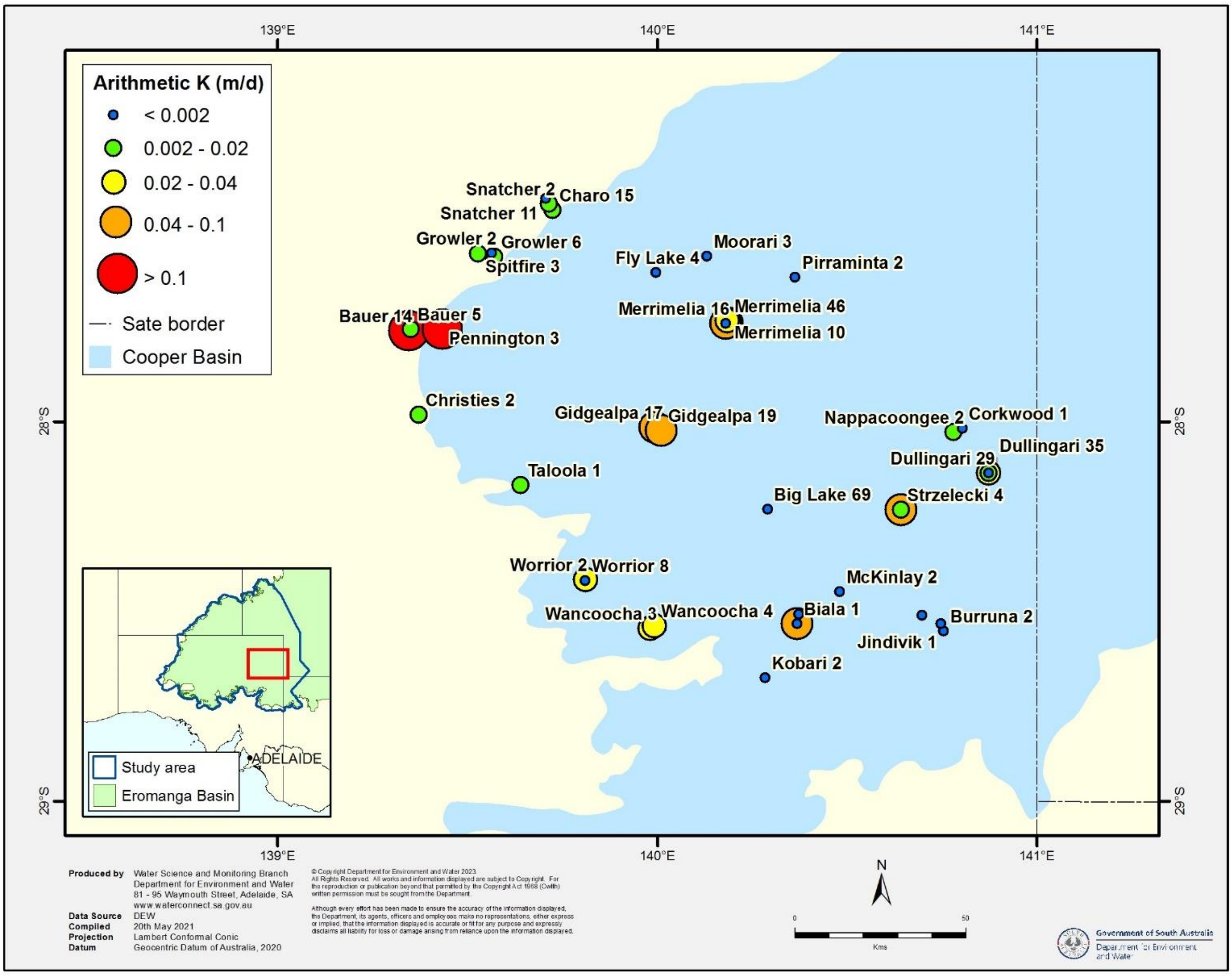


Figure 5.9: Summary arithmetic mean hydraulic conductivity values from DEM core-derived permeability.

5.2.2 Comparison of core-derived porosity and permeability to previous analysis

Core-derived porosity and permeability compiled for this study were compared against the correlation and trend relationships for core-derived porosity and permeability data for SA Eromanga strata developed by Gravestock and Alexander (1986, 1988, 1989).

The trend identified between porosity and permeability data first identified by Gravestock and Alexander (1988) is replicable in core-derived porosity and permeability data collated for this study (Figure 5.10, Lithological demarcation lines replicate envelopes presented by Gravestock and Alexander (1988) (Figure 2.1)). Consequently, porosity and permeability data may be used to confirm the gross qualitative hydrogeological characteristics inferred for each formation type replicated in the model as first identified by Gravestock and Alexander (1988). Specifically, the Namur and Hutton Sandstones are predominantly permeable aquifers whereas the Murta and Birkhead Formations are predominantly confining layers with minor aquifer layers.

Like what Gravestock and Alexander (1988) noted in their analysis, there is difficulty of selecting which equation to use to estimate permeability for porosity range between 0.05 and 0.20, although this may be resolved using the methodology described in Chapter 2.

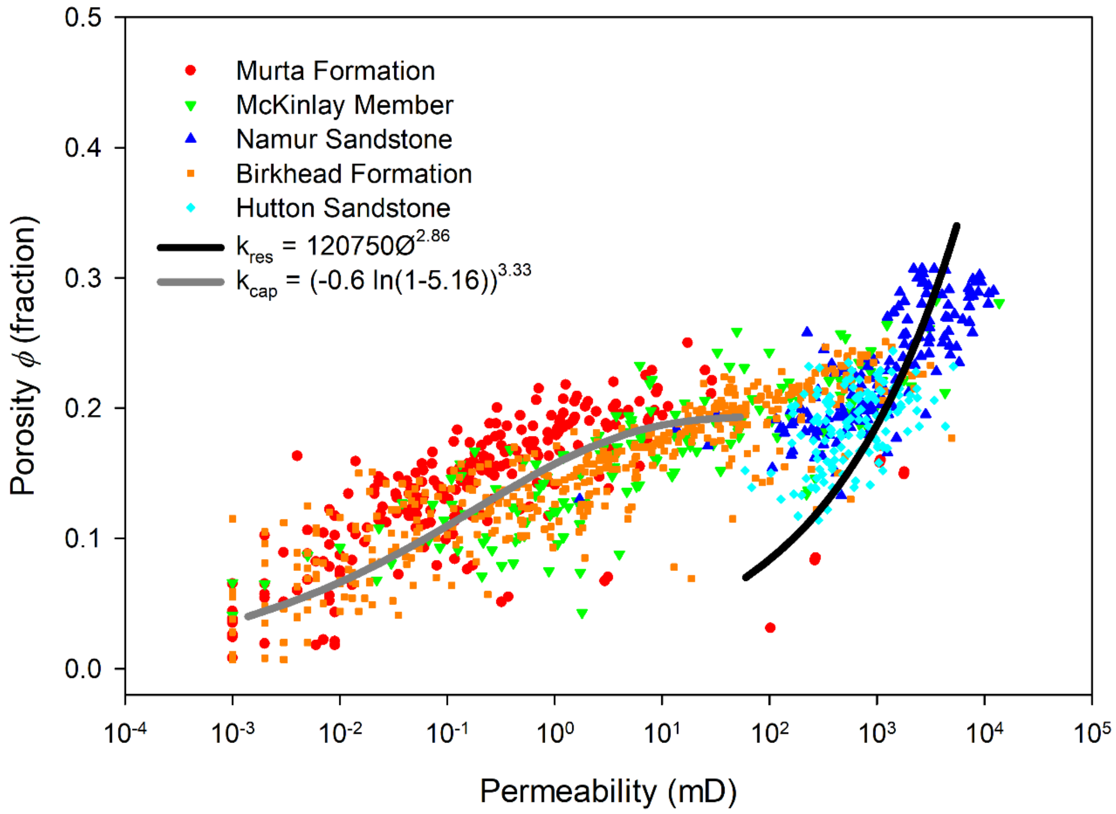


Figure 5.10: Porosity–permeability trends (reservoir rock and cap rock) and their derived functions

6 Summary of hydraulic properties of the hydrostratigraphic units

The following chapter presents the results of study-specific investigations to determine hydraulic properties of the hydrostratigraphic units of interest captured within the study area, as well as a summary of previous studies where appropriate. Finally, the results of these study-specific investigations are provided in summary.

6.1 Summary of hydraulic conductivity of the Main Eromanga Aquifer Sequence

K values from the J-K aquifer vary considerably across the mapped area. Table 6.1 provides summary statistics. This table considers the determinable hydraulic conductivity from transmissivity data obtained from artesian well shut-in monitoring tests, as well as *K* values determined from energy industry data and found after literary review. Typically, *K* and *apparent T* values are relatively higher near the margins and shallower portions of the study area, whilst being lower in the Cooper Basin region (Table 6.1; Figure 6.1).

With respect to the Hutton–Poolowanna Aquifer unit, data derived from Energy Industry studies in SA suggest a range between 1.54 x 10^{-4} and 6.52 m/d. In contrast, Jiang et al. (2013) and Jiang (2014) noted that an equivalent unit in the Surat Basin in Queensland may have *K* values as high as 170 m/d, although the hydrogeological framework of the unit in this area may be different to the one found in this study area.

Determined *K* values for the confining units of the Murta and Birkhead Formations range between 1.44 x 10^{-8} and 6.34, and 1.44 x 10^{-8} and 1.85 m/d respectively. We note however that many field and laboratory-based analyses may have an inherent sampling bias toward more conductive parts of the strata. This is discussed in Chapter 5 with respect to core analysis, but may also impact data from water wells, given well completions are likely to favour the better producing sections of an encountered aquifer. A more general discussion of this limitation is presented in Chapter 7.

6.2 Summary of hydraulic conductivity of overlying confining units and underlying basin fomations

6.2.1 Overlying confining units

Overlying the Main Eromanga Aquifer Sequence is the Rolling Downs Group (Neocretaceous marine clays, silts and shales which includes the Bulldog Shale and Oodnadatta Formation). The Rolling Down group are regarded as a confining unit above the Main Eromanga Aquifer Sequence. The Rolling Downs Group is considered the most effective aquitard in the GAB because of its extent, thickness and low permeability from mudstones and other fine-grained sediments (see Volume 2). Table 6.2 summarises the hydraulic properties of the confining unit above the Main Eromanga Aquifer Sequence.

6.2.2 Underlying basins

Selected literature-derived hydraulic properties of underlying strata associated with the Permo-Carboniferous Arckaringa, Pedirka and Cooper, the Triassic Simpson Basin, the Cambrian Stuart Shelf and Precambrian rocks of the Adelaide Geosyncline are presented in Chapter 2 and are summarized in Table 6.1. Below is a summary of key observations. Further, a summary description of lithology and depositional history and hydrogeological characterisation may be found in Volume 2 of this report.

Table 6.1: Summary of horizontal hydraulic conductivities (m/d)

Model Layer (Table 1.1)	Formation	Region (defined by the basins underlying the Eromanga Basin)					
		Simpson	Cooper	Arckaringa	Pedirka	Stuart Shelf	Min.to Max.
1	Cadna-owie Fm		8 x 10^{-2}	20.0	7.0		0.1 to 100
2	Murta Fm		1.44 x 10^{-8} to 4.43				
	McKinlay Mbr		1.44 x 10^{-8} to ^{6}.34				
	Algebuckina Sst	22.1				22.1	0.1 to 100
	Namur Sst		1.18 x 10^{-4} to 5.48				
3	Hooray Sst		0.12				<18.7
	Westbourne Fm		0.1				
	Adori Sst		0.77				10 (mean)
4	Birkhead Fm		1.44 x 10^{-8}– to 1.85				
5	Hutton Sst–Poolowanna Fm		1.5 x 10^{-4} to 4.35				<170
	Mt Toondina Fm			9 x 10^{-5} to 5.0			
	Stuart Range Fm			3.46 x 10^{-8} to1 x 10^{-4}			
	Boorthanna Fm			0.2 to 2.53			
	Purni Fm				2.5 x 10^{-4} to 6		
	Crown Point Fm				0.1 to 2.3		
	Cuddapan Fm		1.7 x 10^{-2}				
	Tinchoo Fm		0.28				
	Wimma Sst		1.0 x 10^{-2}				
	Paning Mbr		2.1 x 10^{-2}				
	Callamura Mbr		6.7 x 10^{-3}				
	Toolache Fm		3.6 x 10^{-2}				
6	Daralinge Fm		4.3 x 10^{-3}				
	Epsilon Fm		7.3 x 10^{-3}				
	Patchawarra Fm		1.0 x 10^{-2}				
	Tirrawarra Sst		1.7 x 10^{-2}				
	Merrimelia Fm		1.2 x 10^{-3}				
	Andamooka Lmst					5	
	Arcoona Qtz					0.05	
	Tent Hill Fm					1 x 10^{-2}	
	Tregolana Sh					1 x 10^{-4}	
	Generic Basement						1 x 10^{-4} to 0.3

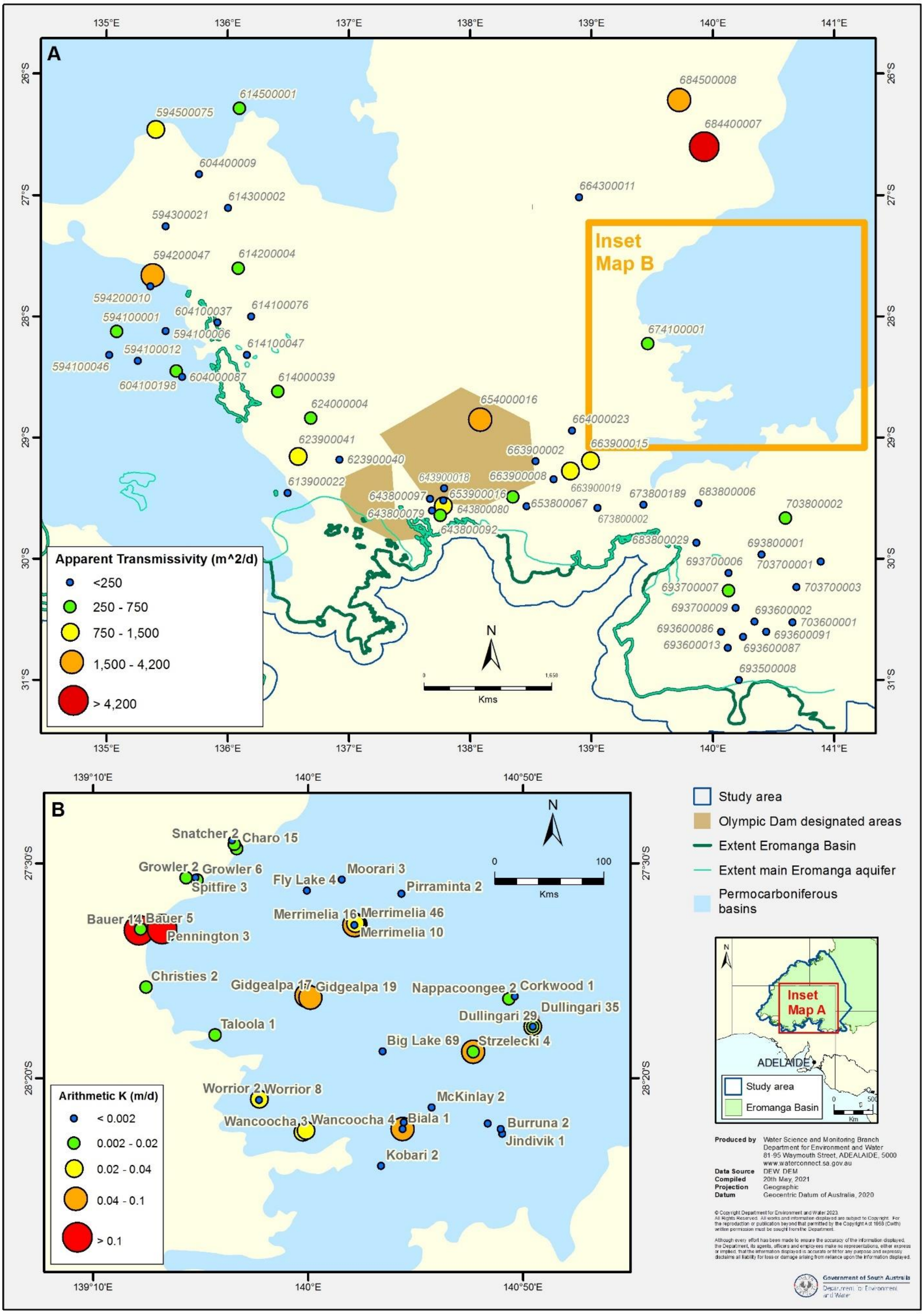


Figure 6.1: **Distribution of transmissivity results from shut-in tests and mean arithmetic conductivity results from core-derived air permeability.**

Table 6.2: Summary of minimum and maximum hydraulic property values for the main confining unit

Parameter	Symbol	Unit	Model min.	Model max.	Field study min.	Field study max.
Vertical hydraulic conductivity (aquitard)	K_v	m/d	1×10^{-8} [a]	1×10^{-4} [a]	8.12×10^{-9} [b]	7.78×10^{-5} [b]
Vertical hydraulic conductivity (leaky aquitard)	K_v	m/d	1×10^{-8}	0.5	8.64×10^{-5} [b]	8.68×10^{-4} [b]
Specific storage	S_s	m^{-1}	1×10^{-5} [a]		8×10^{-6} [b]	1×10^{-5} [b]
Transmissivity	T	m^2/d			1.7 [c]	79.1 [c]

[a] Table 2.2

[b] Table 2.1

[c] Fractured rock aquifer within confining layer, near Mount Willoughby, Table 2.1

Arckaringa Basin

The Arckaringa Basin underlies the Main Eromanga Aquifer Sequence in the south-western portion of the study area (Figure 6.2). From oldest to youngest, the main hydrostratigraphic units of the Arckaringa Basin consist of the Boorthanna, the Stuart Range Formation and the Mount Toondina Formation. The Stuart Range Formation is characterised as a confining layer and the Mount Toondina and Boorthanna formations as aquifers to partial aquifers, although there may be intra-formational sequences with more confining unit characteristics at a sub-regional scale. From a summary of company logs presented in Wohling et al. (2013) the Mt Toondina Formation had the most variable porosity, ranging between 4 to 37% (Table 2.3), due largely to the variable assortment of sedimentary rock, ranging from coarse sandstone to coal beds. Most recent horizontal hydraulic conductivities for the Mt Toondina Formation come from the energy industry and show variation between 1.4×10^{-4} to 1.4 m/d whereas Boorthanna Formation values can range up to 2 m/d. With respect to the Stuart Range Formation, Kleinig et al. (2015) determined laboratory and model-based vertical hydraulic conductivities that ranged between 4.5×10^{-8} to 3.46×10^{-5}m/d.

Pedirka Basin

The Pedirka Basin underlies the Main Eromanga Aquifer Sequence in the north-western portion of the study area (Figure 6.2). From oldest to youngest, the main hydrostratigraphic units of the Pedirka Basin sequence comprise glacial and glacio-lacustrine sands and shales of the Crown Point Formation, overlain by interbedded sands, silts and coals of the Purni Formation. Much of the hydraulic property information for the Pedirka Basin is derived from either petroleum exploration works or from a pump test study undertaken by Fulton et al. (2015). Like the Arckaringa Basin, the high variability in porosity (3 to32%) (Table 2.3) is related to the variable assortment of sedimentary rock found, ranging from coarse sandstone to coal beds. Resultant horizontal hydraulic conductivities may range from 2.5×10^{-4} m/d (Purni Formation coal beds) to 6 m/d (Purni Formation, siliceous sedimentary rocks).

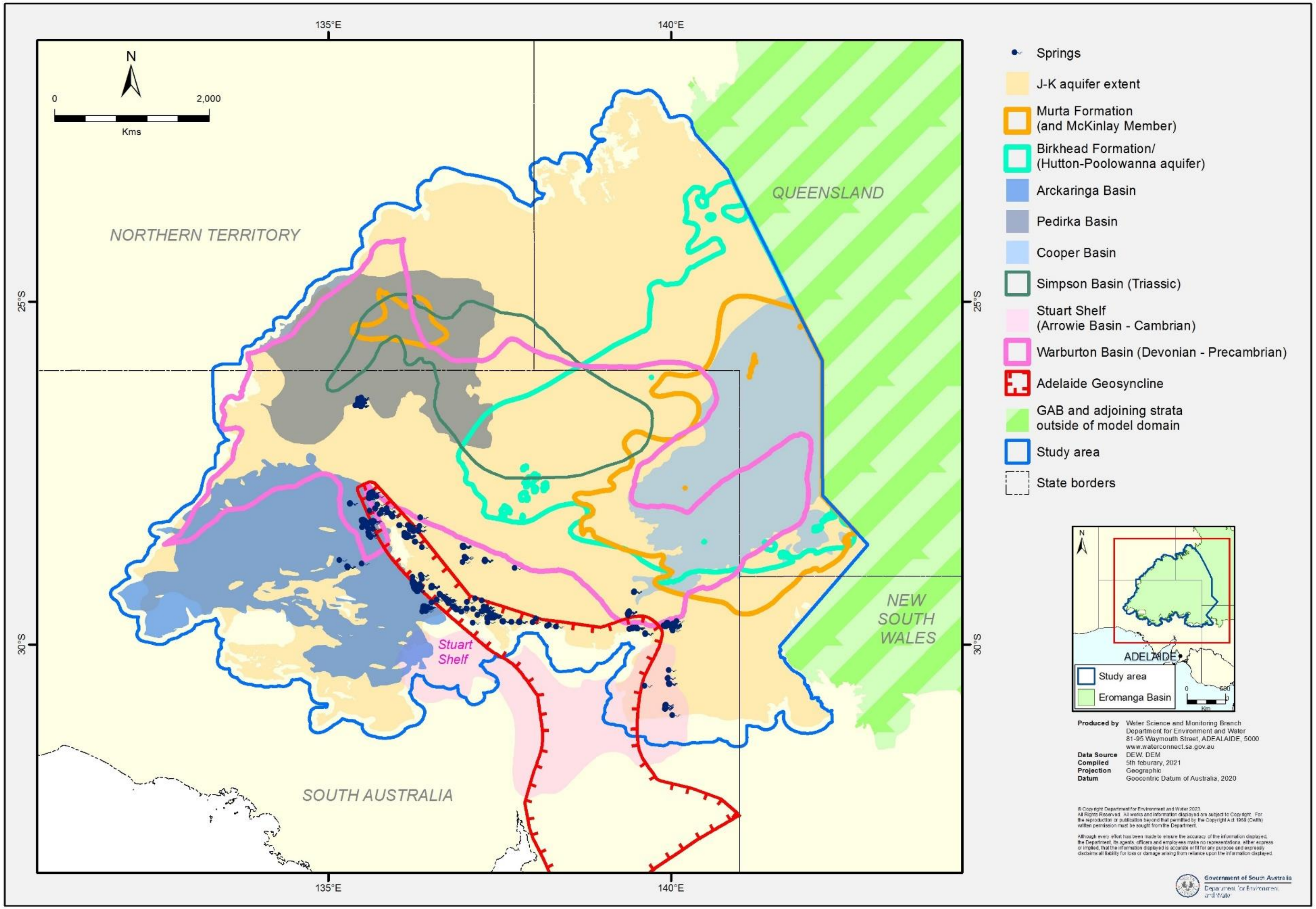


Figure 6.2: Regions pertaining to variations in hydraulic properties.

Cooper Basin

The Cooper Basin is within the eastern portion of the study area (Figure 6.2). Strata within the Cooper Basin is well documented and is generally composed of glaciogene sediments, non-marine coal measures, lacustrine sediments, largely composed of interbedded shales, conglomerate, sandstone, mudstone and siltstone. The porosity and permeability data shown in Table 2.4 are based on the results of routine core analysis (measured at ambient conditions) held in the DEM PEPS database and includes company and DEM generated analyses (Gravestock et al. 1998). Average porosity values range between 16.5 to 25.3% whereas equivalent average horizontal hydraulic conductivities vary between 5.04 x 10^{-4} to 3.31 x 10^{-2} m/d. These values are overestimates since porosity and permeability decrease under overburden pressures, and a correction factor of 0.95 needs to be applied (Morton 1989).

Simpson Basin

The Simpson Basin is a Triassic basin that overlies Palaeozoic and older strata and is overlain by the Eromanga Basin (Jurassic to Cretaceous) and is found near the centre of the study area (Figure 6.2). The Simpson Basin contains Early to Middle Triassic Walkandi Formation overlain conformably by Late Triassic Peera Formation. The Walkandi Formation consists of interbedded shale, siltstone, and minor sandstone redbeds deposited in a shallow ephemeral lacustrine environment. Limited drilling indicates that sandstone interbeds in the Walkandi Formation are fine grained, with low porosity and permeability. Peera Formation has a maximum measured porosity of 7.4% (Goldstein et al. 2011) in the vicinity of Poolowanna Trough. The depth of Simpson Basin strata means that very little is known about the hydrogeological characteristics of these rocks.

Warburton Basin

The Warburton Basin underlies a large portion of the northern and eastern portions of the study area (Figure 6.2). Understanding of aquifer morphology is poor, however, there are units that could conceivably act as aquifers. These include the Pando Formation (predominantly quartzose sandstone and quartz arenite), Weena Sandstone, Mudrangie Sandstone, and other coarser grained units within the Innamincka Formation. Additionally, sandstone within the Kalladeina Formation, Narcoonowie Formation, Dullingari Group and Lycosa Formation may also be aquifers. Finally, karstic, or fractured rock aquifer might occur within carbonate units such as the Diamond Bog Dolomite and Coongie Limestone Member. Little is known about the hydraulic properties of the Warburton Basin; a single vertical hydraulic conductivity of 0.19 m/d was reported by Sheard (1982).

Stuart Shelf (Arrowie Basin)

The Stuart Shelf forms part of the Arrowie Basin and may be found within the south-central margin of the study area (Figure 6.2). Aquifer units of particular interest include the Andamooka Limestone, and the underlying Tent Hill Formation, which includes the Arcoona Quartzite, Yarloo Shale, and Corraberra Sandstone. These aquifers are the most well known in the Stuart Shelf and are the subject of several studies (BHP 2009a; BHP 2009b; Kellett et al. 1999). Other aquifers noted in the region include the Pandurra Formation and the Nucaleena Formation (basal conglomerate). The Tregolana Shale is a noted aquitard (BHP 200a). Typical porosities are reasonably low, varying between 2 to 8%; however, secondary porosity is considered important. Horizontal hydraulic conductivities may vary between 1 x 10^{-4} and 2 m/d.

Adelaide Geosyncline and Precambrian basement rocks

Although Precambrian basement rocks are ubiquitous underneath all sedimentary basins, with respect to the hydrogeology of the study area, they are of most importance where such rocks occur relatively near the surface. This occurs in locations associated with the Northern Flinders Ranges, the Mt Woods Inlier and the Peake and Denison Inliers in the southern and central portions of the study area (Figure 6.2). Secondary porosity and permeability development predominantly govern aquifer composition and extent. Consequently, aquifers may occur in numerous formations. Faulting, fold-axis jointing, monocline development, and other structural deformation leading to secondary porosity and permeability development largely shapes the morphology of aquifers, whereas permeability destruction through cementation and compaction due to burial has been postulated by Gravestock and Zang, (1996). Gravestock and Zang (1996) reported a porosity value of 9.6% and a horizontal hydraulic conductivity of approximately 2.54 x 10^{-5} m/d for sandstone within the Etina Formation.

6.3 Specific Storage

While a number of specific storage values for the J-K aquifer and other hydrostratigraphic units have been estimated previously (Table 2.2, Table 2.3, Table 6.3), recent work presented and summarized by Rau et al. (2018) indicate that specific storage has a physical upper limit of approximately ≤ 1.3 x 10^{-5} m^{-1}. This figure was determined using a combination of field techniques such as cross-hole seismic surveys and loading efficiency from the groundwater responses to atmospheric tides, as well as literature review. It also re-visited poroelastic theory that suggested uniaxial specific storage could be calculated from undrained poroelastic properties of an aquifer medium.

Table 6.3: Summary of estimated specific yield S_y and storage S_s values.

Collective term	Region (Figure 6.2)	Hydrostratigraphic unit	S_s (1/m)	S_y (−)
Main Confining Unit		Rolling Downs Group	4.3×10^{-6} to 1 x 10^{-3}	
Main Eromanga Aquifer Sequence	Cooper Basin	Cadna-owie Fm	1.75 x1 0^{-6} to 1.9 x 10^{-3}	8 x 10 x 10^{-6} to 7
		Murta Fm		
		Namur–Algebuckina Sandstone Aquifer	3 x 10^{-7} to 1.9 x 10^{-3}	0.1 to 0.3*
		Birkhead Fm	5.8 x 10^{-7}	
		Hutton-Poolowanna Aquifer		0.05 to 0.25*
Pre-Jurassic Basement		Generic Pre-Jurassic Basement	1 x 10^{-5}	
		Mt Toondina Fm	1 x 10^{-5}	
	Arckaringa Basin	Stuart Range Fm		
		Boorthanna Fm		
	Pedirka Basin	Purni Fm	1.1^{-6} to 1 x 10^{-4}	0.04 to 0.32*
		Crown Point Fm		0.11 to 0.32*
	Arrowie Basin	Stuart Shelf	4 x 10^{-5} to 0.02	

*Estimated based on effective porosity

7 Limitations

Through the processes of data compilation, analysis and literature review, several limitations were made apparent, both with respect to raw data as well as conceptual understanding. The following section provides a discussion of these data gaps and limitations considered important with respect to the development of the conceptual hydrogeological model and ultimately the numerical model construction.

7.1 Sampling bias in core-plug data

Porosity and permeability estimates from cored plugs may not be representative of the bulk formation due to sampling bias. This occurs because sampling favours reservoir rocks (i.e., more productive units with higher permeability). Further, such core plugs are generally obtained from depth. Consequently, porosity and permeability values may be over-estimated because of depressurisation from the removal of overburden pressure.

7.2 Sampling bias in DST, MDT and pump-test data

Similarly, the hydraulic property estimates obtained from DST, MDT and pumping tests may not be representative of the formation because they are obtained from restricted vertical intervals, which may be considerably smaller than the full thickness of the unit. The area and volume of a model hydrogeological zone may be considerably bigger than the area and volume within which the initial hydraulic parameters were determined.

Like core-plug data, pump-test data undertaken for hydrogeological assessment may also favour the more highly conductive units, as it is less likely that wells will be completed in the less conductive zones. An example is from the Cadna-owie and Westbourne Formations in the Cooper Basin region. Historically, the Cadna-owie Formation has been recognized as part of the J-K aquifer (e.g., see Habermehl 1980; Radke et al. 2000): however, more recently Ransley and Smerdon (2012) interpreted the Cadna–owie Formation to be a leaky aquitard in the Cooper Basin region based on measured hydraulic parameters from that area (Figure 6.2). Given the Cadna-owie Formation is interpreted as a transition unit between terrestrial and marine depositional environments, sedimentological variation at more localised scales may be expected. However, wells may not necessarily be expected to be routinely completed in parts of the Cadna-owie formation that have leaky aquitard characteristics.

Further, Ransley and Smerdon (2012) noted that permeability values from the Westbourne Formation tend to favour sandier parts of the formation, which also highlights the issue of sampling bias.

8 Closing remarks, modelling assumptions and conclusions

Spatially distributed hydraulic parameters are required to describe groundwater flow within the aquifers and confining units of the Main Eromanga Aquifer Sequence, as well as overlying and underlying units of note. Of primary importance are hydraulic conductivities for model layers and head-dependent boundaries. Other needed parameters include specific storage for the aquifer and aquitard units, and transmissivity for the aquifer layers.

A summary of hydraulic conductivities either collected or calculated during this study are presented in Table 6.1 and Table 6.2. Storage values are provided in Table 6.3, however, recent work by Rau et al. (2018) indicates that specific storage (S_s) is limited to 2.3×10^{-7} m^{-1} $\leq S_s \leq$ 1.3×10^{-5} m^{-1}.

Estimated aquifer transmissivities from monitoring reviewed for this study were highly variable and ranged from 1.21 m^2/d to 22,900 m^2/d. This large range of values may be due to factors such as variability in local hydraulic characteristics and measurement errors. Results at the higher end of the scale are thought to be more impacted by error or local factors.

Ultimately the selection of initial hydraulic property values for numerical model construction will be guided by the following principles:

- Hydraulic data should be collated for individual hydrostratigraphic units.
- The values should reflect the conceptual hydrogeological model.
- The initial properties should be consistent with measured, field-based values and consistent with values from previous notable groundwater flow models.
- Where the lateral and vertical extent of a model layer encompasses different facies such as sandstone, siltstone and shale, the initial hydraulic property values should be reflective of the lithology or lithologies that have the greatest influence on the groundwater flow system. For example, high K_h (sand-dominant) units convey horizontal flow predominantly and vertical flow is predominantly constrained by low K_v (shale-dominant) units, whereas aquifer storage properties have a more complex relationship with lithology.

During this study, several limitations were made apparent. These include:

- Porosity and permeability data obtained from core plugs may not be representative of the bulk formation because of sampling bias. This bias occurs because sampling tends to favour sections of strata more favourable as reservoir rocks (i.e., towards more high-hydraulic conductivity, more productive units). Further, cores used for the analysis are generally obtained from depth. Consequently, resultant porosity and permeability values may be exaggerated because of depressurisation from the removal of overburden pressure.
- Similarly, the hydraulic property estimates obtained from DST, MDT and pumping tests may not be representative because they are obtained from restricted vertical intervals, which may be considerably smaller than the full thickness of the unit. Like core-plug data, pump-test data undertaken for hydrogeological assessment may also favour the more highly conductive units, as it is less likely that wells will be completed in the less conductive zones of strata.

9 Appendices

A. Calculated transmissivity from shut-in pressures from artesian monitoring wells

Table 9.1: **Calculated transmissivity from shut-in pressures from artesian monitoring wells**

Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity (=K_h/γ) (m^2/d
WRA002	5941-001	508371	6888740	3.42	295.9	28.0	5,310	2,971.6	1.6	0.16	331.8
	5941-001			3.25	280.8	29.2	-		2.1	0.21	239.9
	5974-1	508371	6888740	29.20	2,522.9	6.0	2.54		1.8	0.18	2,515.0
WRA003	5941-006	548062	6888932	0.78	67.5	26.0	4,420	2,465.2	57.5	5.87	2.1
	5941-006			0.57	49.2	28.5	4,380	2,442.8	73.0	7.45	1.2
	5974-6	548062	6888932	0.57	49.2	28.5	4,380	2,442.8	62.0	6.32	1.4
WRA026	5941-046			0.70	60.5	27.5	-		5.8	0.59	18.7
	5974-46	502343	6867215	0.70	60.5	27.5	-		6.2	0.63	17.5
ODN014	5942-047	537685	6940075	8.33	720.0	22.0	3,370	1,872.3	0.5	0.05	2,583.9
	5942-047			14.15	1,222.6	46.7	3,250	1,804.2	0.5	0.05	4,218.8
	5942-47	537685	6940075	14.15	1,222.6	46.7	3,250	1,804.2			
ODN015	5943-021	548548	6984648	5.21	450.0	48.0	3,820	2,125.1	20.0	2.04	40.4
	5943-021			4.80	414.7	47.6	3,660	2,035.8	22.0	2.24	33.8
	5943-21	548548	6984648	4.80	414.7	47.6	3,660	2,035.8	23.0	2.35	32.4
DLH008	5945-075			8.20	708.5	43.7	1,700	938.0	0.6	0.06	2,118.8
	5945-75	540783	7073160	8.20	708.5	43.7	1,700	938.0	1.3	0.13	977.9

Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity (=K_h/γ) (m^2/d)
WRA029	6040-087			1.60	138.2	27.4	-		7.6	0.78	32.6
	6040-087			1.64	141.7	26.1	5,790	3,246.4	6.2	0.63	41.0
	6040-87	561003	6846894	1.64	141.7	26.1	5,790	3,246.4	10.0	1.02	25.4
WRA012	6041-037	590121	6896530	7.67	662.7	30.5	4,029	2,243.1	7.5	0.77	158.5
	6041-037			13.40	1,157.8	30.4	4,130	2,300.7	11.4	1.16	182.2
	6041-37	590121	6896530	16.90	1,460.2	31.0	4.59		22.0	2.24	119.1
	6041-37	590121	6896530	13.40	1,157.8	30.4	4,130	2,300.7	15.0	1.53	138.5
DLH009	6044-009	575942	7032101	8.62	744.8	51.4	3,870	2,154.3	10.0	1.02	133.7
	6044-009			10.40	898.6	53.0	3,660	2,035.8	14.0	1.43	115.2
	6044-9	575942	7032101	10.40	898.6	530.0	3,660	2,035.8	12.0	1.22	134.4
BKN005	6139-022	644875	6740092	0.63	54.0	25.0	8,830	5,008.0	2.8	0.28	35.2
	6139-022			0.55	47.5	23.9	-		7.0	0.71	12.2
	6193-22	644875	6740092	0.55	47.5	23.9	8.85		4.0	0.41	21.3
WRA021	6140-039	638139	6833250	8.93	771.4	27.0	8,040	4,546.6	2.6	0.27	532.4
	6140-039			8.00	691.2	37.2	7,620	4,302.3	4.2	0.43	295.3
	6140-039			14.40	1,244.2	47.2	9,020	5,120.4	3.1	0.31	732.0
	6140-039			3.77	325.7	44.4	4,890	2,732.4	2.8	0.29	208.7

Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity (=K_h/γ) (m^2/d
WRA020	6141-047	613712	6866741	2.78	240.0	27.2	4,031	2,244.3	16.0	1.63	26.9
	6141-047			2.60	224.6	27.2	-		19.0	1.94	21.2
	6141-47	613712	6866741	2.60	224.6	27.2	4.22		20.0	2.04	20.2
ODN008	6141-076			14.20	1,226.9	40.0	3,680	2,046.9	17.0	1.73	129.5
	6141-76	617426	6901943	14.20	1,226.9	40.0	3,680	2,046.9	18.0	1.84	122.3
ODN007	6142-004			24.20	2,090.9	38.9	3,820	2,125.1	6.9	0.70	543.7
	6142-4	607272	6946159	24.20	2,090.9	38.9	3,820	2,125.1	7.0	0.71	536.0
ODN017	6143-002			11.13	961.6	64.3	4,330	2,413.7	4.5	0.46	383.5
	6143-2	599485	7001423	11.13	961.6	64.3	4,330	2,413.7	7.0	0.71	246.5
CDM018	6239-041	653765	6773211	16.67	1,440.0	27.0	9,530	5,420.1	0.8	0.08	3,229.9
	6239-041			14.35	1,239.8	32.7	9,210	5,231.7	1.6	0.16	1,390.5
	6239-41	653765	6773211	14.35	1,239.8	32.7	9,210	5,231.7	1.6	0.16	1,390.5
KPM007	6540-00016	215641	6804688	33.00	2851.2	77.2	2,158	1,192.8			
	6540-016			33.00	2851.2	77.2	2,158	1192.8	2.0	0.20	2,558.1
KPM006	6640-023			12.38	1069.6	97.3	2,700	1496.0	14.3	1.45	134.7
	6640-23	289518	6796237	12.38	1,069.6	62.8	1,525	840.8			
GSN005	6643-011			36.90	3,188.2	99.1	1161	639.5	16.0	1.63	357.6
	6643-11	291421	7009757	36.90	3,188.2	9.1	1161	639.5	28.0	2.86	204.3

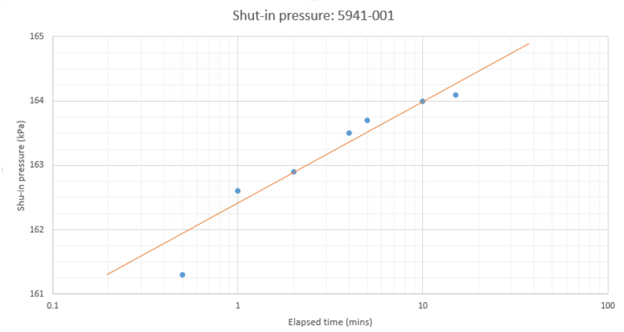
Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity (=K_h/γ) (m^2/d
MRE004	6738-002	311227	6725853	3.65	315.3	44.4	2,580	1,428.9	7.0	0.71	80.8
	6738-002			5.00	432.0	34.3	2,021	1,116.6	5.8	0.59	134.9
	6738-002			3.40	293.8	45.5	2,383	1,318.6	6.2	0.63	85.0
MRE021	6738-189	347735	6729162	6.07	524.4	51.2	1,770	977.4	3.3	0.34	285.2
	6738-189	347735	6729162	5.56	480.0	22.0	1,970	1,088.4	6.0	0.61	143.6
	6738-189	347735	6729162	5.30	457.9	37.5	1,739	959.5	9.1	0.93	90.3
	6738-189			6.07	524.4	51.2	1,770	977.4	2.4	0.24	392.1
KPM004	6741-001			26.00	2,246.4	87.8	1,161	639.5	6.0	0.61	671.8
	6741-1	349469	6876628	26.00	2,246.4	87.8	1,161	639.5	5.4	0.55	746.5
CBN005	6838-006			6.60	570.2	45.7	1,6360	9,532.8	22.5	2.30	45.5
	6838-6	391596	6731330	6.60	570.2	45.7	1,6360	9,532.8	22.0	2.24	46.5
CBN008	6838-029	390575	6694912	10.42	900.0	45.0	3,100	1,720.0	12.5	1.28	129.2
	6838-029			9.60	829.4	63.4	2,690	1,490.5	15.0	1.53	99.2
	6838-29	390575	6694912	9.60	829.4	64.3	2,690	1,490.5	16.0	1.63	93.0
COR003	6845-008			26.00	2,246.4	97.3	891	490.1	1.0	0.10	4,030.9
	6845-8	372471	7099707	26.00	2,246.4	97.3	891	490.1			

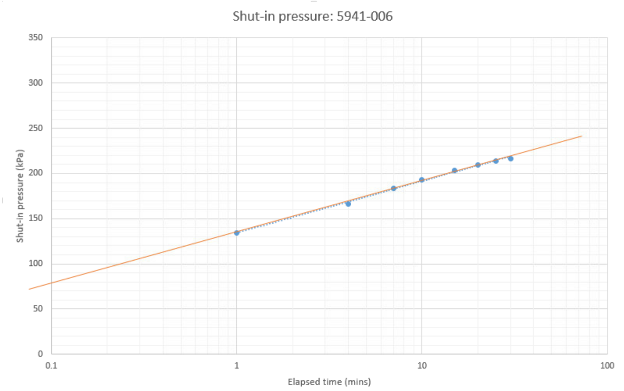
Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity ($=K_h/\gamma$) (m^2/d
FRM004	6937-009	422261	6635945	7.85	678.2	41.8	-		20.0	2.04	60.9
	6937-009			8.15	704.2	50.1	2,920	1,619.1	12.5	1.28	101.1
	6937-9	422259	6635941	8.15	704.2	50.1	2,920	1,619.1	12.5	1.28	101.1
FRM005	7037-003			11.30	976.3	50.6	3,240	1,798.2	17.1	1.74	102.5
	7037-3	470339	6654851	11.30	976.3	50.6	3,240	1,798.2	9.5	0.97	184.4
CBN004	7038-2	461015	6717325	16.00	1,382.4	53.3	3,200	1,,776.0	4.2	0.43	590.6
Fortville 3		490259	6778174	1.20	103.7	40.0	2,248	1,242.5	7.8	0.80	23.9
CDM010	6239-40	687011	6770021	3.77	325.7	44.4	4,890	2,732.4	4.0	0.41	146.1
WRA021	6040-39	638139	6833250	8.00	691.2	37.2	7,620	4,302.3	2.9	0.30	427.7
LKE002	6040-4	664364	6808510	14.40	1,244.2	47.2	9,020	5,120.4	12.0	1.22	186.0
	6438-004	769380	6730863	5.22	451.0	34.5	2,400	1,328.0	85.0	8.67	9.5
	6438-079	760112	6721872	0.55	47.5	26.3	3,300	1,832.0	12.0	1.22	7.1
	6438-080	769427	6725937	13.18	1,138.3	32.6	2,820	1,563.1	2.1	0.21	973.0
	6438-092	766521	6717625	14.60	1,261.4	30.2	3,460	1,922.8	4.1	0.42	552.2
	6438-097	758902	6732785	3.24	279.9	30.4	2,740	1,518.2	5.2	0.53	96.6
	6439-018	770263	6742042	12.30	1,062.7	42.4	2,310	1,277.5	64.0	6.53	29.8
	6639-019	288997	6759093	27.60	2,384.6	37.0	1,790	988.5	3.0	0.31	1,426.7
	5941-012	525435	6861879	0.30	25.9	28.4	-		0.4	0.04	132.9

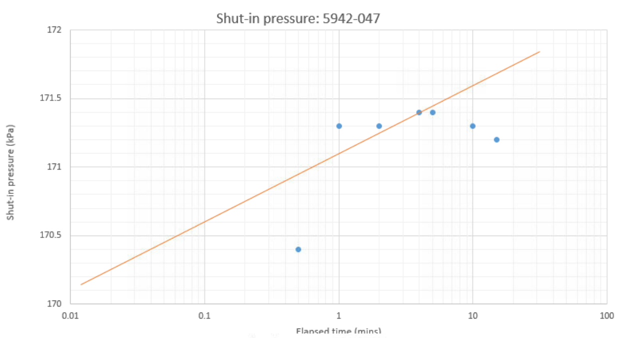
Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity (=K_h/γ) (m^2/d
	6935-008	425004	6569853	0.23	19.9	-	-		10.0	1.02	3.6
	6936-013	416326	6599033	0.90	77.8	42.1	-		0.7	0.07	214.7
	6936-086	410910	6613909	6.67	576.3	43.0	-		12.0	1.22	86.2
	6936-087	423398	6609420	6.75	583.2	40.1	-		19.0	1.94	55.1
	6936-091	446586	6613982	2.00	172.8	41.1	-		21.1	2.15	14.7
	6937-006	416315	6667751	10.15	877.0	51.0	-		90.0	9.18	17.5
	6937-007	410955	6655653	10.00	864.0	46.9	-		5.0	0.51	310.1
	6938-001	442314	6684723	10.00	864.0	51.4	-		10.9	1.11	142.2
DLH 7	6145-001			5.04	435.5	70.0	-		2.6	0.26	306.4
	6844-007			236.00	20,390.4	91.4	1,050	577.5	1.6	0.16	22,867.7
	6844-007			236.00	20,390.4	91.4	1,050	577.5	2.7	0.28	13,551.3
	6639-015			19.70	1702.1	41.4	1,582	872.1	2.2	0.22	1,421.0
	6639-015			3.90	337.0	43.5	1,684	929.2	0.5	0.05	1,209.6
	7036-001	-	-	7.20	622.1	45.9	-		8.6	0.87	130.6
	7037-001			2.70	233.3	32.0	2,585	1,431.7	4.1	0.42	102.1
	6538-067			1.25	108.0	34.2	5,720	3,206.2	11.0	1.12	17.6
	6539-016			1.80	155.5	36.6	2,518	1,394.0	0.7	0.07	398.8
	6639-002			7.00	604.8	40.4	1,855	1,024.2	10.2	1.04	106.4

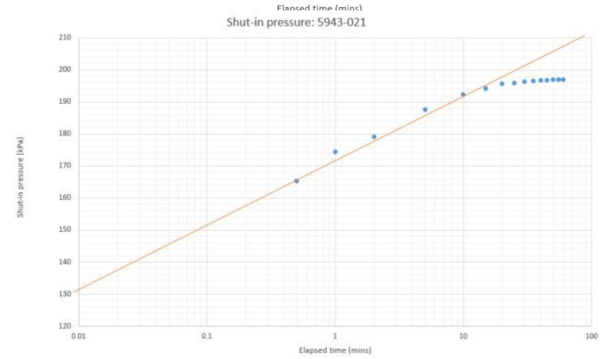
Site	Well ID	Easting	Northing	Stabilised flow rate (L/s)	Stabilised flow rate (m^3/d)	Stable Temperature (˚C)	Field EC µS/cm @ 25˚C	TDS (mg/L)	Slope (ΔP (kPa)) per log10	Slope (Δh (m)) per log10	Apparent Transmissivity ($=K_h/\gamma$) (m^2/d
	6639-008			9.00	777.6	37.0	1,980	1,094.0	17.0	1.73	82.3
	6041-198			17.47	1,509.4	28.8	-		4.0	0.41	677.3
	5942-010			0.25	21.6	35.3	-		2.8	0.29	13.8
	6936-002	-	-	2.50	216.0	35.2	-		8.5	0.87	45.6
ODN016	6142-7	638168	6955157	14.00	1,209.6	62.9	3,360	1,866.8			
	6442-2	787004	6910285	23.60	2,039.0	97.0	2,700	1,496.0			
	6445-004	-	-	-		97.4	2,214	1,223.7	24.0	2.45	
	6239-45	673276	6751849	-		32.7	9,210	5,231.7	6.0	0.61	

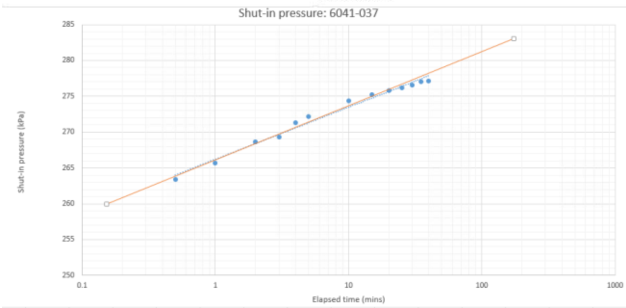
B. Semi-log plots of build-up against time for transmissivity

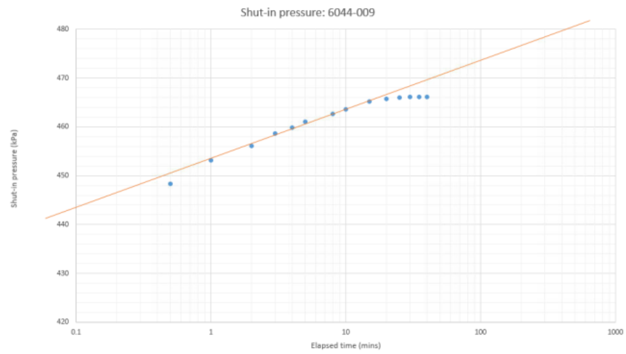

Shut-in pressure: 5941-001
Shut-in pressure (kPa)
165
164
163
162
161
0.1
1
10
100
Elapsed time (mins)

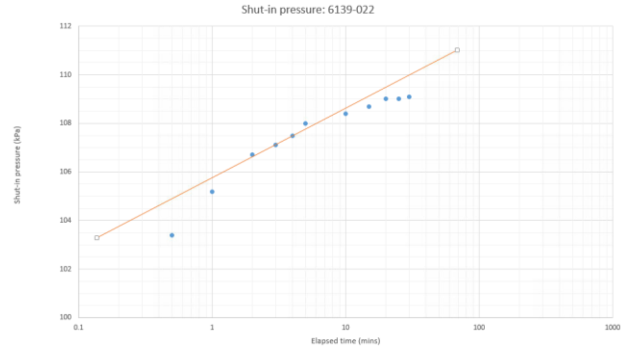

Shut-in pressure: 5941-006
Shut-in pressure (kPa)
350
300
250
200
150
100
50
0
0.1
1
10
100
Elapsed time (mins)

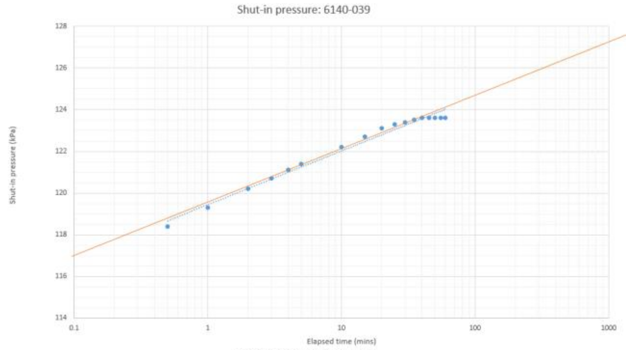

Shut-in pressure: 5942-047
Shut-in pressure (kPa)
172
171.5
171
170.5
170
0.01
0.1
1
10
100

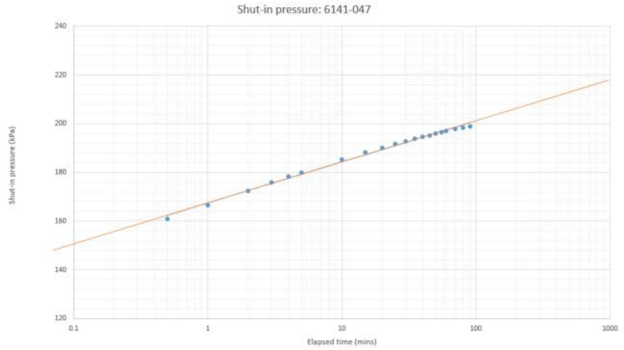

Shut-in pressure: 5943-021
Shut-in pressure (kPa)
210
200
190
180
170
160
150
140
130
120
0.01
0.1
1
10
100
Elapsed time (mins)

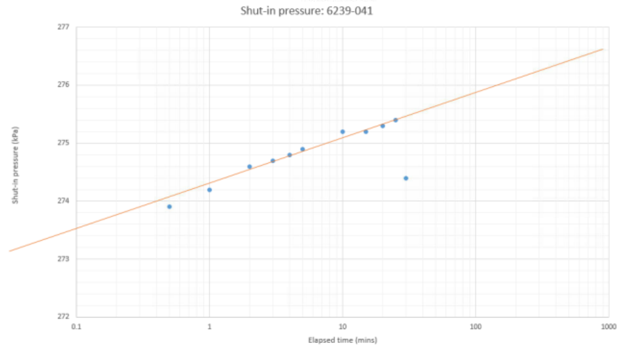

Shut-in pressure: 6041-037
Shut-in pressure (kPa)
285
280
275
270
265
260
255
250
0.1
1
10
100
1000
Elapsed time (mins)

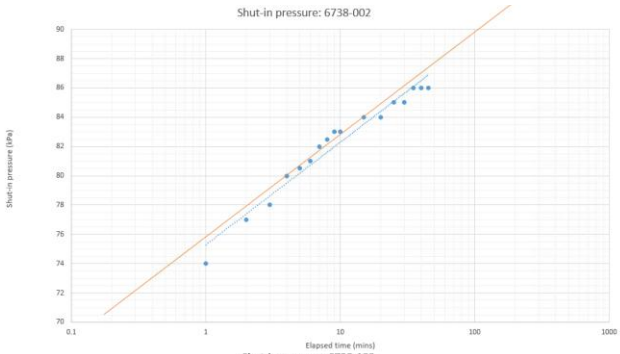

Shut-in pressure: 6044-009
Shut-in pressure (kPa)
480
470
460
450
440
430
420
0.1
1
10
100
1000
Elapsed time (mins)

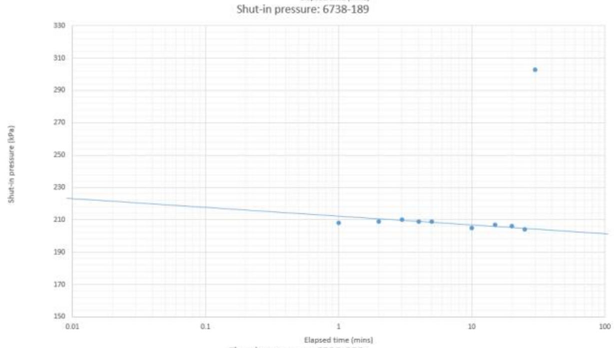

Shut-in pressure: 6139-022
Shut-in pressure (kPa)
112
110
108
106
104
102
100
0.1
1
10
100
1000
Elapsed time (mins)

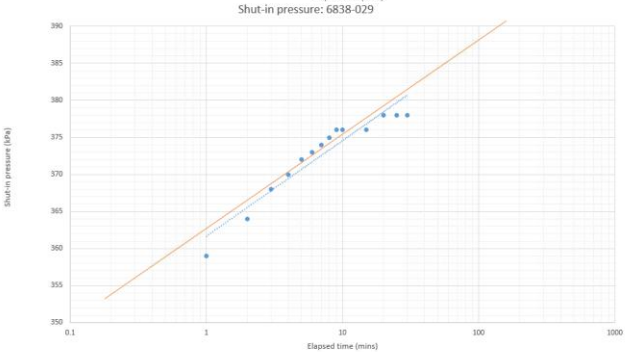

Shut-in pressure: 6140-039
Shut-in pressure (kPa)
128
126
124
122
120
118
116
114
0.1
1
10
100
1000
Elapsed time (mins)

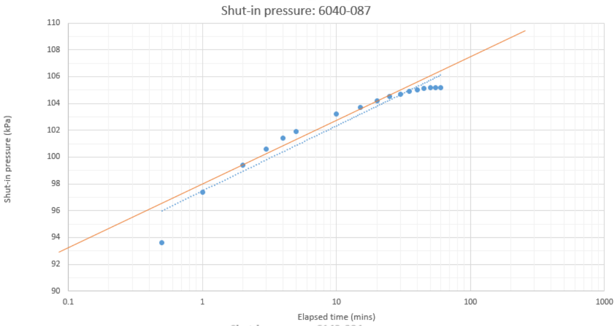

Shut-in pressure: 6141-047
Shut-in pressure (kPa)
240
220
200
180
160
140
120
0.1
1
10
100
1000
Elapsed time (mins)

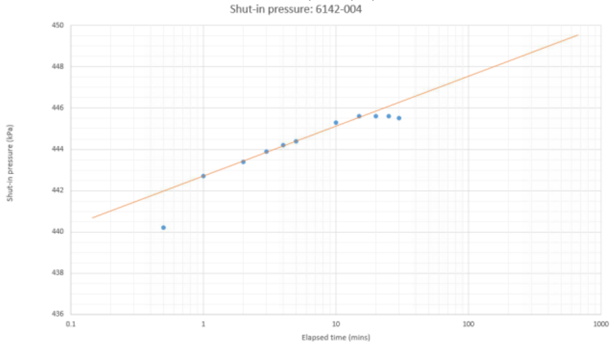

Shut-in pressure: 6239-041
Shut-in pressure (kPa)
277
276
275
274
273
272
0.1
1
10
100
1000
Elapsed time (mins)

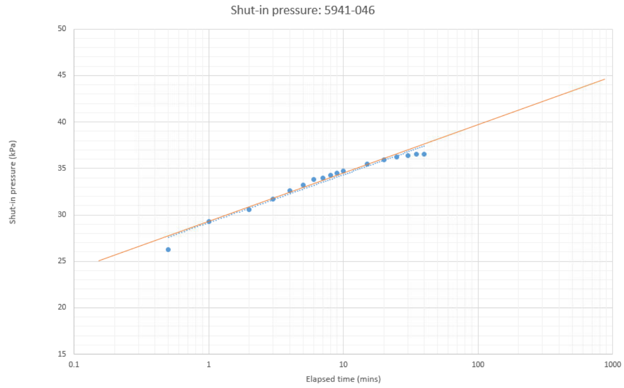

Shut-in pressure: 6738-002
Shut-in pressure (kPa)
Elapsed time (mins)

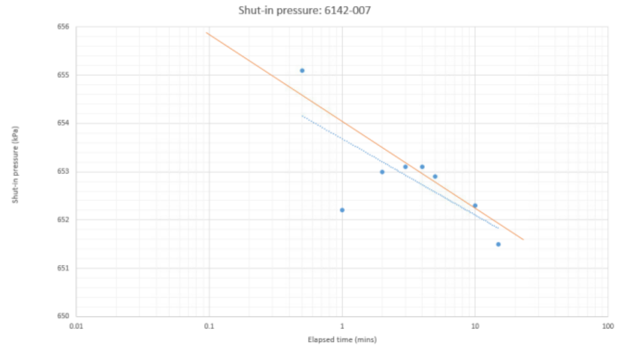

Shut-in pressure: 6738-189
Shut-in pressure (kPa)
Elapsed time (mins)

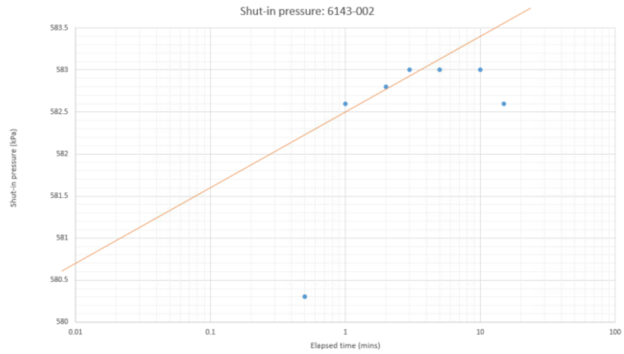

Shut-in pressure: 6838-029
Shut-in pressure (kPa)
Elapsed time (mins)

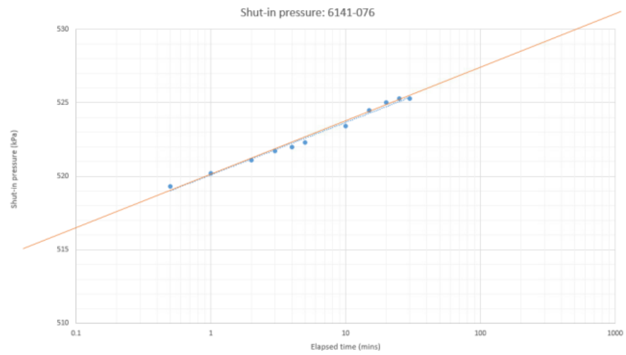

Shut-in pressure: 6040-087
Shut-in pressure (kPa)
Elapsed time (mins)

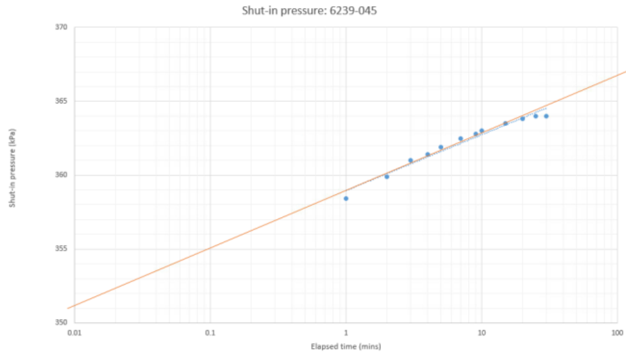

Shut-in pressure: 6142-004
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 5941-046
Shut-in pressure (kPa)
Elapsed time (mins)

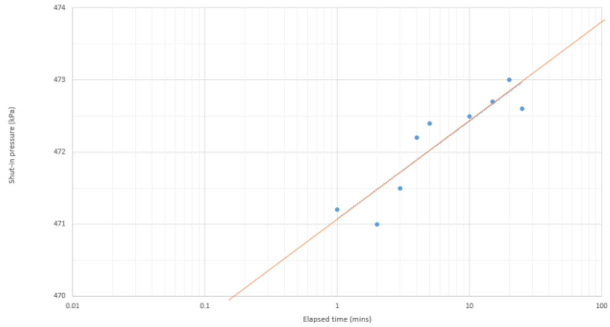

Shut-in pressure: 6142-007
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 6143-002
Shut-in pressure (kPa)
Elapsed time (mins)

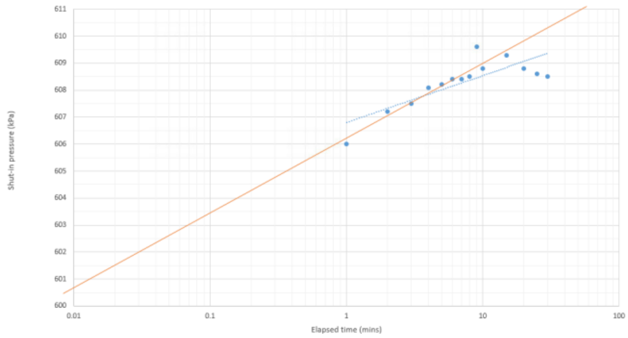

Shut-in pressure: 6141-076
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 6239-045
Shut-in pressure (kPa)
Elapsed time (mins)

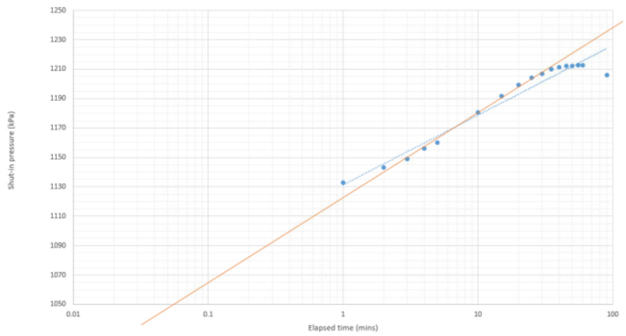
Shut-in pressure: 6240-004



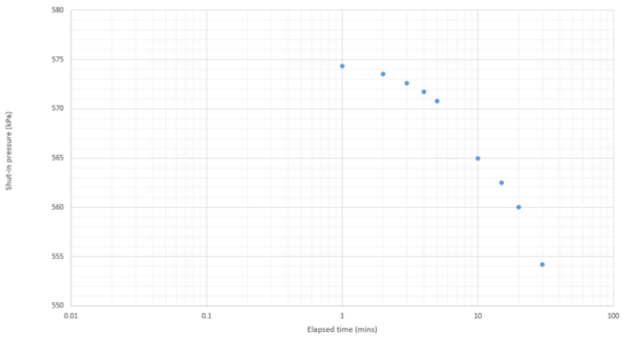
Shut-in pressure: 6239-040



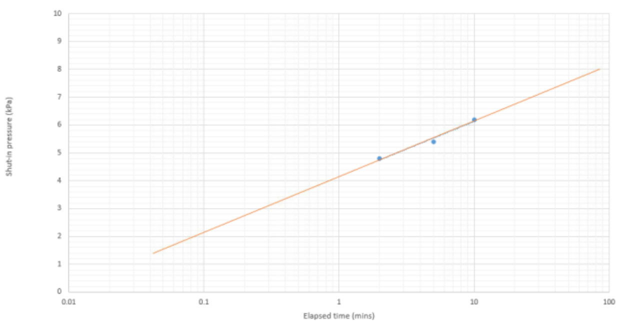
Shut-in pressure: 6445-004



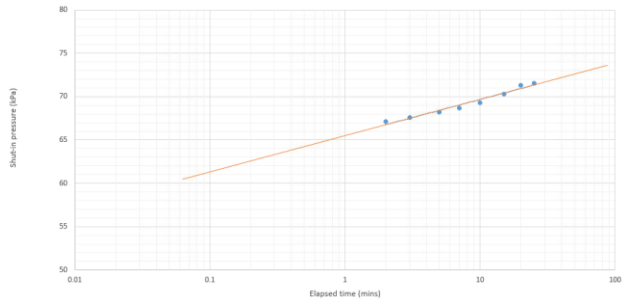
Shut-in pressure: 6640-023



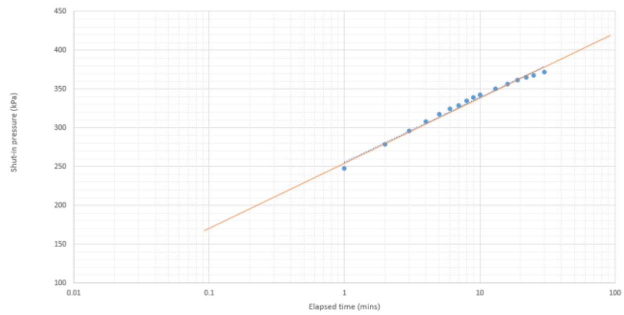
Shut-in pressure: 6438-080



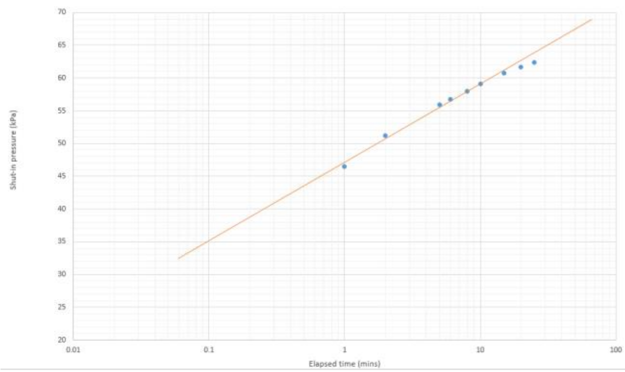
Shut-in pressure: 6438-092



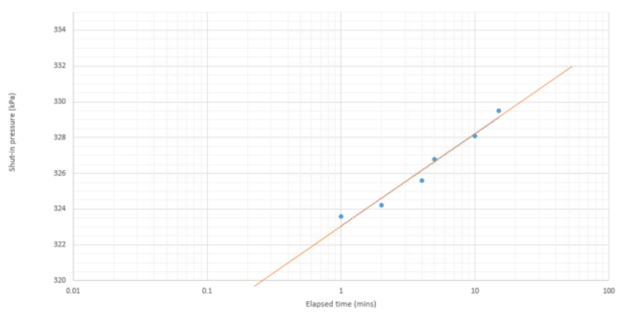
Shut-in pressure: 6438-004



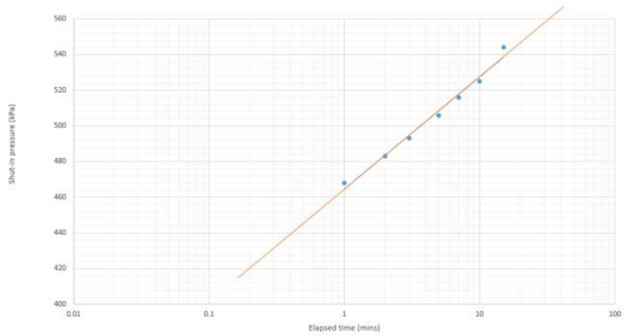
Shut-in pressure: 6438-079

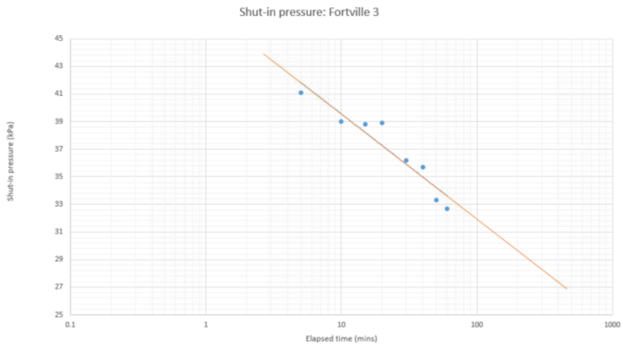


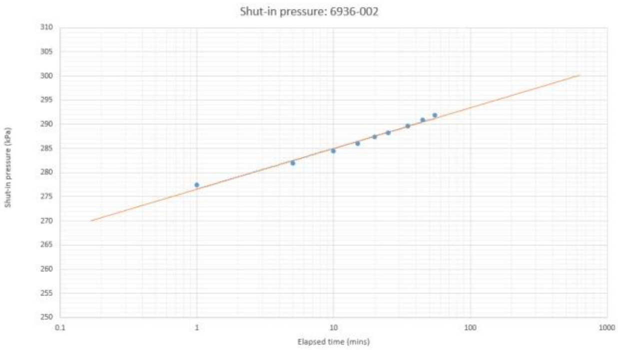
Shut-in pressure: 6438-097

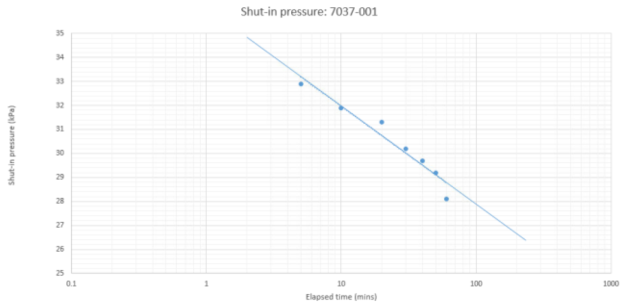


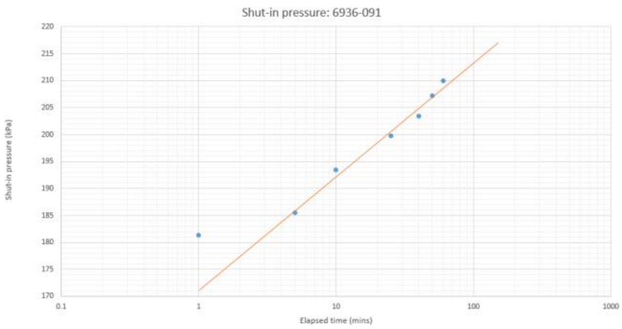
Shut-in pressure: 6439-018

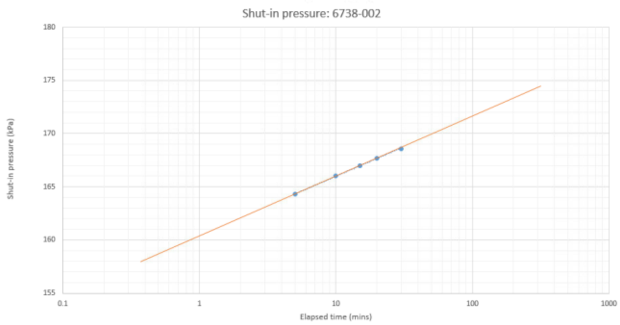


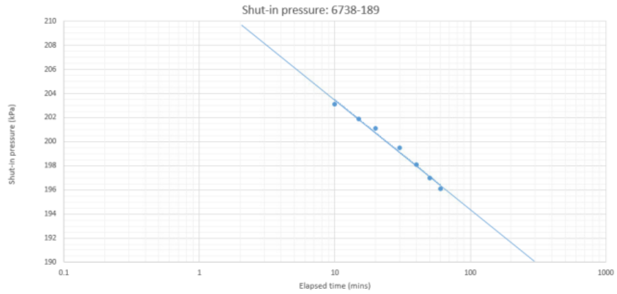

Shut-in pressure: Fortville 3
Shut-in pressure (kPa)
Elapsed time (mins)

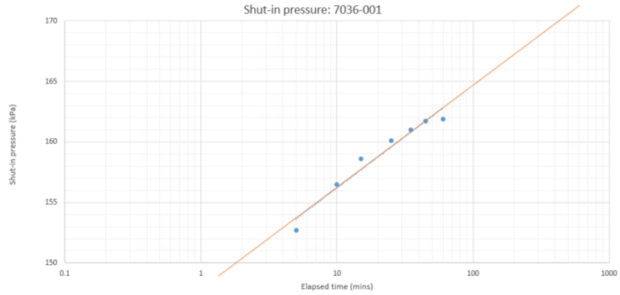

Shut-in pressure: 6936-002
Shut-in pressure (kPa)
Elapsed time (mins)

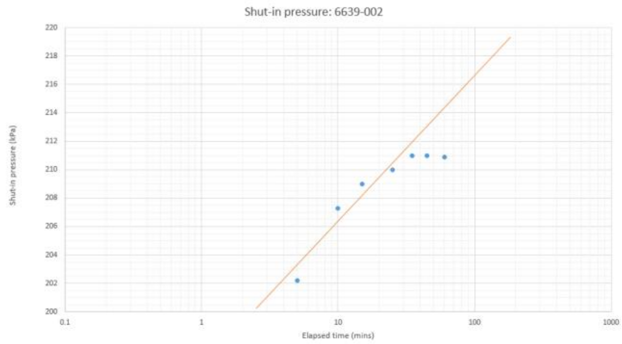

Shut-in pressure: 7037-001
Shut-in pressure (kPa)
Elapsed time (mins)

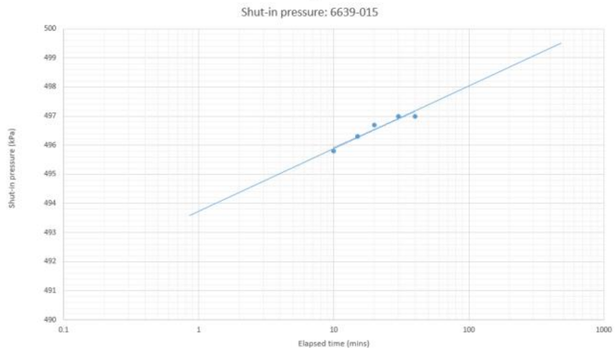

Shut-in pressure: 6936-091
Shut-in pressure (kPa)
Elapsed time (mins)

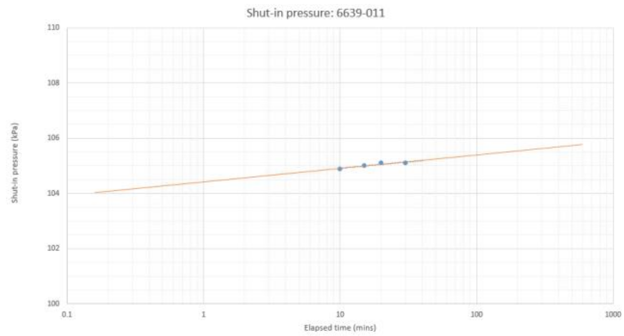

Shut-in pressure: 6738-002
Shut-in pressure (kPa)
Elapsed time (mins)

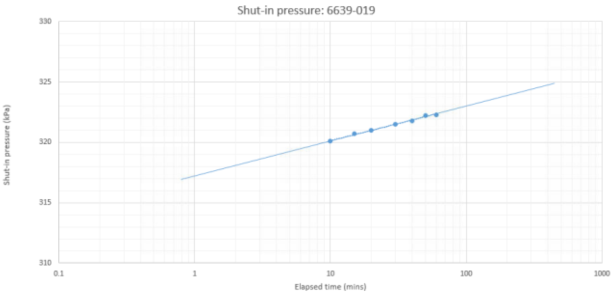
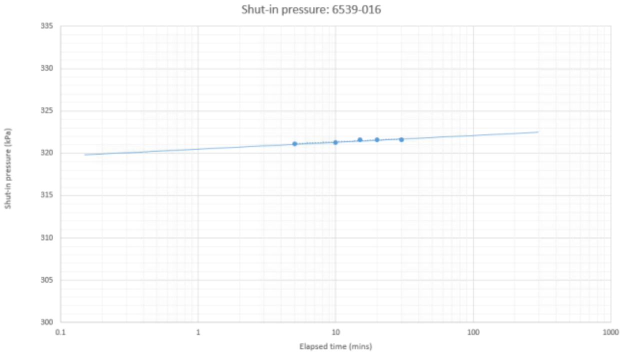
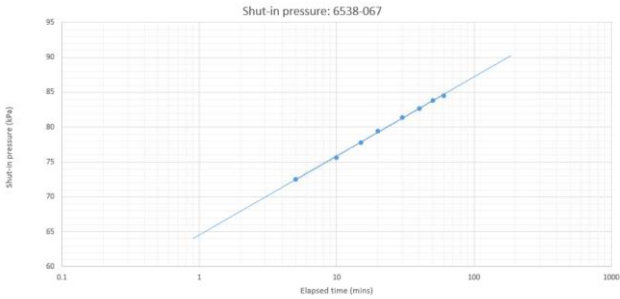
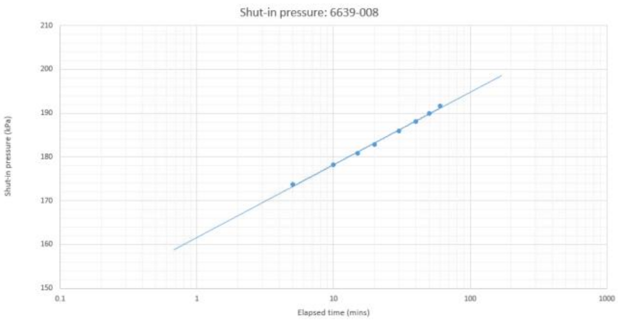
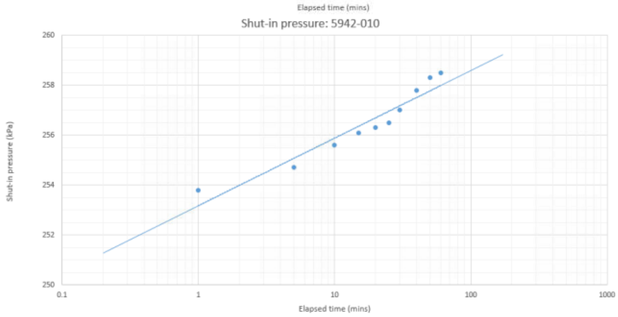
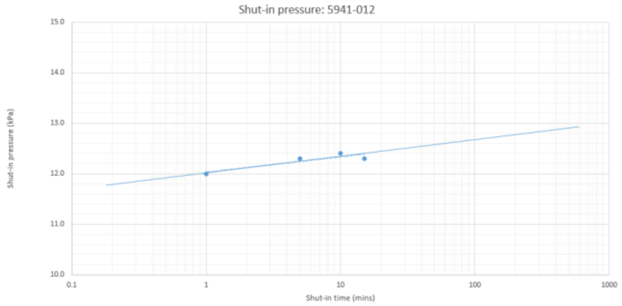
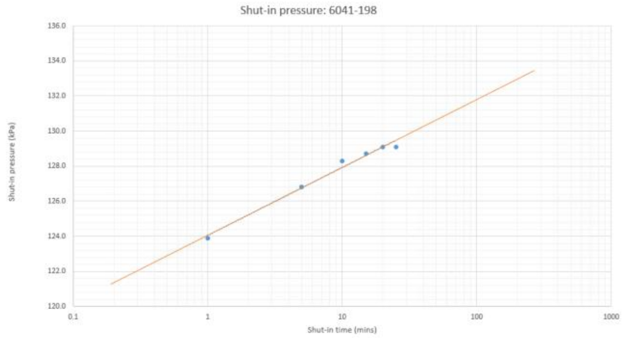
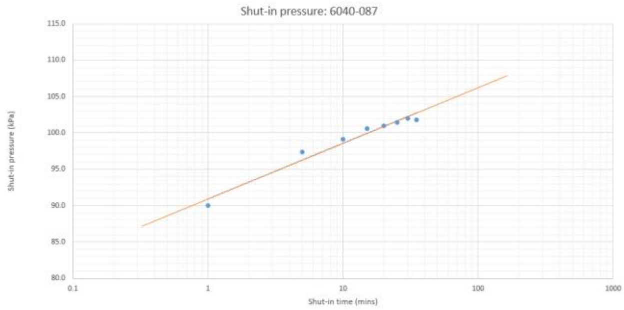
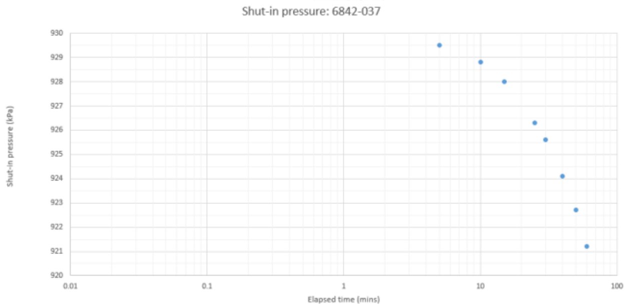
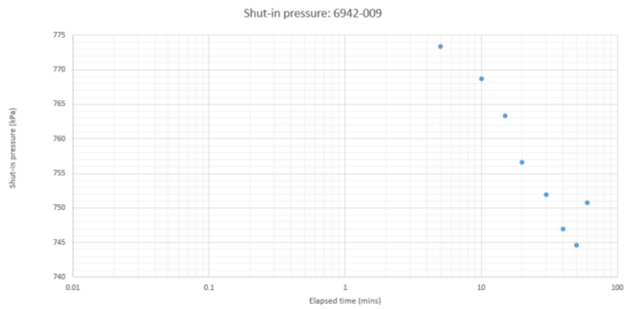
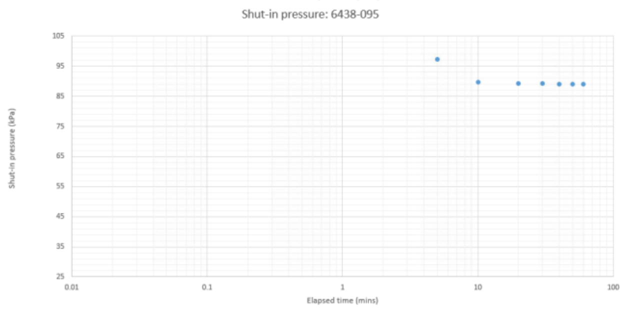

Shut-in pressure: 6738-189
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 7036-001
Shut-in pressure (kPa)
Elapsed time (mins)

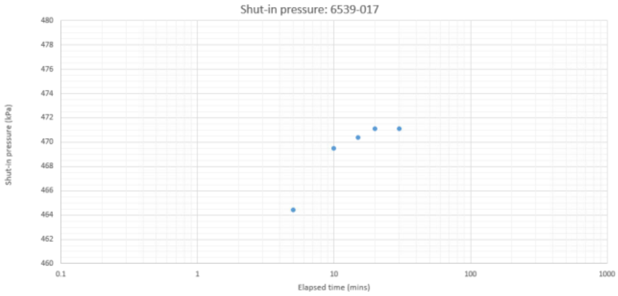

Shut-in pressure: 6639-002
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 6639-015
Shut-in pressure (kPa)
Elapsed time (mins)

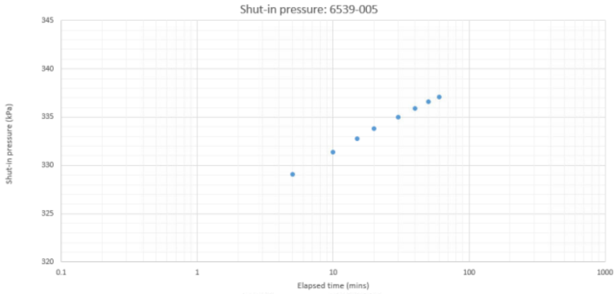

Shut-in pressure: 6639-011
Shut-in pressure (kPa)
Elapsed time (mins)


Shut-in pressure: 6639-019
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 6539-016
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 6538-067
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 6639-008
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 5942-010
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 5941-012
Shut-in pressure (kPa)
Shut-in time (mins)

Shut-in pressure: 6041-198
Shut-in pressure (kPa)
Shut-in time (mins)

Shut-in pressure: 6040-087
Shut-in pressure (kPa)
Shut-in time (mins)

Shut-in pressure: 6842-037
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 6942-009
Shut-in pressure (kPa)
Elapsed time (mins)

Shut-in pressure: 6438-095
Shut-in pressure (kPa)
Elapsed time (mins)

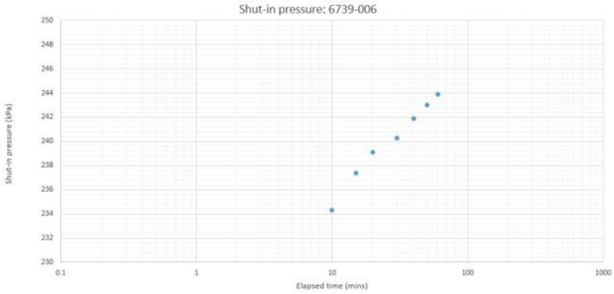
Shut-in pressure: 6539-017



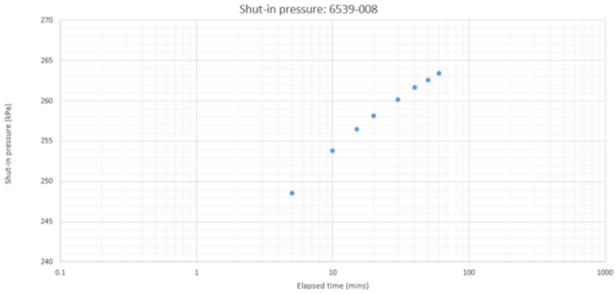
Shut-in pressure: 6539-005



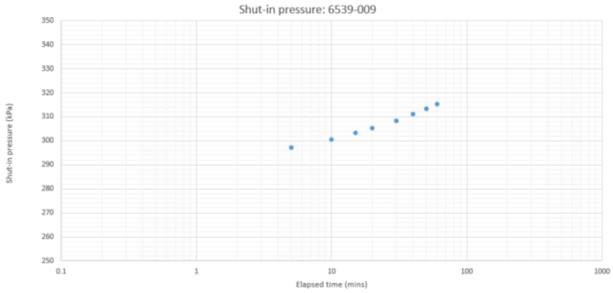
Shut-in pressure: 6739-006



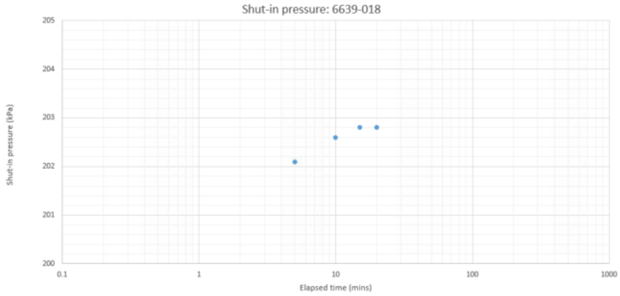
Shut-in pressure: 6539-008



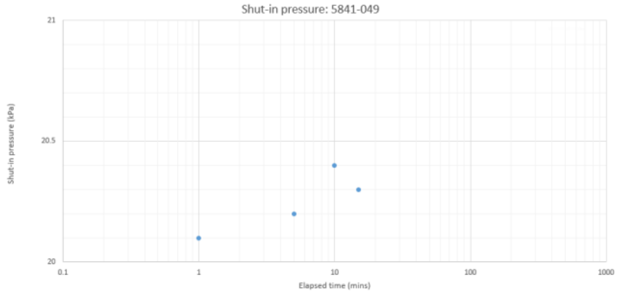
Shut-in pressure: 6539-009



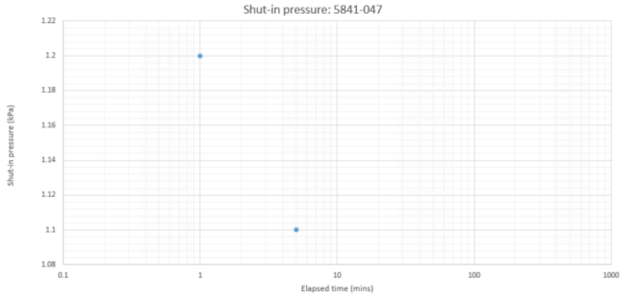
Shut-in pressure: 6639-018



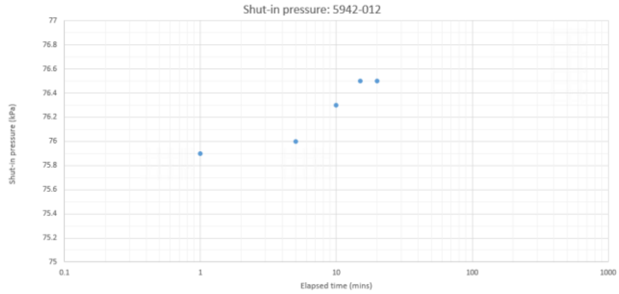
Shut-in pressure: 5841-049



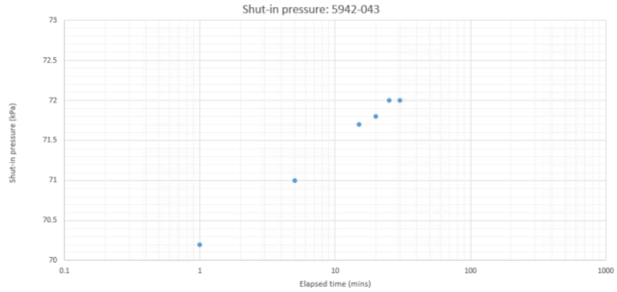
Shut-in pressure: 5841-047



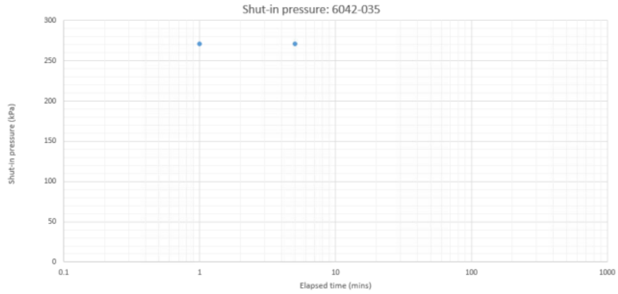
Shut-in pressure: 5942-012



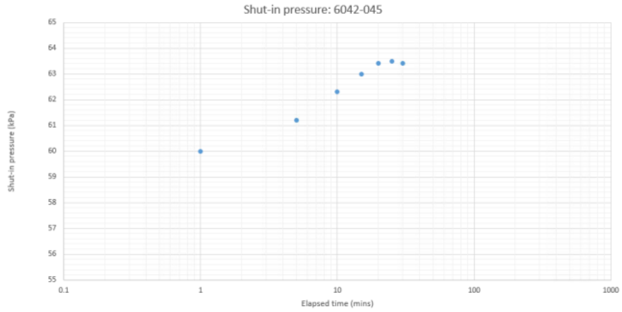
Shut-in pressure: 5942-043

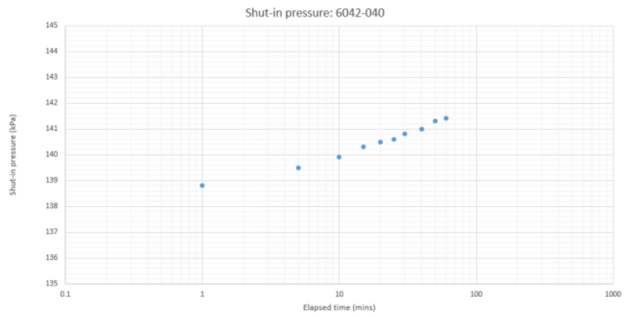


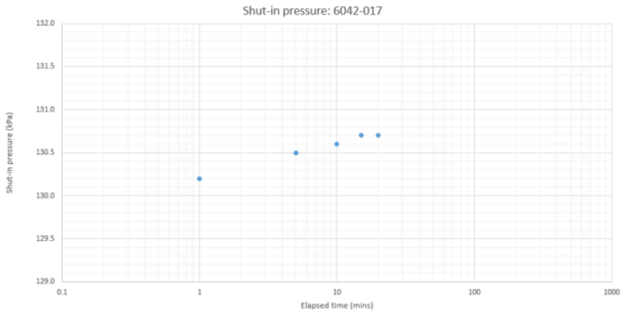
Shut-in pressure: 6042-035

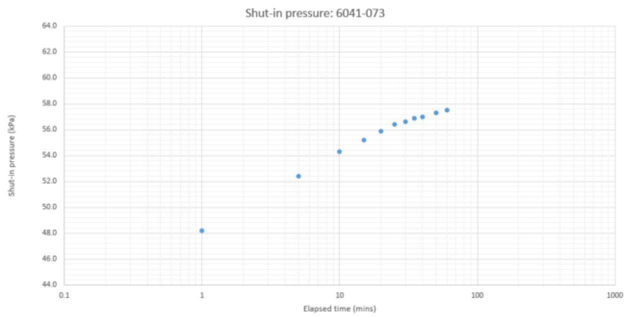


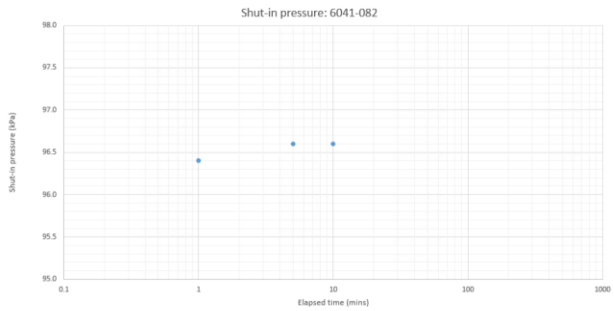
Shut-in pressure: 6042-045

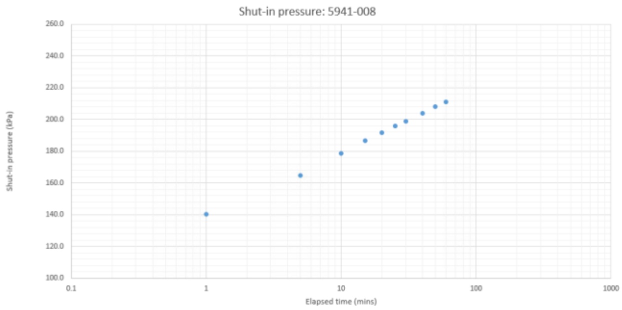


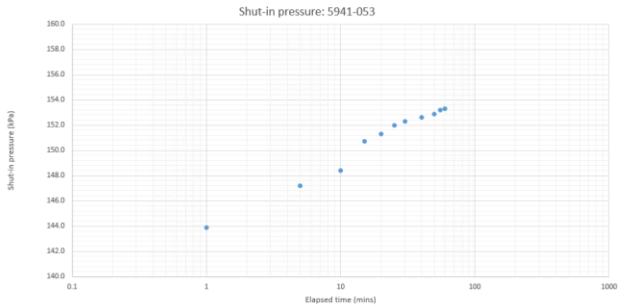

Shut-in pressure: 6042-040
Shut-in pressure (kPa)
Elapsed time (mins)

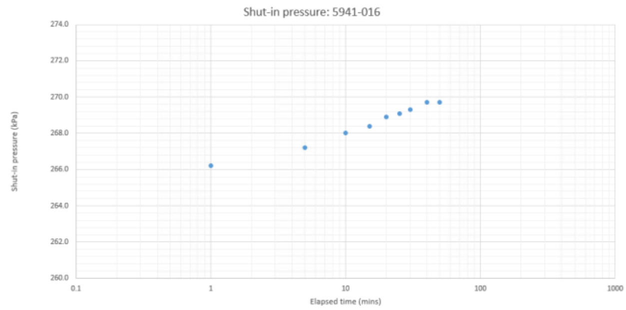

Shut-in pressure: 6042-017
Shut-in pressure (kPa)
Elapsed time (mins)

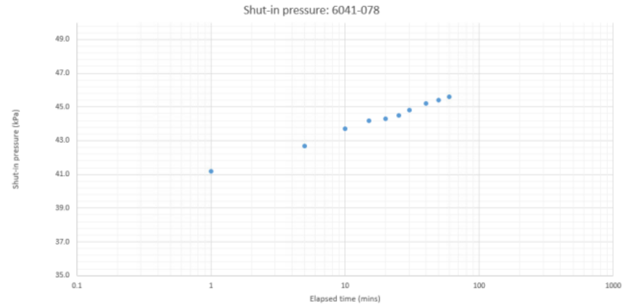

Shut-in pressure: 6041-073
Shut-in pressure (kPa)
Elapsed time (mins)

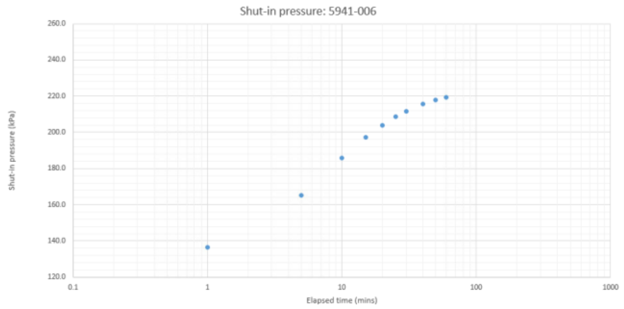

Shut-in pressure: 6041-082
Shut-in pressure (kPa)
Elapsed time (mins)

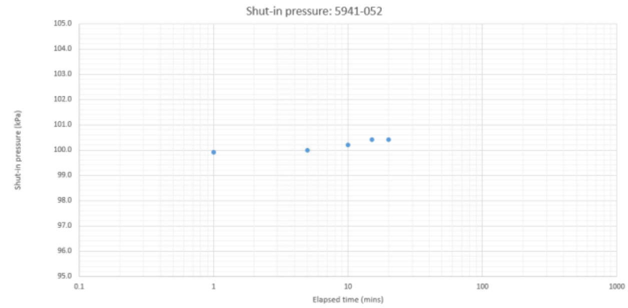

Shut-in pressure: 5941-008
Shut-in pressure (kPa)
Elapsed time (mins)

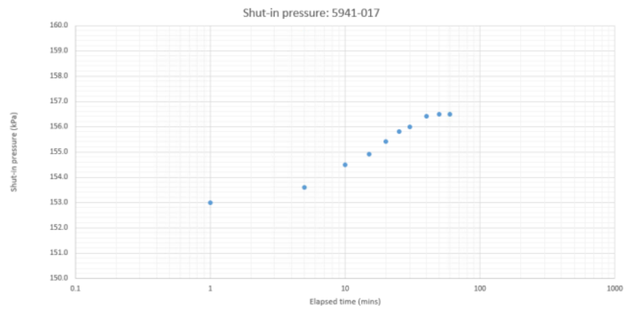

Shut-in pressure: 5941-053
Shut-in pressure (kPa)
Elapsed time (mins)

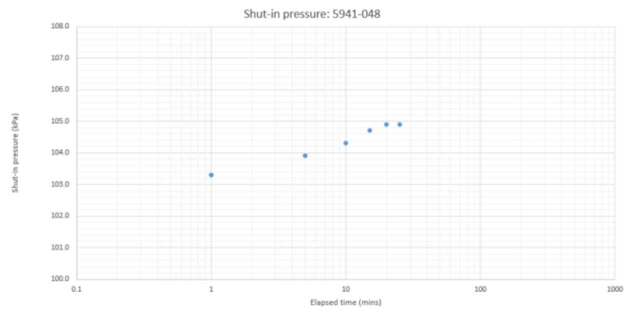

Shut-in pressure: 5941-016
Shut-in pressure (kPa)
Elapsed time (mins)

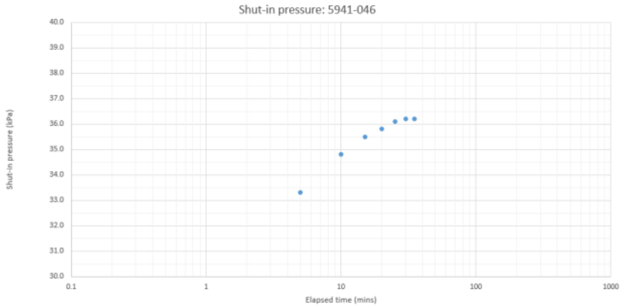

Shut-in pressure: 6041-078
Shut-in pressure (kPa)
Elapsed time (mins)

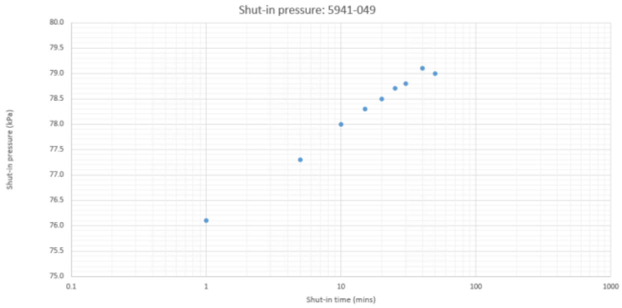

Shut-in pressure: 5941-006
Shut-in pressure (kPa)
Elapsed time (mins)

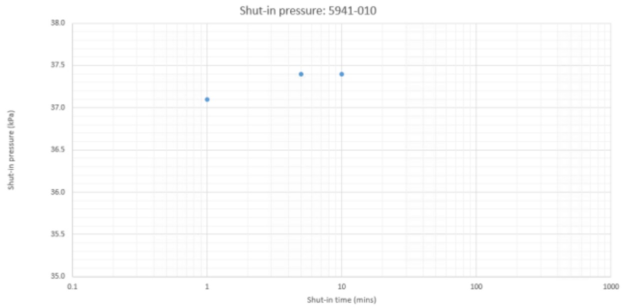

Shut-in pressure: 5941-052
Shut-in pressure (kPa)
Elapsed time (mins)

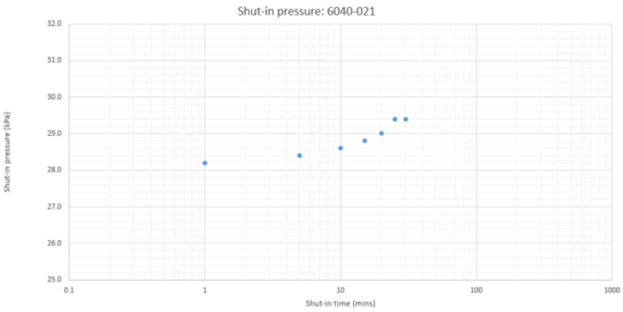

Shut-in pressure: 5941-017
Shut-in pressure (kPa)
Elapsed time (mins)

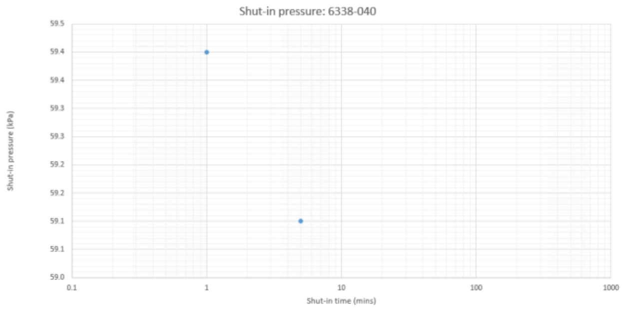

Shut-in pressure: 5941-048
Shut-in pressure (kPa)
Elapsed time (mins)

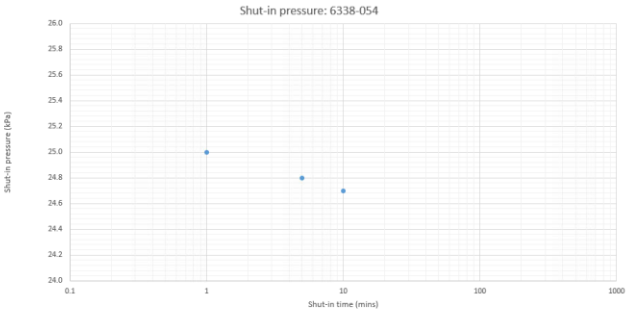

Shut-in pressure: 5941-046
Shut-in pressure (kPa)
Elapsed time (mins)

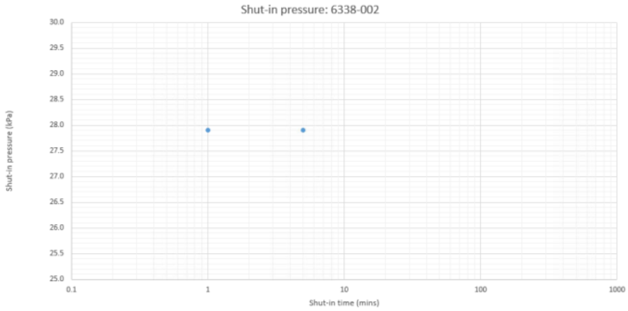

Shut-in pressure: 5941-049
Shut-in pressure (kPa)
Shut-in time (mins)

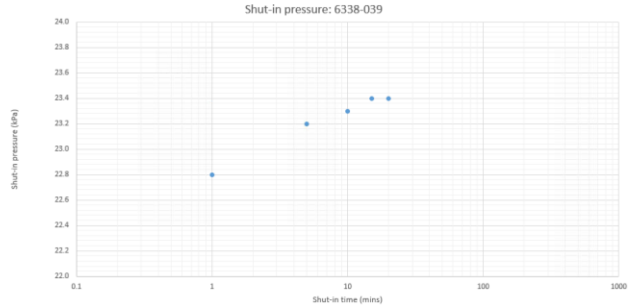

Shut-in pressure: 5941-010
Shut-in pressure (kPa)
Shut-in time (mins)

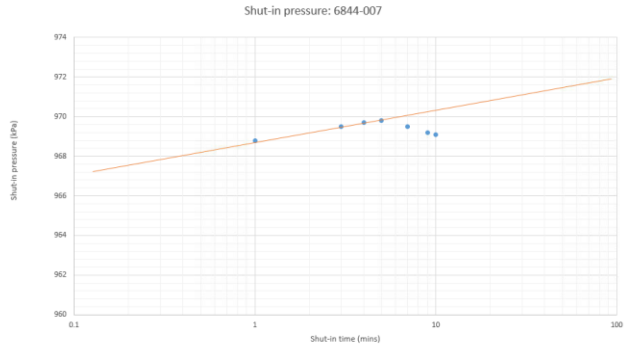

Shut-in pressure: 6040-021
Shut-in pressure (kPa)
Shut-in time (mins)

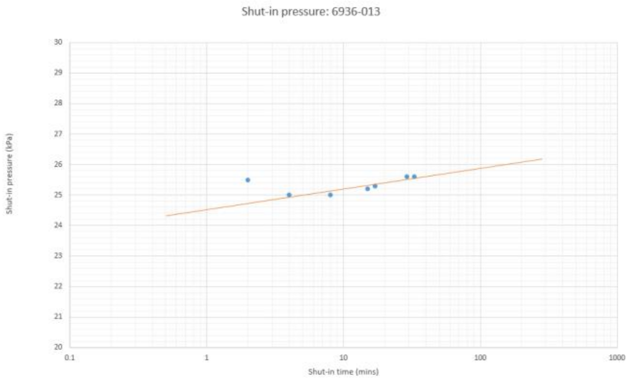

Shut-in pressure: 6338-040
Shut-in pressure (kPa)
Shut-in time (mins)

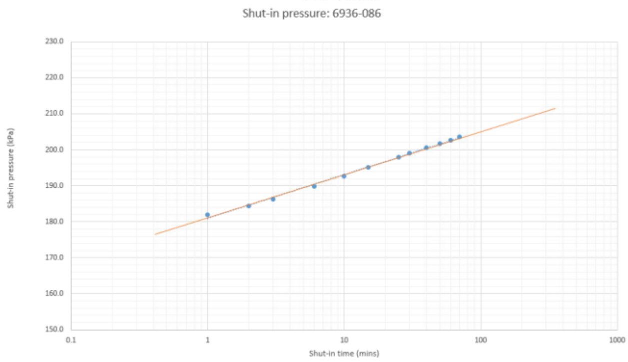

Shut-in pressure: 6338-054
Shut-in pressure (kPa)
Shut-in time (mins)

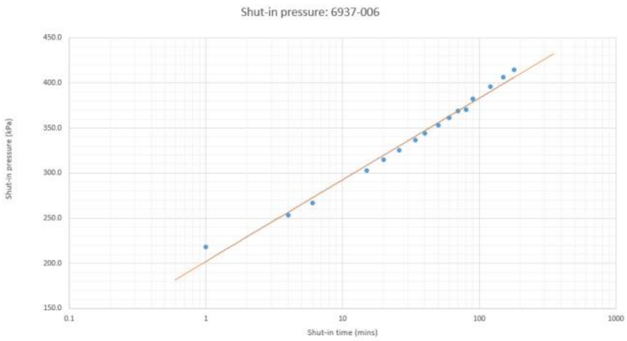

Shut-in pressure: 6338-002
Shut-in pressure (kPa)
Shut-in time (mins)

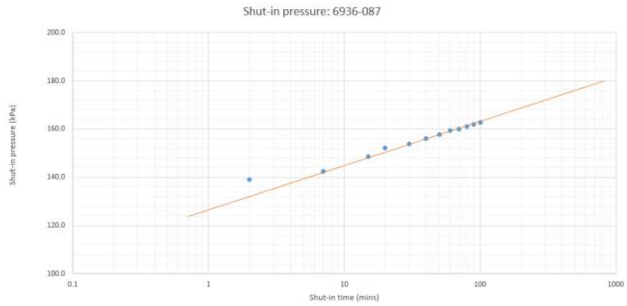

Shut-in pressure: 6338-039
Shut-in pressure (kPa)
Shut-in time (mins)

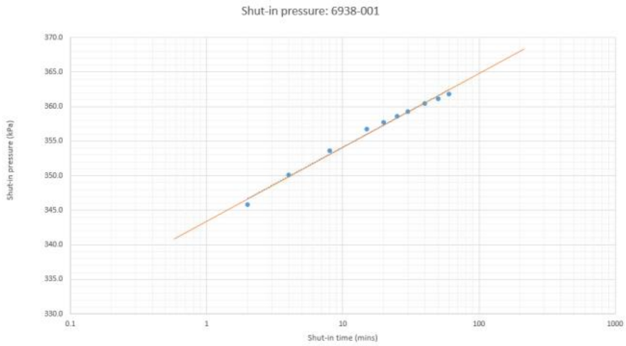

Shut-in pressure: 6844-007
Shut-in pressure (kPa)
Shut-in time (mins)

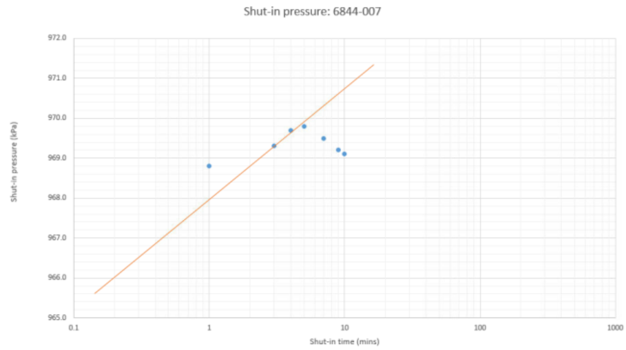

Shut-in pressure: 6936-013
Shut-in pressure (kPa)
Shut-in time (mins)

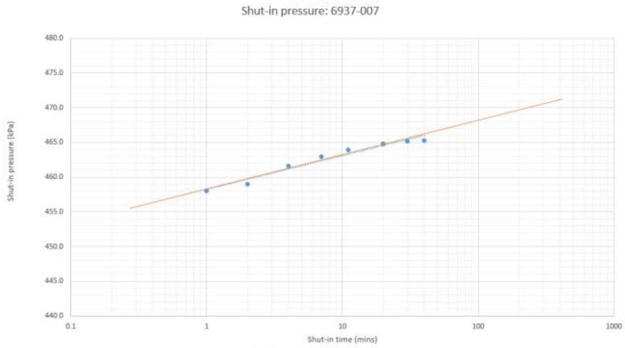

Shut-in pressure: 6936-086
Shut-in pressure (kPa)
Shut-in time (mins)

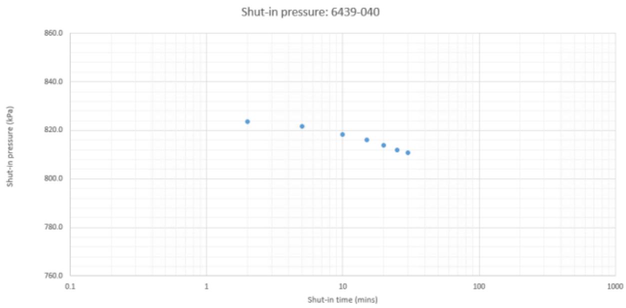

Shut-in pressure: 6937-006
Shut-in pressure (kPa)
Shut-in time (mins)

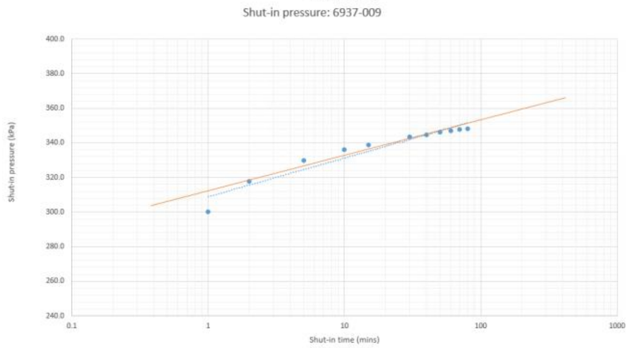

Shut-in pressure: 6936-087
Shut-in pressure (kPa)
Shut-in time (mins)

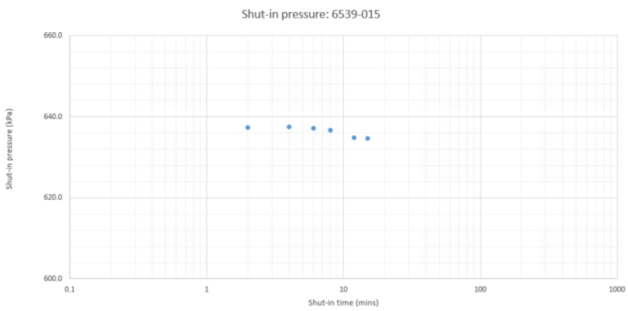

Shut-in pressure: 6938-001
Shut-in pressure (kPa)
Shut-in time (mins)

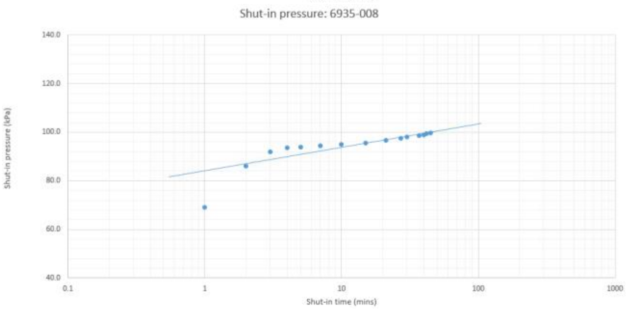

Shut-in pressure: 6844-007
Shut-in pressure (kPa)
Shut-in time (mins)

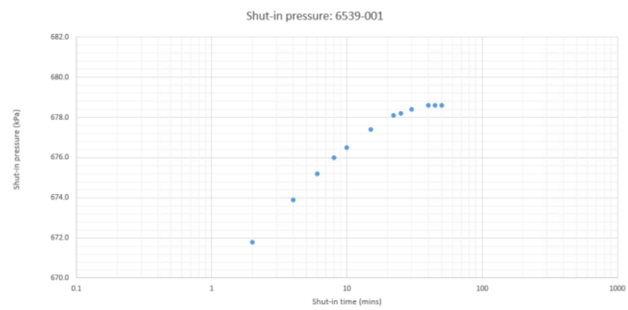

Shut-in pressure: 6937-007
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6439-040
Shut-in pressure (kPa)
Shut-in time (mins)

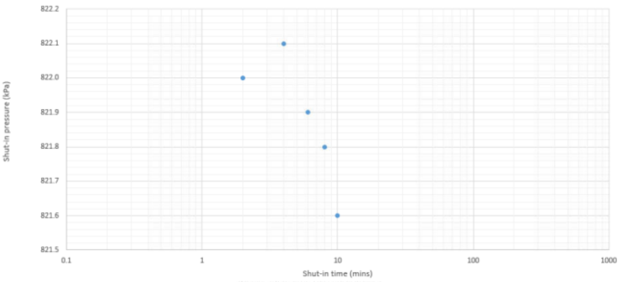

Shut-in pressure: 6937-009
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6539-015
Shut-in pressure (kPa)
Shut-in time (mins)

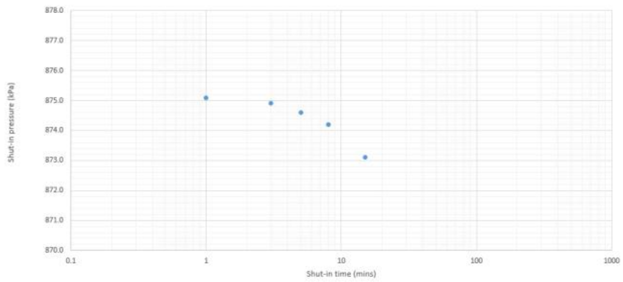

Shut-in pressure: 6935-008
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6539-001
Shut-in pressure (kPa)
Shut-in time (mins)

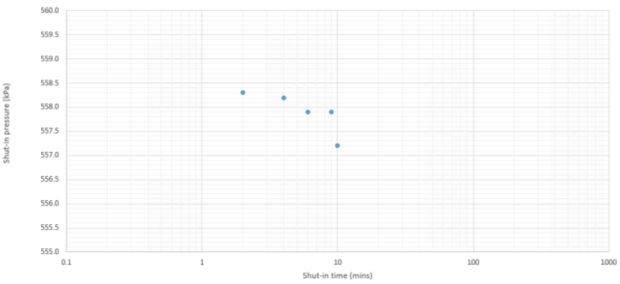
Shut-in pressure: 6640-004



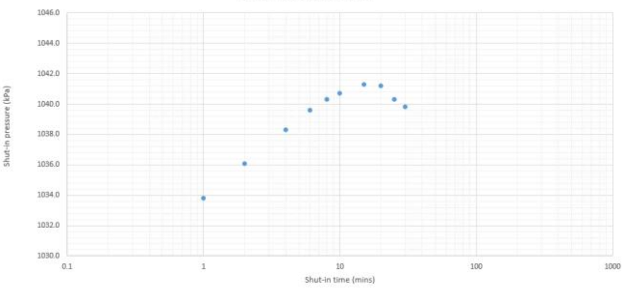
Shut-in pressure: 6640-001



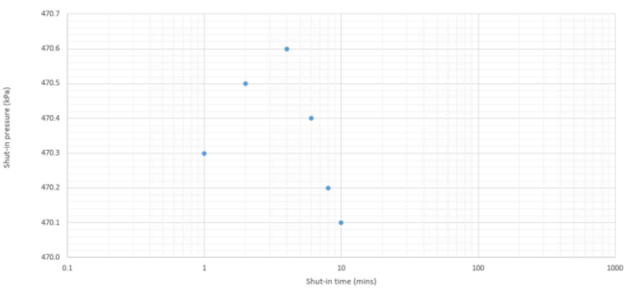
Shut-in pressure: 6641-003



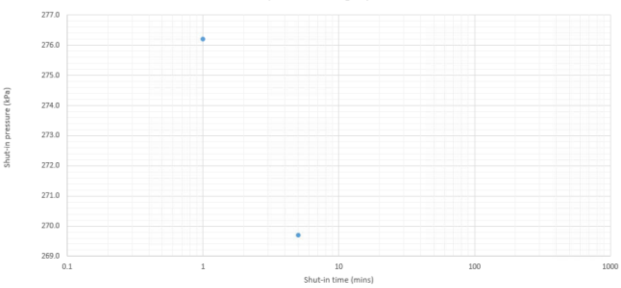
Shut-in pressure: 6643-11



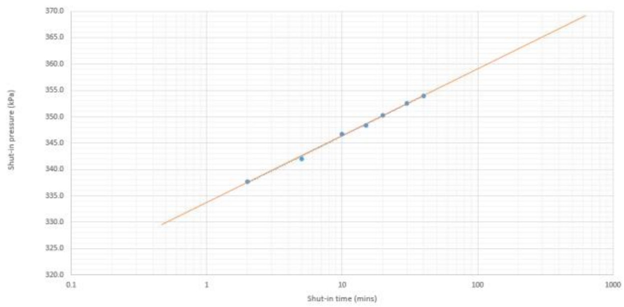
Shut-in pressure: 6739-017



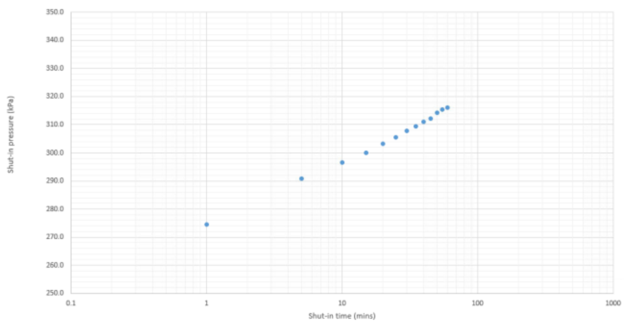
Shut-in pressure: Strangways 2



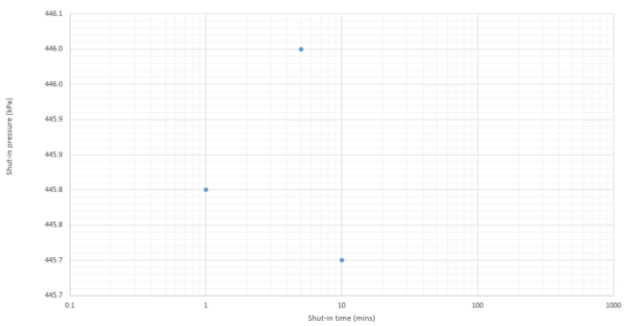
Shut-in pressure: 6937-09



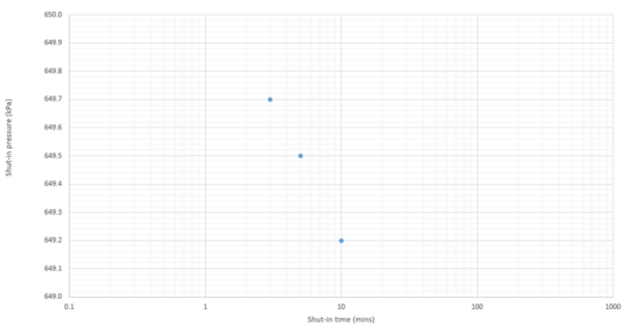
Shut-in pressure: 6239-042



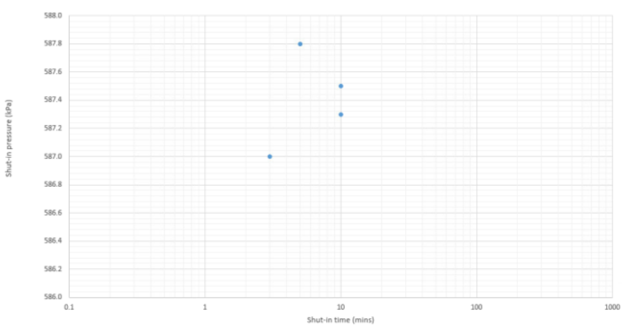
Shut-in pressure: 6142-004



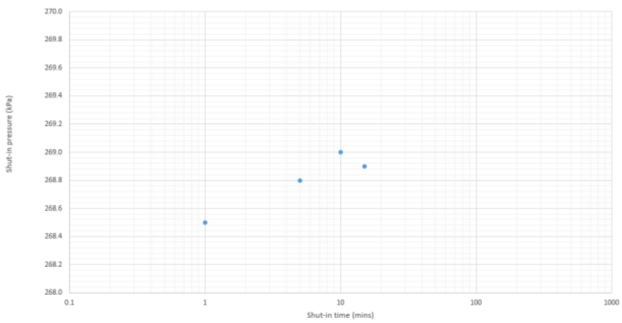
Shut-in pressure: 6142-007



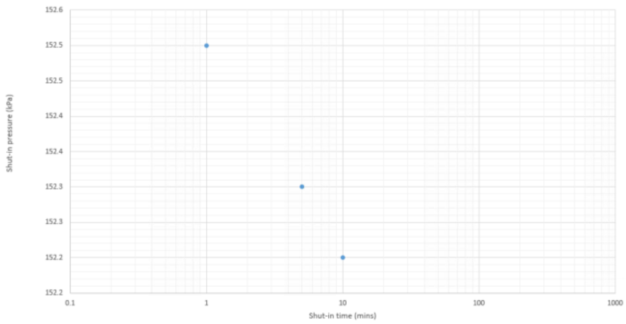
Shut-in pressure: 6173-002



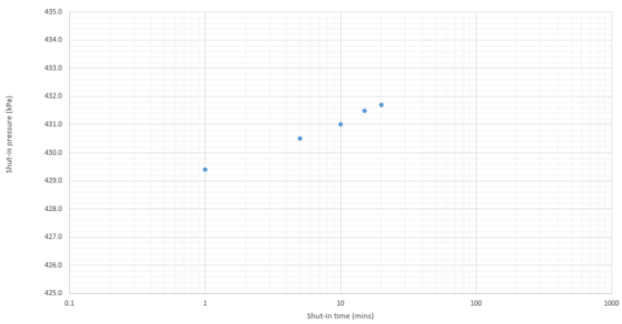
Shut-in pressure: 6044-010



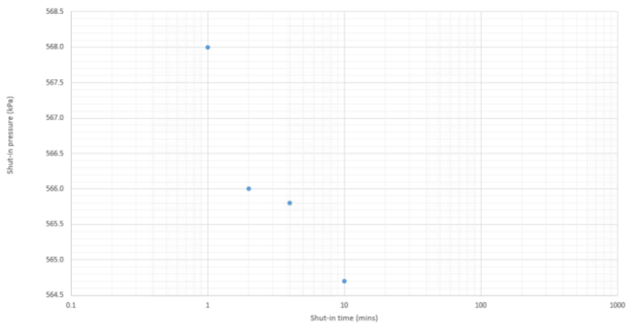
Shut-in pressure: 3 O'Clock



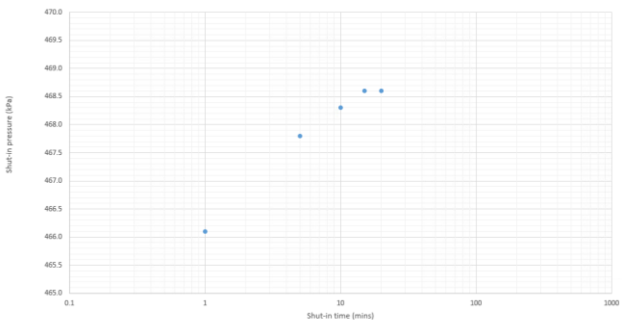
Shut-in pressure: 6044-004



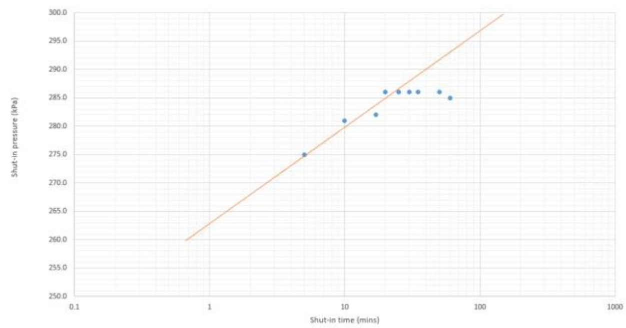
Shut-in pressure: 6145-001



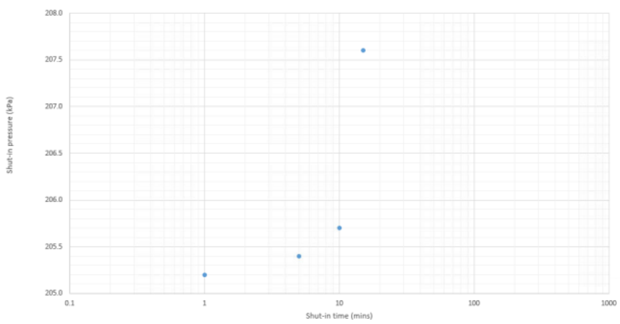
Shut-in pressure: 6044-009



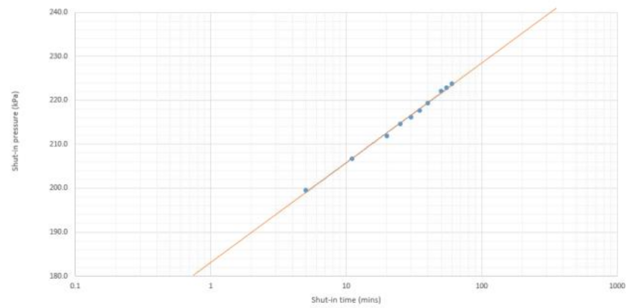
Shut-in pressure: 7037-003



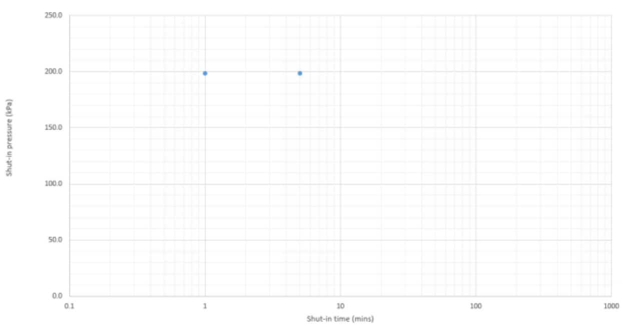
Shut-in pressure: 5943-021



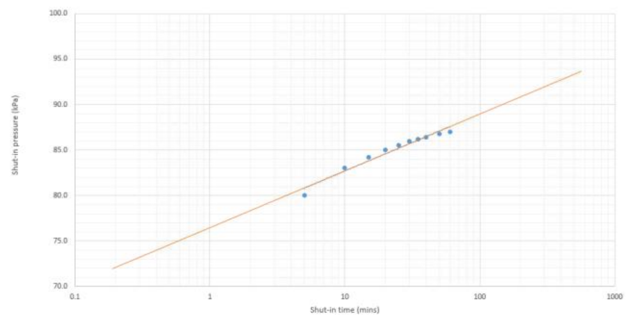
Shut-in pressure: 6838-006

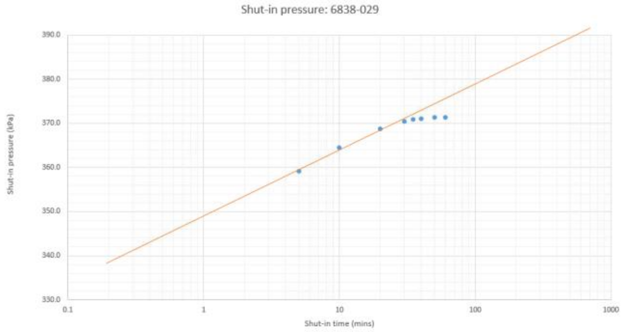


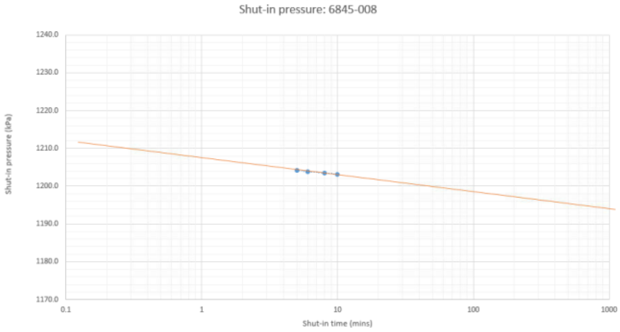
Shut-in pressure: 6044-002

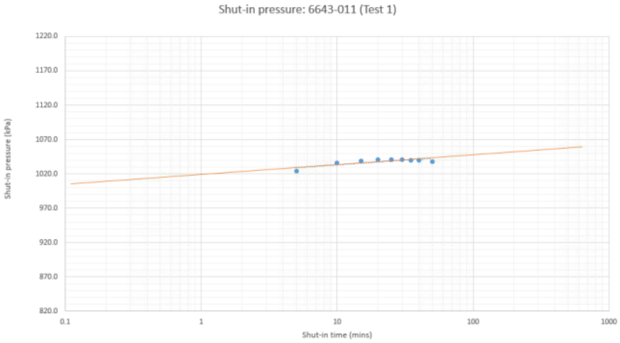


Shut-in pressure: 6738-002 (Test 1)




Shut-in pressure: 6838-029
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6845-008
Shut-in pressure (kPa)
Shut-in time (mins)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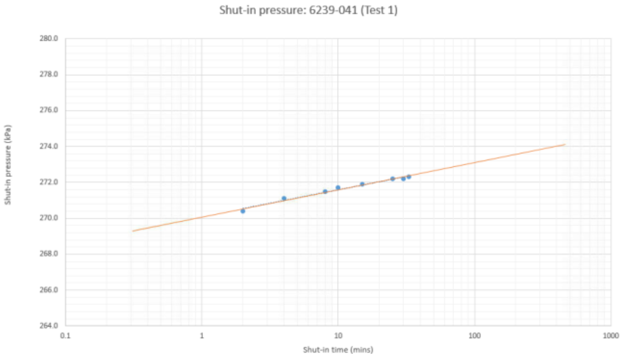
Shut-in pressure (kPa)
Shut-in time (mins)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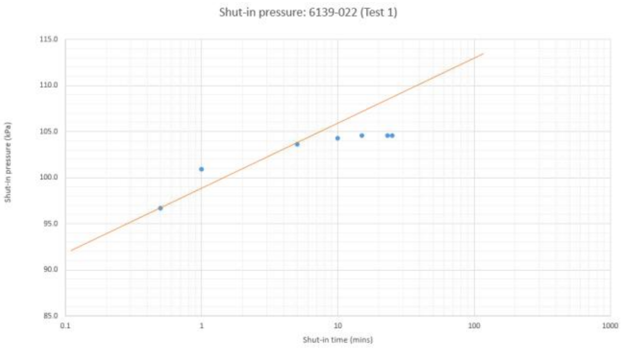
Shut-in pressure (kPa)
Shut-in time (mins)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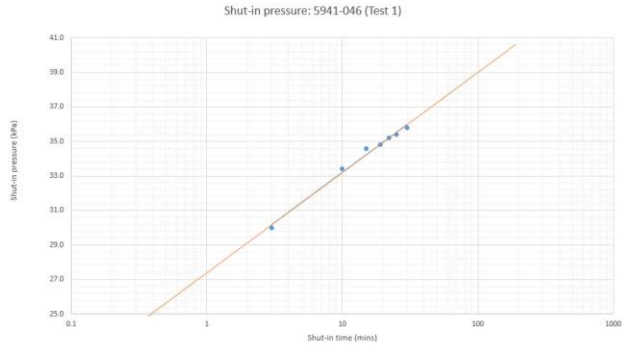
Shut-in pressure (kPa)
Shut-in time (mins)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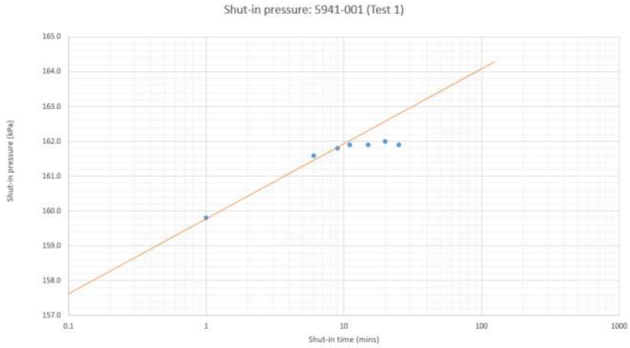
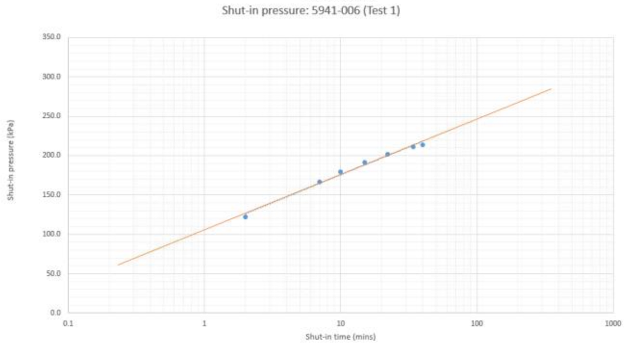
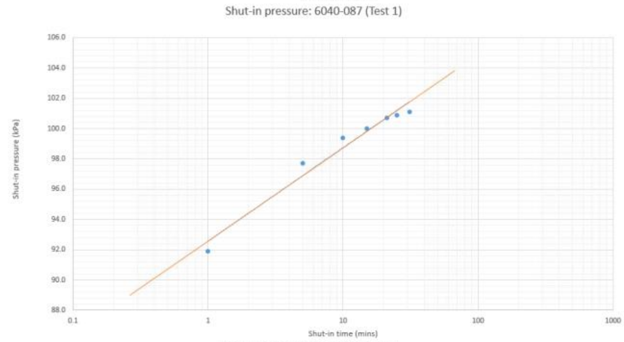
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 5941-001 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 5941-006 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)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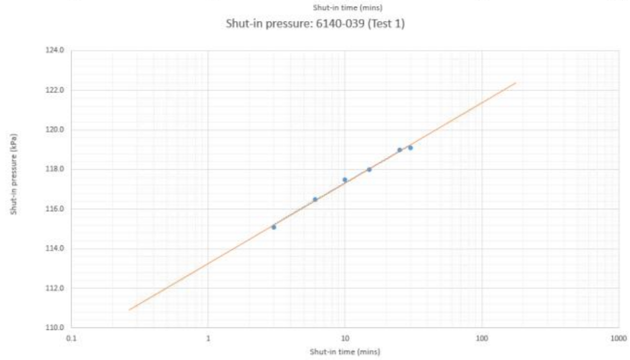
Shut-in pressure (kPa)
Shut-in time (mins)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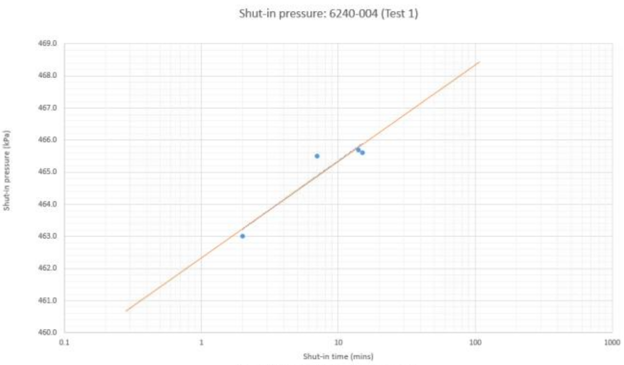
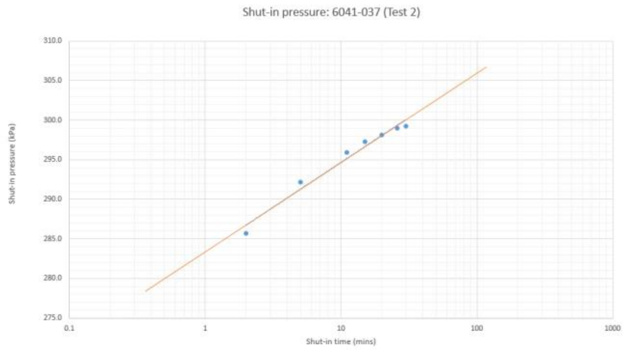
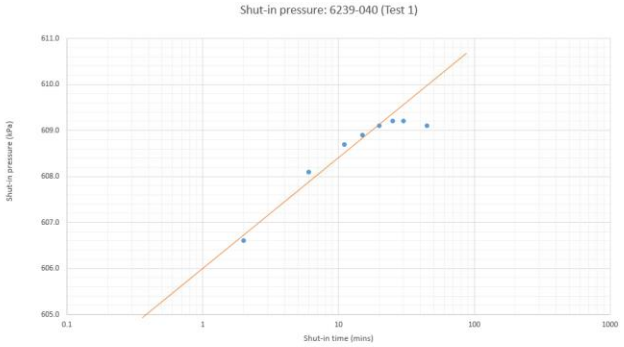
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6240-004 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6041-037 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)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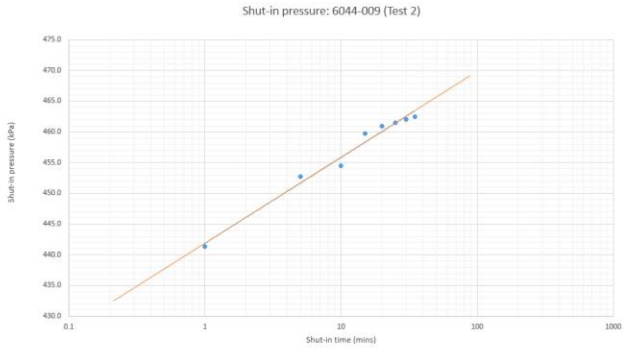
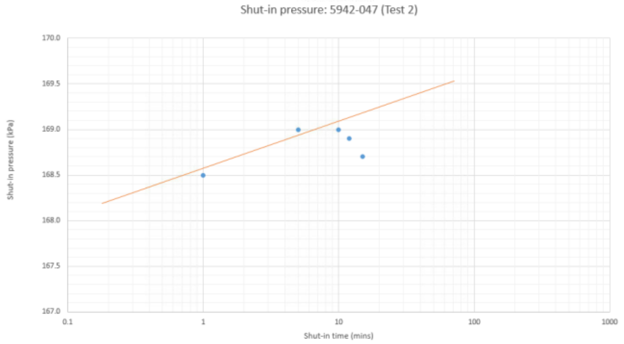
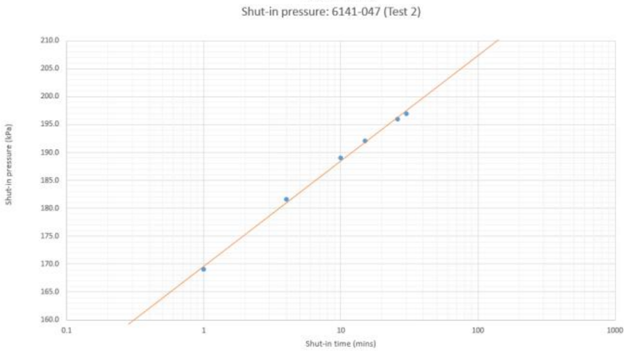
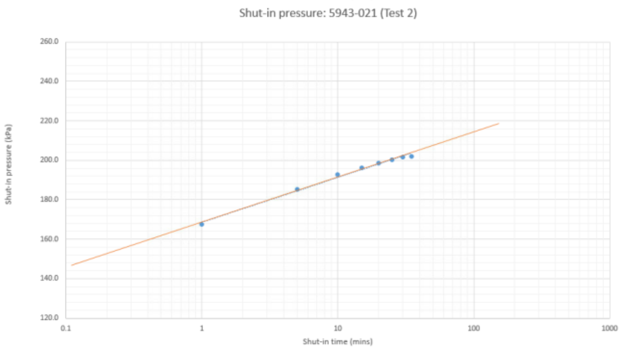
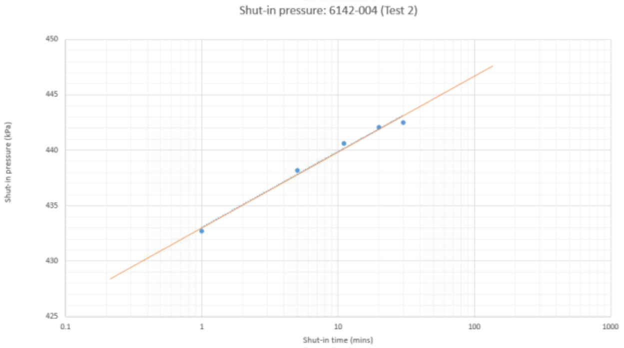
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6044-009 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 5942-047 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6141-047 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 5943-021 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6142-004 (Test 2)
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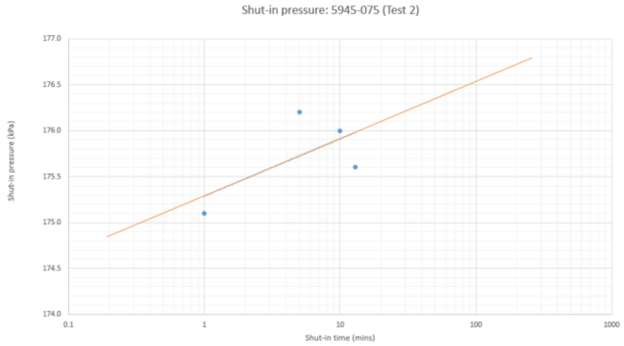
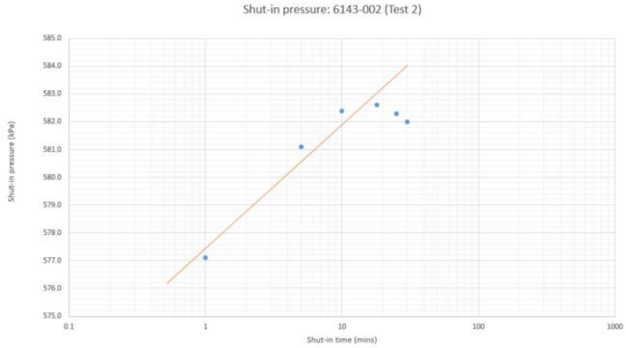
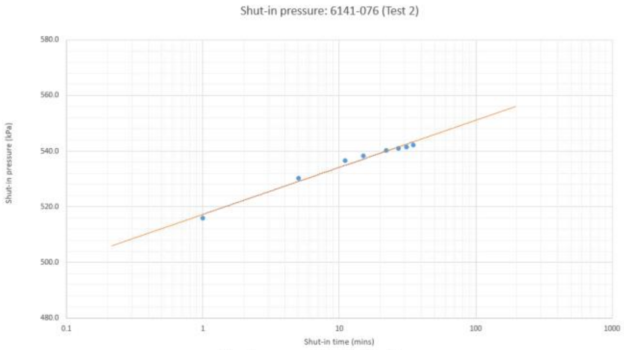
Shut-in time (mins)


Shut-in pressure: 5945-075 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6143-002 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)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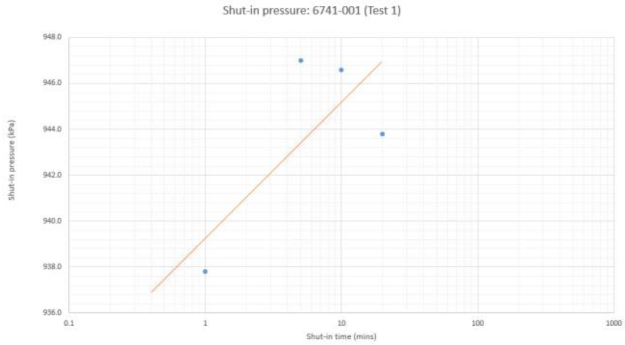
Shut-in pressure (kPa)
Shut-in time (mins)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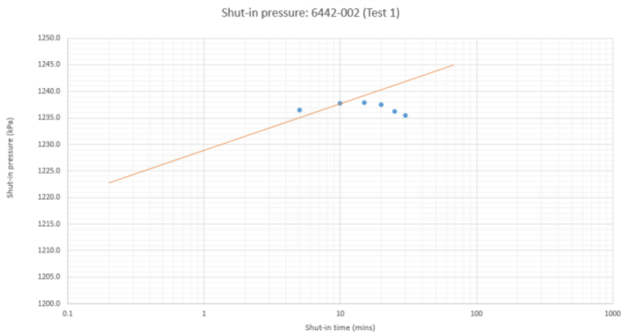
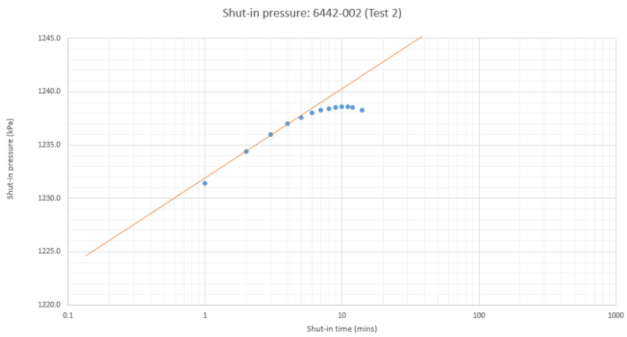
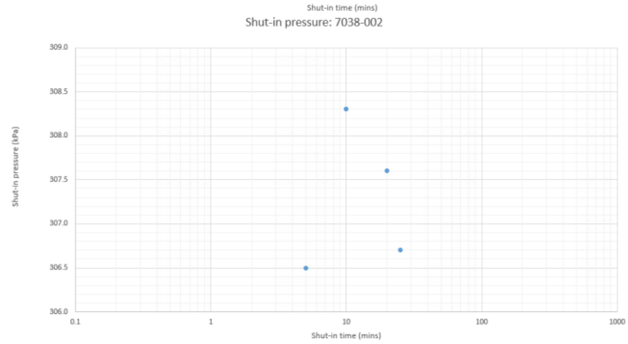
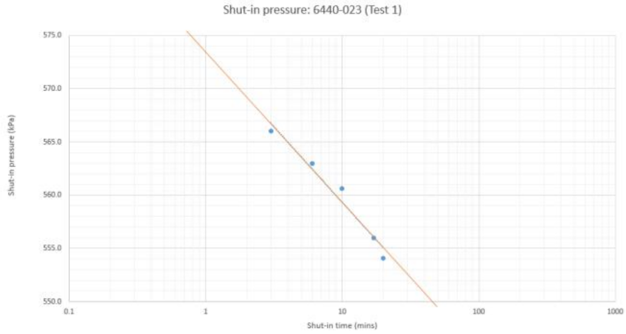
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6442-002 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6442-002 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 7038-002
Shut-in pressure (kPa)
Shut-in time (mins)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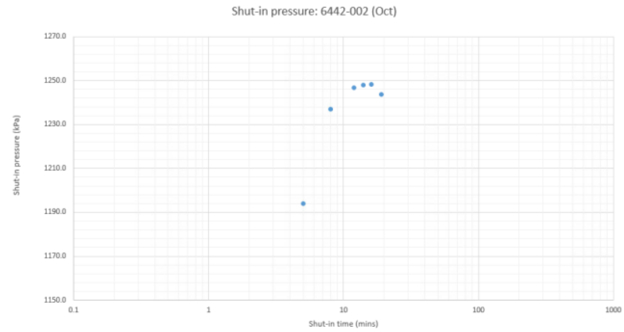
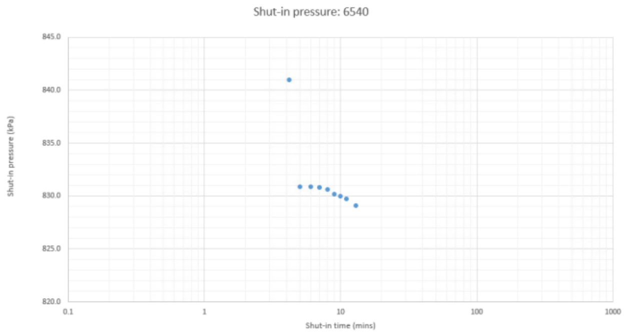
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6442-002 (Oct)
Shut-in pressure (kPa)
Shut-in time (mins)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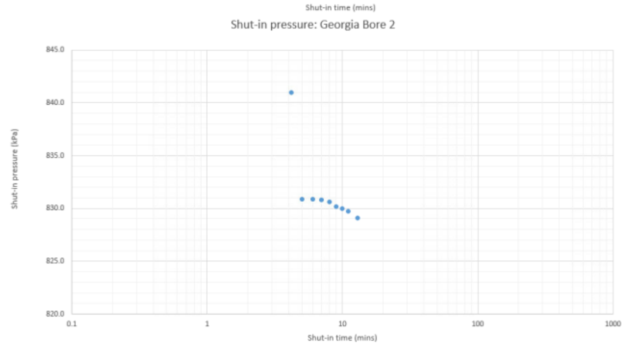
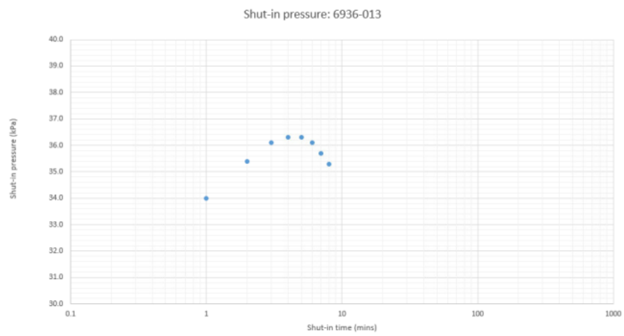
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: Georgia Bore 2
Shut-in pressure (kPa)
Shut-in time (mins)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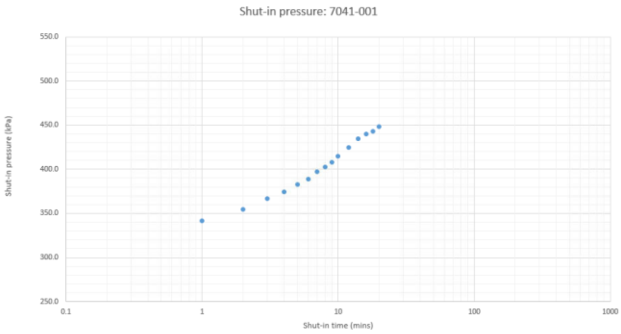
Shut-in pressure (kPa)
Shut-in time (mins)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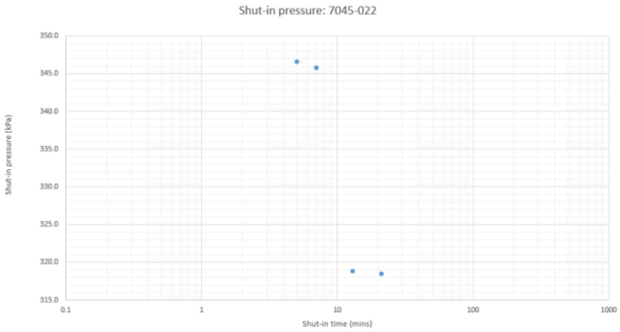
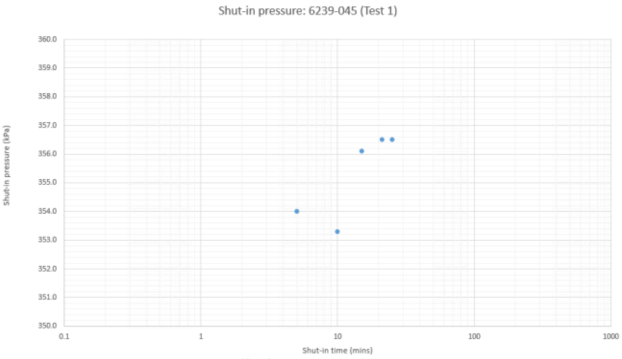
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 7045-022
Shut-in pressure (kPa)
Shut-in time (mins)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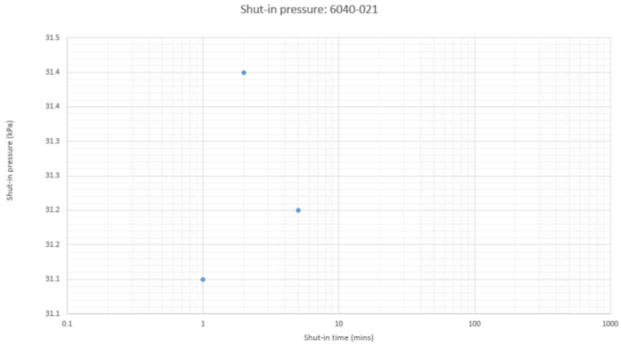
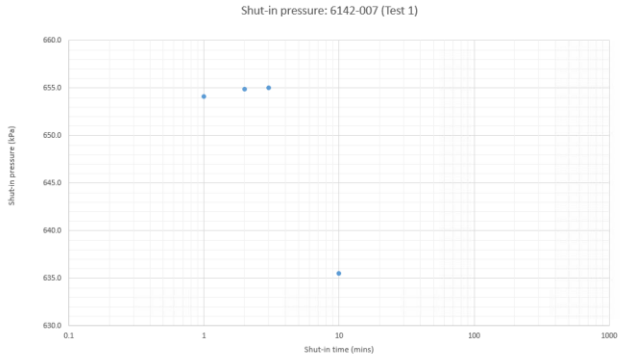
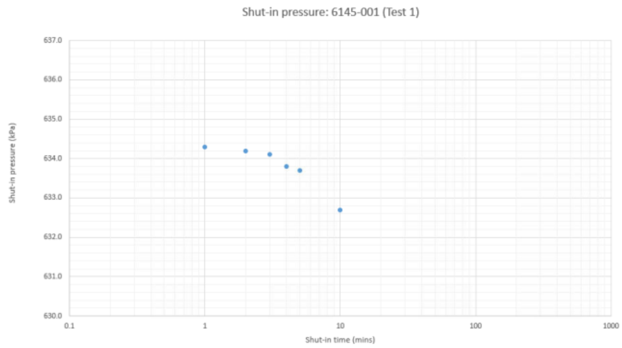
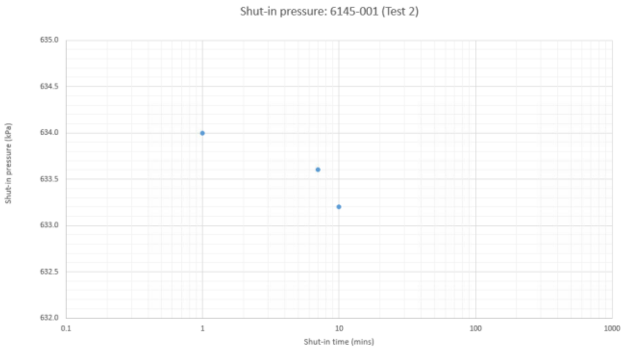
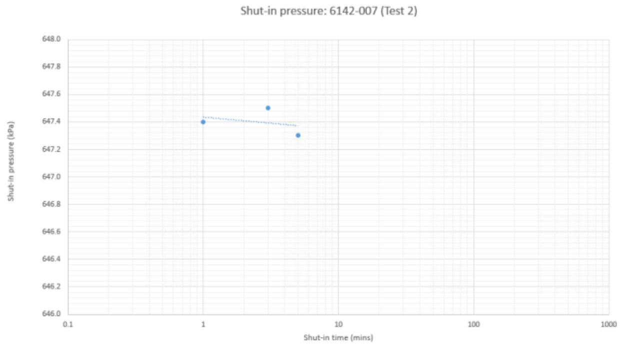
Shut-in pressure (kPa)
Shut-in time (mins)

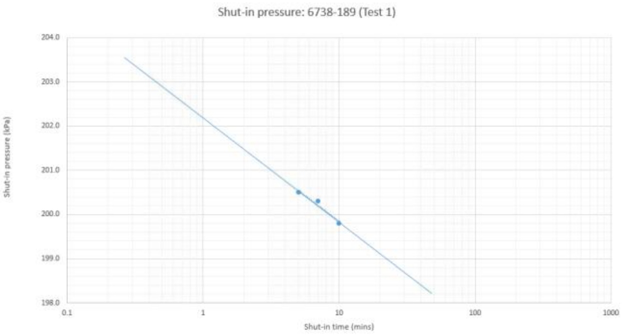

Shut-in pressure: 6040-021
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6142-007 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6145-001 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6145-001 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6142-007 (Test 2)
Shut-in pressure (kPa)
Shut-in time (mins)


Shut-in pressure: 6738-189 (Test 1)
Shut-in pressure (kPa)
Shut-in time (mins)

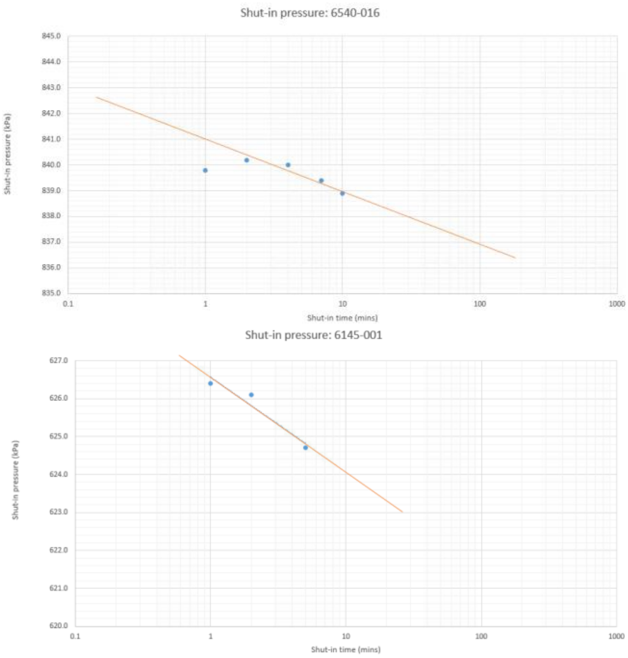


Figure 9.1: Semi-log plots of build-up against time for transmissivity

10 Units of measurement

10.1 Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

10.2 Shortened forms

EC electrical conductivity (µS/cm)

11 Glossary

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

Ambient — The background level of an environmental parameter (e.g. a measure of water quality such as salinity)

Ambient water monitoring — All forms of monitoring conducted beyond the immediate influence of a discharge pipe or injection well, and may include sampling of sediments and living resources

Ambient water quality — The overall quality of water when all the effects that may impact upon the water quality are taken into consideration

Aquiclude — In hydrologic terms, a formation that contains water but cannot transmit it rapidly enough to furnish a significant supply to a well or spring

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining unit') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

ArcGIS — Specialised GIS software for mapping and analysis developed by ESRI

Arid lands — In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping

Artesian — An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well, which penetrates the overlying confining aquifer

Artificial recharge — The process of artificially diverting water from the surface to an aquifer; artificial recharge can reduce evaporation losses and increase aquifer yield; see also 'natural recharge', 'aquifer'

Basin — The area drained by a major river and its tributaries

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

Buffer zone — A neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses)

^{14}C — Carbon-14 isotope (percent modern Carbon; pMC)

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point

CFC — Chlorofluorocarbon; measured in parts per trillion (ppt)

Climate change — The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere, such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

CMB — Chloride mass balance

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining unit — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSG — coal seam gas

CSIRO — Commonwealth Scientific and Industrial Research Organisation

δD — Hydrogen isotope composition, measured in parts per thousand (**°/₀₀**)

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source; may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

Dams, turkey nest dam — An off-stream dam that does not capture any surface water from the catchment above the dam

DEW — Department for Environment and Water

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

DfW — former Department for Water (Government of South Australia)

dGPS — differential Global Positioning System

DO — Dissolved Oxygen

DOC — Dissolved Organic Carbon

Domestic purpose — The taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

Dryland salinity — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure, and the environment.

DSS — Dissolved suspended solids

DWLBC — former Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecology — The study of the relationships between living organisms and their environment

Ecological processes — All biological. physical or chemical processes that maintain an ecosystem

Ecological values — The habitats, natural ecological processes, and biodiversity of ecosystems

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical, and biological environment

Endemic — A plant or animal restricted to a certain locality or region

Environmental values — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion — Natural breakdown and movement of soil and rock by water, wind, or ice; the process may be accelerated by human activities

Evapotranspiration — The total loss of water because of transpiration from plants and evaporation from land, and surface water bodies

Fresh — A short duration, small volume pulse of streamflow generated by a rainfall event that temporarily, but noticeably, increases stream discharge above ambient levels

Fully-penetrating well — In theory this is a well-hole that is screened throughout the full thickness of the target aquifer; in practice, any screen that is open to at least the mid 80% of a confined aquifer is regarded as fully-penetrating.

GAB — Great Artesian Basin

GDE — Groundwater dependent ecosystem

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems

Geomorphic — Related to the physical properties of the rock, soil, and water in and around a stream

Geomorphology — The scientific study of the landforms on the Earth's surface and of the processes that have fashioned them

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted, and released into a well for storage underground; see also 'underground water'

Groundwater Data — Interactive map and search tool for viewing information about South Australia's wells with access to well details including, graphs showing water salinity and water level. It provides a variety of search methods, including filtering the results. [*waterconnect.sa.gov.au/Systems/GD/*]

Head (hydraulic) — Sum of datum level, elevation head and pressure head. The altitude to which water will rise in a properly constructed well. In unconfined aquifers it is the groundwater elevation, and in confined aquifers it is the potentiometric head.

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time

Hydrology — The study of the characteristics, occurrence, movement, and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels, or other works; buildings or structures; or pipes, machinery, or other equipment

Injection well — An artificial recharge well through which water is pumped or gravity-fed into the ground

Irrigation — Watering land by any means for the purpose of growing plants

Kati Thanda-Lake Eyre — Lake Eyre was co-named with the name used by the Arabana people in December 2012

Kati Thanda-Lake Eyre National Park — was proclaimed in November 2013 to recognise the significance of Lake Eyre to the Arabana people and co-name the lake Kati Thanda-Lake Eyre.

Lake — A natural lake, pond, lagoon, wetland, or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks, and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Licence — A licence to take water in accordance with the Act; see also 'water licence'

Licensee — A person who holds a water licence

LMWL — Local meteoric water line

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

MAR — Managed aquifer recharge (MAR) is a process where water is intentionally placed and stored in an aquifer for later human use, or to benefit the environment.

Metadata — Information that describes the content, quality, condition, and other characteristics of data, maintained by the Federal Geographic Data Committee

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change

MODFLOW — A three-dimensional., finite difference code developed by the USGS to simulate groundwater flow

Molar (M) — A term describing the concentration of chemical solutions in moles per litre (mol/L)

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

NWC — National Water Commission

$\delta^{18}O$ — Oxygen isotope composition, measured in parts per thousand (‰)

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

ORP — Oxidation Reduction Potential

Owner of land — In relation to land alienated from the Crown by grant in fee simple — the holder of the fee simple; in relation to dedicated land within the meaning of the *Crown Lands Act 1929* that has not been granted in fee simple but which is under the care, control and management of a Minister, body or other person — the Minister, body or other person; in relation to land held under Crown lease or licence — the lessee or licensee; in relation to land held under an agreement to purchase from the Crown — the person entitled to the benefit of the agreement; in relation to any other land — the Minister who is responsible for the care, control and management of the land or, if no Minister is responsible for the land, the Minister for Sustainability, Environment and Conservation.

Paleochannels — Ancient buried river channels in arid areas of the state. Aquifers in paleochannels can yield useful quantities of groundwater or be suitable for ASR

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m/d

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc.

PIRSA — Primary Industries and Regions South Australia (Government of South Australia)

Population — (1) For the purposes of natural resources planning, the set of individuals of the same species that occurs within the natural resource of interest. (2) An aggregate of interbreeding individuals of a biological species within a specified location

Porosity — The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment (Middlemis, 2000).

Porosity, effective — The volume of the inter-connected void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

Porosity, Primary — The porosity that represents the original pore openings when a rock or sediment formed (Middlemis, 2000).

Porosity, Secondary — The porosity that has been caused by fractures or weathering in a rock or sediment after it has been formed (Middlemis, 2000).

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled based on previous exploration wells

PWA — Prescribed Wells Area

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

RSWL —Reduced Standing Water Level measured in meters AHD (Australian Height Datum). The elevation of the water level is calculated by subtracting the Depth to Water (DTW) from the reference elevation. A negative value indicates that the water level is below mean sea level.

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DEW, respectively. DEW should be contacted for database extracts related to groundwater

Salinity — The concentration of dissolved salts in water or soil, expressed in terms of concentration (mg/L) or electrical conductivity (EC)

SDE — South Australian government dataset containing all other spatially explicit data not housed by SA GEODATA, HYDSTRA, or BDBSA

Seasonal— Pertaining to a phenomena or event that occurs on a on a seasonal basis

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; measured in m^{-1}

Specific yield (S_y) — The volume ratio of water that drains by gravity to that of total volume of the porous medium. It is dimensionless

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Storativity (S) — Storage coefficient; the volume of groundwater released or taken into storage per unit plan area of aquifer per unit change of head; it is the product of specific storage Ss and saturated aquifer thickness (dimensionless)

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

SWL — Standing Water Level (meters) recorded for the water well. This is the distance from the ground surface to the water surface. A negative value indicates that the water level is above ground level.

TDS — Total dissolved solids, measured in milligrams per litre (mg/L), a measure of water salinity

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago). Also known as the Paleogene to Neogene period.

Threatened species — Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

Tributary — A river or creek that flows into a larger river

Turbidity — The cloudiness or haziness of water (or other fluid) caused by individual particles that are too small to be seen without magnification, thus being much like smoke in air; measured in Nephelometric Turbidity Units (NTU)

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted, or released into a well for storage underground

USGS — United States Geological Survey

Volumetric allocation — An allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period, usually per water use year (as distinct from any other sort of allocation)

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

WAP — Water Allocation Plan; a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes, and groundwater aquifers

Water column — a section of water extending from the surface of a body of water to its bottom. In the sea or ocean, it is referred to as 'pelagic zone'

Watercourse — A river, creek, or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water dependent ecosystems — Those parts of the environment, the species composition, and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries, and lakes are all water dependent ecosystems

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Water plans — The State Water Plan, water allocation plans and local water management plans prepared under Part 7 of the Act

Water quality data — Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and wastewater, and of the immediate environment in which the water exists

Water quality information — Derived through analysis, interpretation, and presentation of water quality and ancillary data

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Water resource monitoring — An integrated activity for evaluating the physical., chemical., and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Water resource quality — (1) The condition of water or some water-related resource as measured by biological surveys, habitat-quality assessments, chemical-specific analyses of pollutants in water bodies, and toxicity tests. (2) The condition of water or some water-related resource as measured by habitat quality, energy dynamics, chemical quality, hydrological regime, and biotic factors

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses several concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial., permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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