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The University of Queensland Surat Deep Aquifer Appraisal Project (UQ-SDAAP)

Scoping study for material carbon abatement via carbon capture and storage

Supplementary Detailed Report

Appraisal well test design

30 April 2019

Research team

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Referenced throughout the UQ-SDAAP reports as **Honari et al. 2019c.**

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1. Executive summary

The purpose of this report is to capture work done in the consideration of well test designs for the UQ SDAAP research study. The work considered well-examples with different reservoir conditions and types. The final appraisal well test design described in the main project report (Garnett et al 2019) was based on the work done for the Fantome 1 well described herein.

The research planned originally to access existing, suspended oil and gas well infrastructure in the Surat Basin to conduct extended well tests and obtain dynamic pressure data over time. These data could be used to estimate the Blocky Sandstone Reservoir bulk permeability at various locations, to calibrate the regional model consequently and to better predict CO_2 injectivity over time. In anticipation of access to some wells across the basin, UQ-SDAAP designed several well tests for the Fantome 1 well, a well in the Myall Creek area, the Wandoan and Miles town bores and the Woleebee Creek area. Each test was specifically designed based on operational constrains highlighted by the well owners (Shell-QGC, Armour Energy and the Western Down Regional Council). These test designs were to be utilised as the basis of field requirements for testing operations such as type/size of DST tool, surface facilities, field personnel, testing duration and budgeting.

Ultimately the wells initially proposed could not be accessed. Issues arising with wells and progress on clarifying regulations is described in Garnett 2019.

2. Results

2.1 Description of well test models not used

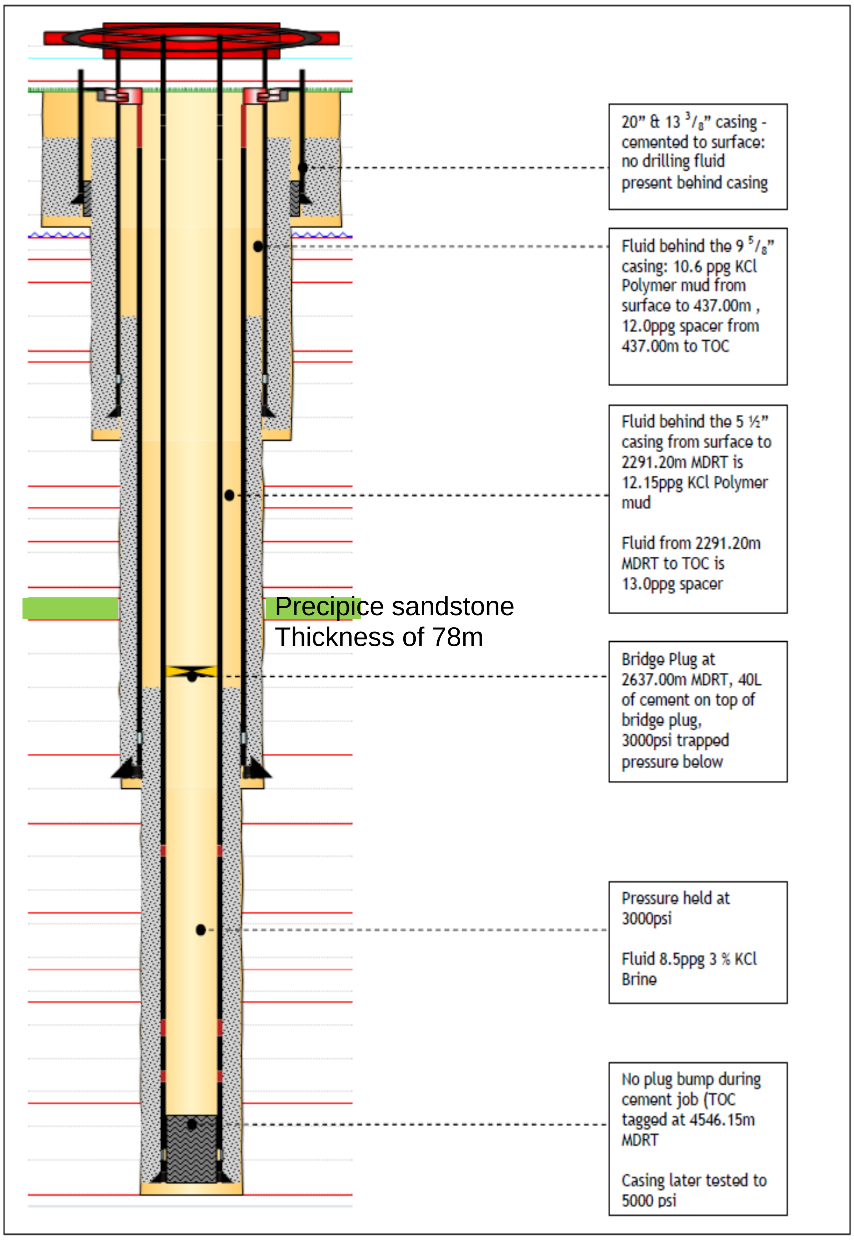
One of the key strategies proposed in the UQ-SDAAP proposal was to access existing and available well infrastructure in the Surat Basin that penetrate the Precipice Sandstone and run large volume pumping tests with a large radius of investigation (ROI) to gain dynamic pressure data over time. These can be used to estimate the Blocky Sandstone Reservoir bulk permeability at various locations. Maximizing the ROI is desirable to de-risk reservoir hydraulic characteristics as far away from the well as possible. In anticipation of access to a number of wells across the basin, the UQSDAAP developed well test designs that would achieve the project objectives and allow for the budgeting of field operational costs. These included well test designs for Fantome 1 (Shell – QGC), a well in the Myall Creek area (to have been drilled by Armour Energy), the Wandoan and Miles town bores (Western Downs Regional Council) and the Woleebee Creek area (Shell – QGC). Each of the wells has specific operational constraints determined by the well owners that required certain well test design constraints. This report describes the well test design for each of these well testing opportunities.

2.2 Well test design in the Fantome 1 well

Based on Fantome-1 well configuration and Blocky Sandstone Reservoir characteristics, a radius of investigation of at least 20km was possible given the limitations of available space for water storage (39ML) and assuming the use of accurate, down-hole pressure gauges. The ROI mainly relates to the length of the shut-in time. As a longer shut-in time increases, the pressure change per unit time decreases. Therefore, the gauge detection limit is also an important constraint on the achievable ROI. Building on earlier work done for the ZeroGen Project (Garnett et al. 2012, pp 434), this ROI could have been significant in establishing confidence in the pressure response for a 2-3 million tpa injection scheme over a 30 year period.

Figure 1 shows the Fantome 1 well schematic as reported in the well completion report (Drake et al., 2013). It shows the basic well construction design. The total Blocky Sandstone Reservoir thickness in Fantome 1 is 78m and for the purpose of test design it was assumed that the entire interval could be perforated through the 9 5/8” casing and cement.

Figure 1 Fantome 1 well schematic in the final suspension status (adapted from QGC Fantome 1 Well Completion Report (Drake et al. 2013).

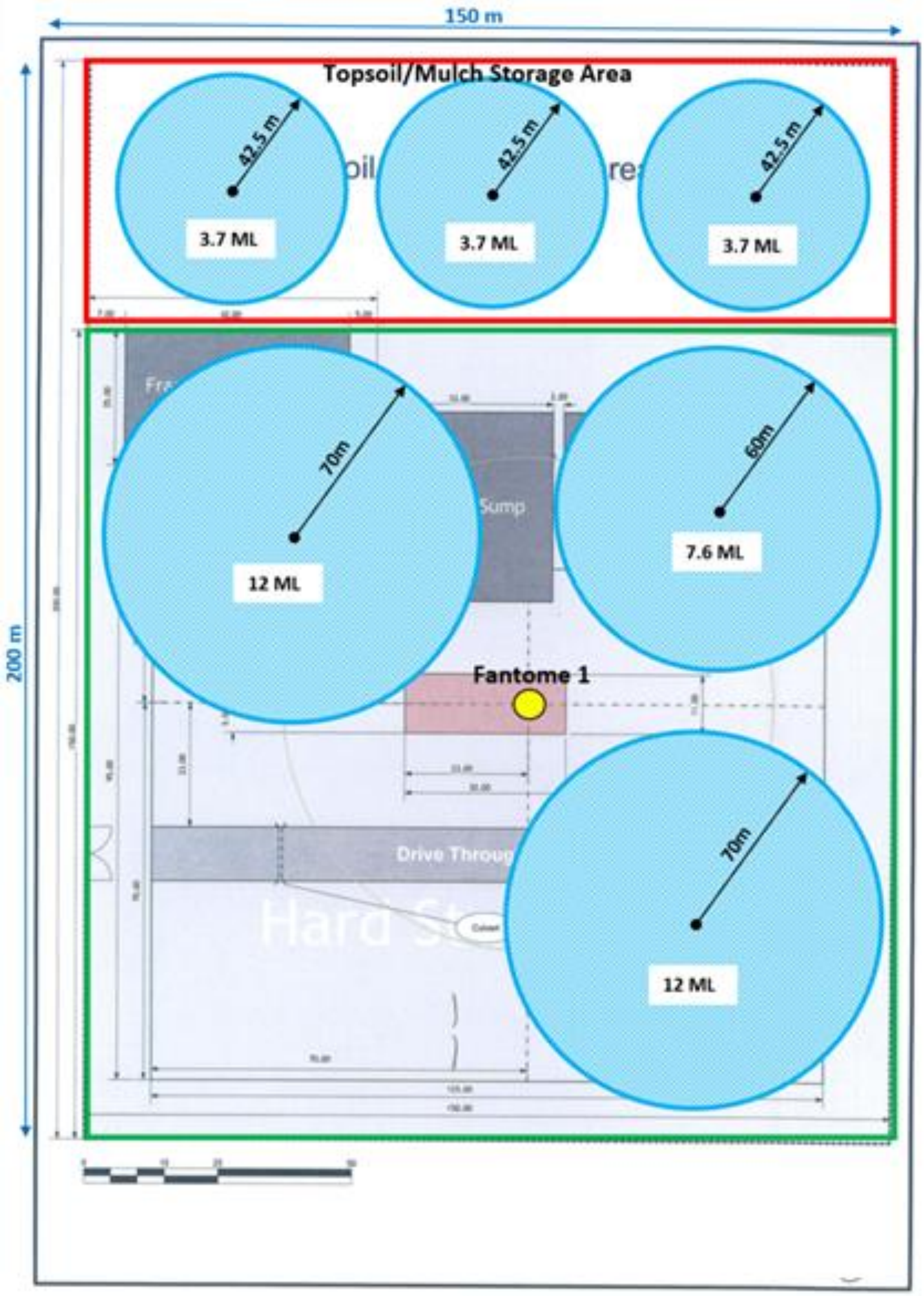


2.2.1 Water storage options

Based on the wellsite layout provided by QGC (Shell), the total area of 150x200 m was available for well testing operations. A pumping test designed to achieve a maximum radius of investigation into Blocky Sandstone Reservoir required temporary surface storage of the produced water. The following site layout, shown on Figure 2, was designed to fit the maximum possible water tank volume into the existing Fantome 1 wellsite constraints. The size of tanks are based on information provided by "Concept Services" (http://conceptservices.com.au/), a company that rents temporary steel and concrete water storage facilities.

By taking into account the space required for well testing service companies to conduct the operations, a maximum of 42.7ML produced water could have been stored on site. Thus, this maximum water storage was considered as the main constraint of well test design for Fantome 1.

Figure 2 Fantome 1 wellsite layout and proposed water storage arrangement.



The UQ-SDAAP investigated a number of surface water storage options that could support a large radius of investigation pump testing. The most effective solution appeared to be large, circular steel and concrete temporary storage in above ground tanks. These provided flexibility to be sized (3.7, 7.6 and/or 12 ML) to suit specific site access and available surface space and allowed for the maximizing of ROI for given site constraints.

2.2.2 Petrophysical properties and other input data

Petrophysical data such as porosity, permeability and Net Pay values needed to be calculated as accurately as possible so that the well pump out model could yield more confident predictions. Porosity and Net Pay for Fantome 1 was calculated using wireline logs – GR, density, neutron and sonic logs. Since no DST or core data was available for the Blocky Sandstone Reservoir in Fantome 1 or in other wells in the vicinity, the porosity data has been utilised to calculate a permeability value using the Kozeny-Carman (KC) equation (Xu and Yu, 2008):

$$k = \frac{\varphi^3}{K(1-\varphi)^2 S^2}$$

Where *k* is permeability, *φ* is porosity, *S* is specific surface area and *K* is the Kozeny-Carman constant. In addition, $K = c\tau^2$ where *τ* is tortuosity (which quantifies the additional distance that a fluid element must take through the porous medium to travel a certain distance in the direction of the bulk flow) and *c* is the Kozeny constant. *S = 6/d* where *d* is the mean diameter for spherical solid particles with specific area *S*.

Values used to calculate permeability from KC correlation are as follows:

τ	4.5
c	2.5
d (µm)	500

Table 1 presents a summary of input data used to design the well test scenarios for Fantome 1.

Table 1 Petrophysical-input data for Fantome 1 well test design.

Input data		Comment
Pay zone (m)	67.9	Calculated from GR log with 35% shale cut-off
Porosity (%)	12.5	Calculated from sonic log
Permeability (mD)	355	Based on KC equation
Reservoir temperature (°C)	83	From the log
Initial reservoir pressure (bar)	203.4	Based on Precipice hydraulic groundwater model
Total compressibility (kPa^{-1})	1.03E-06	IHS WellTest software estimation
Viscosity (cP)	0.3393	Carr et al. correlation
Salinity (ppm)	500	
Skin	10	
Well radius (m)	0.12	Based on current well status
Gauge noise (psi)	0.03	Based on manufacturers' datasheet

2.2.3 The Fantome 1 well test design

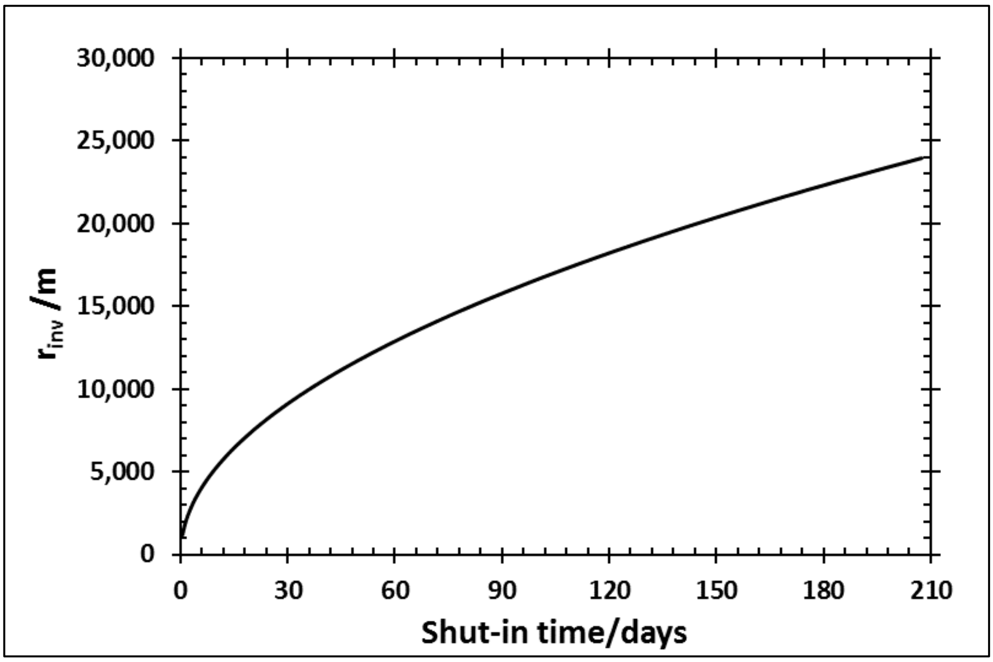
By assuming no restriction to water flow in Fantome 1, various flow rates and draw down periods were chosen while the total produced water was considered to be capped at 39 ML. Thus, in this design, nearly 3.8 ML was allocated for well clean up, any unexpected operational issue, flow rate selection and ultimately pumping test calibration, based on what we might expect during the actual well testing. Then, the term ROI was introduced, which determines the extent of reservoir that is influenced by the pressure disturbance created by the pumping. One of the most commonly used equations to calculate ROI is used herein to define the basis of well test design for Fantome 1 (Muskat 1934, Van Poolen 1964, Stewart 2011):

$$r_{inv} = \sqrt{\frac{4kt}{\varphi \mu c_t}}$$

Where r_{inv} is in m, k is permeability in m^2, t is shut-in time in sec, φ is porosity, μ is viscosity in kg/(m·s) and c_t is total compressibility in Pa^{-1}.

Figure 3 shows the radius of investigation at Fantome 1 by applying petrophysical properties listed in Table 1. It indicates that radius of investigation can be theoretically extended by maintaining a longer shut-in time; however, the pressure change being recorded at the wellbore has to be large enough to be detected by downhole gauges.

Figure 3 Radius of Investigation at Fantome 1 calculated for various build up times.



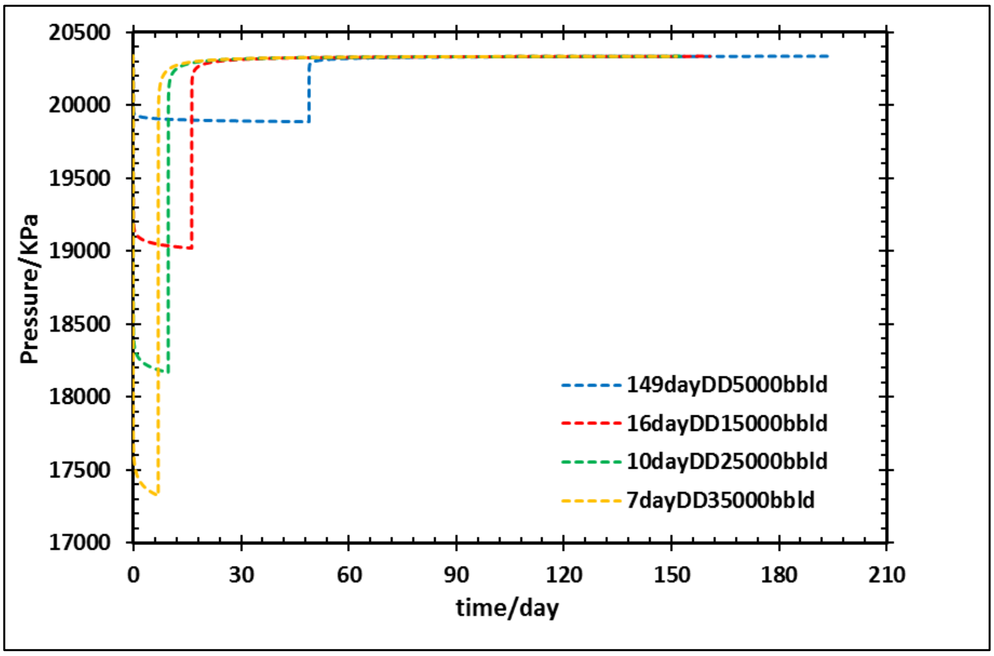
The total produced water of 39ML and a calculated radius of investigation of 20km were considered best estimates for the objectives of pumping test. Then different pumping rates and durations scenarios, as summarised in Table 2, were tested to investigate their effects on build up pressure response at the well.

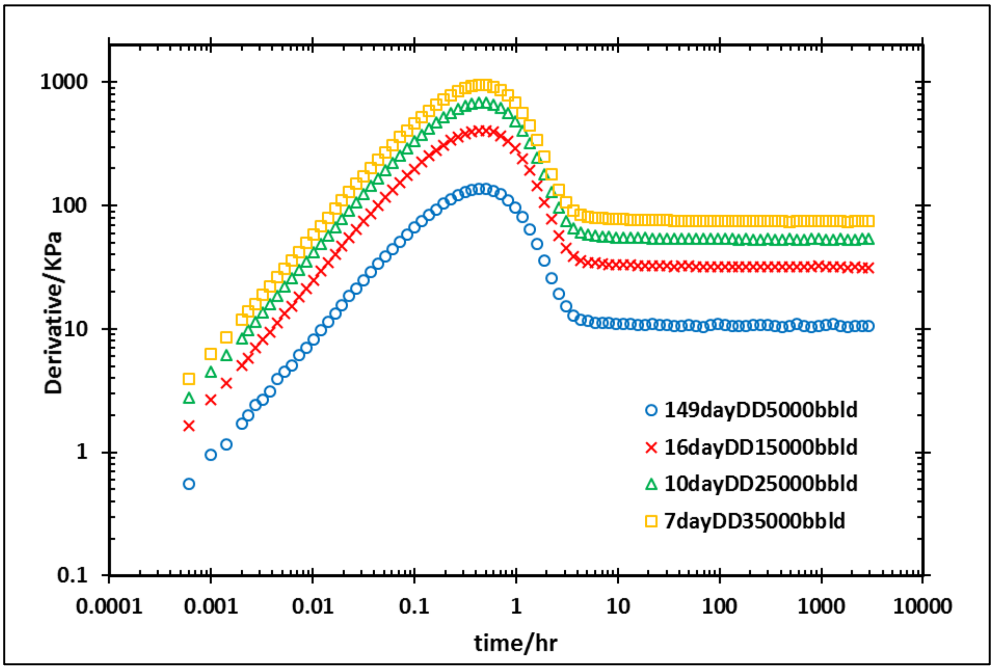
Table 2 Fantome 1 well testing scenarios with various DD duration and pumping rates.

Parameter				
Flow rate (bbl/day)	5000	15000	25000	35000
Flow rate (m^3/day)	794	2385	3975	5565
DD duration (days)	49	16.3	9.8	7
Total produced water (ML)	39			
BU duration (days)	144.4			
r_{inv}(m)	20000			

Figure 4, indicates that pumping rates as low as 794 m^3/day were still able to deliver interpretable pressure changes at the well bore, assuming pressure gauge resolution was equal to 0.03 psi or better. Thus, the decision on what pumping rate and duration would have been the most appropriate to test Fantome 1 depended on finding the optimum cost associated with extended test duration and potentially larger equipment required for higher pumping rates. Also, any unexpected formation damage and/or sand production plus any restrictions in the well and surface facilities that limits the maximum allowable water flow rate could have affected the final decision on pump out rate and duration.

Figure 4 Pressure vs. time (top) and derivative response (bottom) in Fantome 1 at various pumping rates and durations.





2.3 Well test design in Myall Creek area

Our seismic analysis (see Gonzalez et al. 2019b for more details) revealed the fluvial sand development in the Myall Creek area has sand thickness not exceeding 10 metres. Also, the Transition Zone was predicted to be sub-artesian in this region. The limited extent of the sand facies means that well testing will quickly see the sedimentological boundaries and any drill stem test (DST) in this area would have required artificial lift (i.e. nitrogen lift) to keep the water flowing to the surface. Thus, a wireline DST, which is equipped with a downhole pump was considered as an option to be deployed for an interval up to 10m thick. Well test studies showed that the wireline DST tool might deliver a successful test for the sandstone in the Transition Zone, which was expected to be encountered in Myall Creek area. Table 3 summarises the inputs used for the base, low and high case well test design. Most importantly, there is no permeability control in the area from either core or well tests. Additional logs (in the seismic ‘channel’ feature) and modular dynamic tester could reduce this uncertainty even without a full DST and core. Since the new well locations fixed for deeper targets and located near the western pinch out edge of the Blocky Sandstone Reservoir, it is not clear the size of target sandstone that might be encountered, or if it will be a Transition Zone sand at the edge of the Blocky Sandstone Reservoir. We therefor consider several alternatives.

Table 3 Petrophysical properties and other input values used for Myall Creek wireline well test design.

	No sand	Channel sand	Blocky Sandstone Reservoir	Comment
Pay zone (m)	2.3	4.6	9.6	Calculated from GR log
Porosity (%)	12	16.7	22	Core data in Myall Creek area with porosity cut off of 10%
Permeability (mD)	0.7	91	1755	Core data in Myall Creek area with Permeability cut off of 0.5mD
Reservoir temperature (°C)		49		From wells in the Myall Creek area
Initial reservoir pressure (bar)		151.7		From nearby wells at similar depth
Total compressibility (kPa^{-1})		1.03 E-06		IHS WellTest software estimation
Formation volume factor (m^3/sm^3)		1		IHS WellTest software estimation
Viscosity (cp)		0.554		Carr et al. correlation
Salinity (ppm)		500		
skin		10		
Well radius (m)		0.108		Based on planned well program
Gauge noise (psi)		0.03		Based on manufacturers' datasheet

2.3.1 Wireline DST Study 1

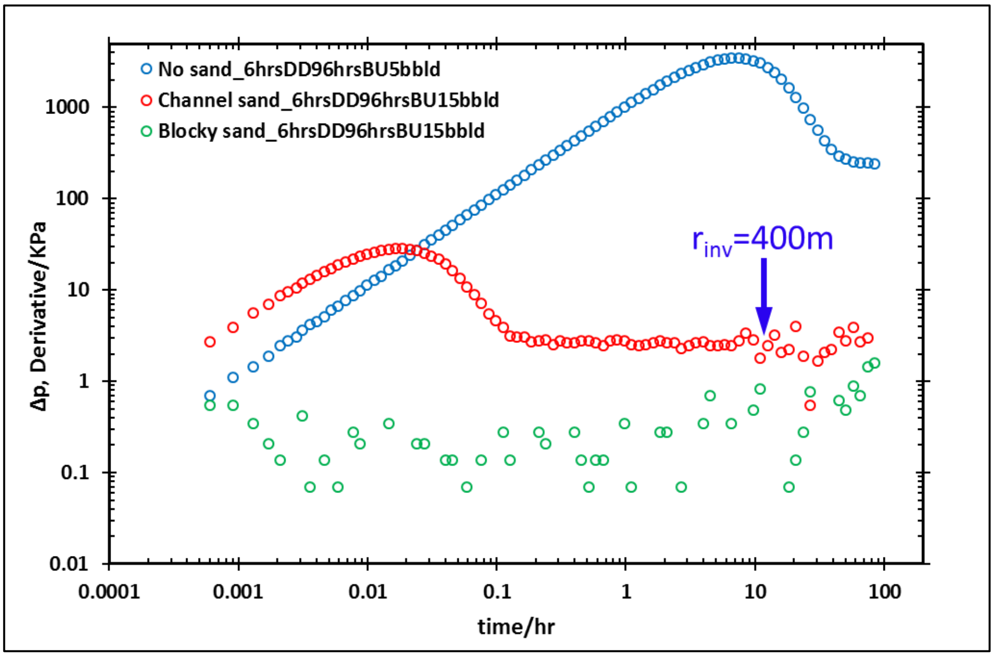
The pumping rate varies between 0.8 m^3/day for a no sand case and 2.4 m^3/day for the channel and blocky sand cases and the pumping and shut-in period were kept constant through all three cases. The details are summarised in Table 4.

Table 4 Myall Creek pumping test scenarios for Wireline DST Study 1.

	No sand	Channel sand	Blocky Sandstone Reservoir
Pay zone (m)	2.3	4.6	9.6
Porosity (%)	12	16.7	22
Permeability (mD)	0.7	91	1755
DD flow rate - bbl/day (m^3/day)	5 (0.8)	15 (2.4)	15 (2.4)
DD duration (hrs)	6	6	6
BU duration (hrs)	96	96	96

Figure 5 shows that the wireline tool can obtain reasonably clean data for interpretation in the no sand and channel sand scenarios and it would be noisy for the high permeability Blocky Sandstone Reservoir case. As highlighted in Gonzalez et al. 2019b, it is highly unlikely to encounter the Blocky Sandstone Reservoir (high permeability) in the Myall Creek area.

Figure 5 Pressure derivative for Myall Creek with no sand, channel sand and Blocky Sandstone Reservoir scenarios for wireline DST Study 1.



2.3.2 Wireline DST study 2

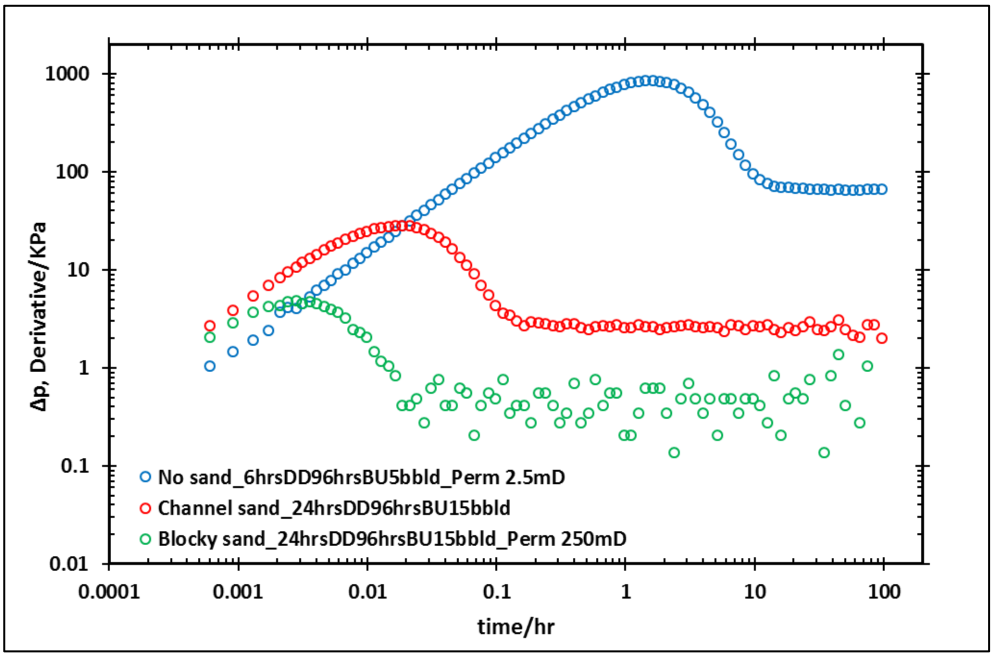
Compared to case study 1, the pumping period increased and the permeability values for both no sand and Blocky Sandstone Reservoir scenarios changed. Table 5 summarises the new values in red.

Table 5 Myall Creek pumping test scenarios for Wireline DST Study 2.

	No sand	Channel sand	Blocky Sandstone Reservoir
Pay zone (m)	2.3	4.6	9.6
Porosity (%)	12	16.7	22
Permeability (mD)	2.5	91	250
DD flow rate - bbl/day (m^3/day)	5 (0.8)	15 (2.4)	15 (2.4)
DD duration (hrs)	6	24	24
BU duration (hrs)	96	96	96

The results in Figure 6 show that the longer pumping period improved the data in the channel sand with an increased radius of investigation. Also, the pressure response observed in the Blocky Sandstone Reservoir with the permeability value of 250 mD was improved but still noisy for the interpretation.

Figure 6 Pressure derivative for Myall Creek with no sand, channel sand and Blocky Sandstone Reservoir scenarios for wireline DST Study 2.



2.4 Well test design in Wandoan and Miles town bores

The Western Downs Regional Council has water bores in the Blocky Sandstone Reservoir at Miles and Wandoan to supply water to the towns. There are two town bores at Wandoan, 1.1 km apart where one well is producing and the other one is in standby status. In addition to two town bores in Wandoan, a third bore has been also drilled by Glencore, which will be handed to the council as a secondary standby bore. The total volume of produced water varies between 2000-4000 bbl per day (0.32-0.64 ML/day) based on Wandoan water consumption. The main bore pump normally discharges water at the rate of 6800 bbl/day (1.1 ML/d) varying the total pumping time between 6.6 and 13.3 hours per day. The flow rate is measured using flow meters installed in the pump discharge pipes at the surface and the water rates are reported on a daily basis.

The Western Downs Regional Council has one town bore at Miles which contributes an average of 3100 bbl per day (0.5 ML/day) to town water supply. The town consumes up to 6,200 barrel water per day (1ML/day) and the difference (3100 bbl/day (0.5ML/day) or less) is provided from creek water. The water rates are reported on a daily basis and the bore does not have downhole gauges.

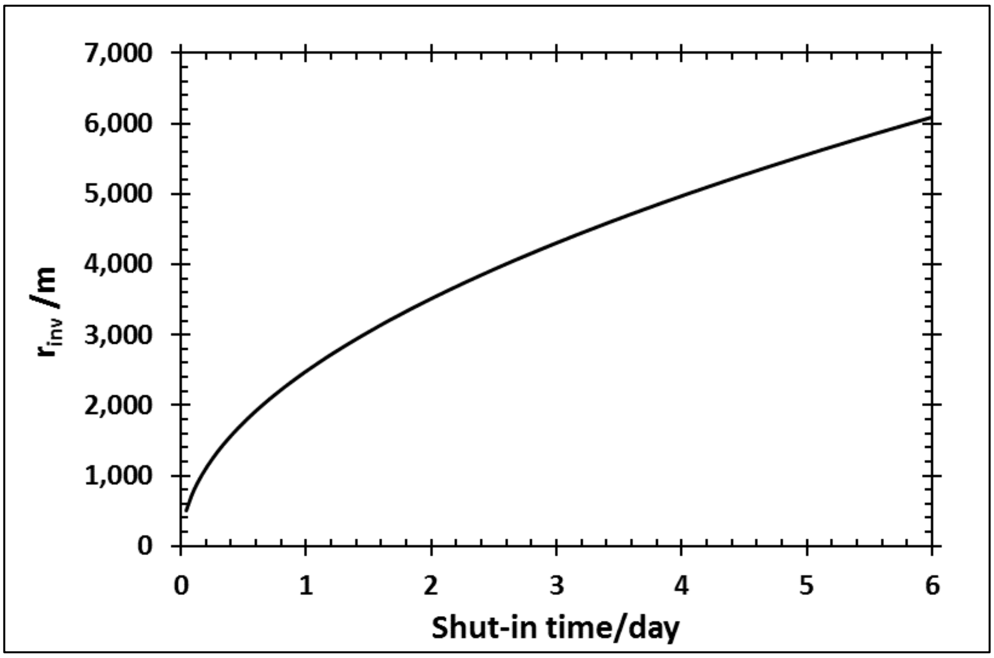
2.4.1 Well test design in the Wandoan town bores

By taking into account the third bore (Glencore) for the Wandoan town, a series of well test studies were undertaken to provide synthetic data. The main advantage of having one pumping well and two monitoring wells at Wandoan would be to quantify any heterogeneity that might exist in Blocky Sandstone Reservoir. Also, as described later, the pulse test would potentially increase the radius of the investigation as long as the pressure change observed in the monitoring wells is larger than the gauge resolution. The pulse test is where the flow rate at the injecting (or producing) well is changed over time in a series of alternating flow and shut-in periods (Kamal 1983). Table 6 summarises the input values for Wandoan town bore test study. In addition, the estimation of radius of investigation (ROI) with various Build Up periods is presented in Figure 7.

Table 6 Petrophysical properties and other input values used for Wandoan town bore well test design.

Input data		Comment
Pay zone (m)	81.6	Calculated from GR log with 35% shale cut-off.
Porosity (%)	18	Zonal core data.
Permeability (mD)	1550	Zonal core data and DSTs.
Reservoir temperature (°C)	60	From the log in nearby wells
Initial reservoir pressure (bar)	106.9	From DST data in nearby wells
Total compressibility (kPa^{-1})	1.03E-06	IHS WellTest software estimation
Viscosity (cp)	0.4622	Carr et al. correlation
Salinity (ppm)	250	
Skin	10	
Well radius (m)	0.107	Based on current well status
Gauge Nnise (psi)	0.03	Based on manufacturers' datasheet

Figure 7 Radius of Investigation for Wandoan bores calculated at various build up times.



Wandoan bore locations relative to each other are shown in Figure 8 and the pumping rates and testing periods are listed in Table 7.

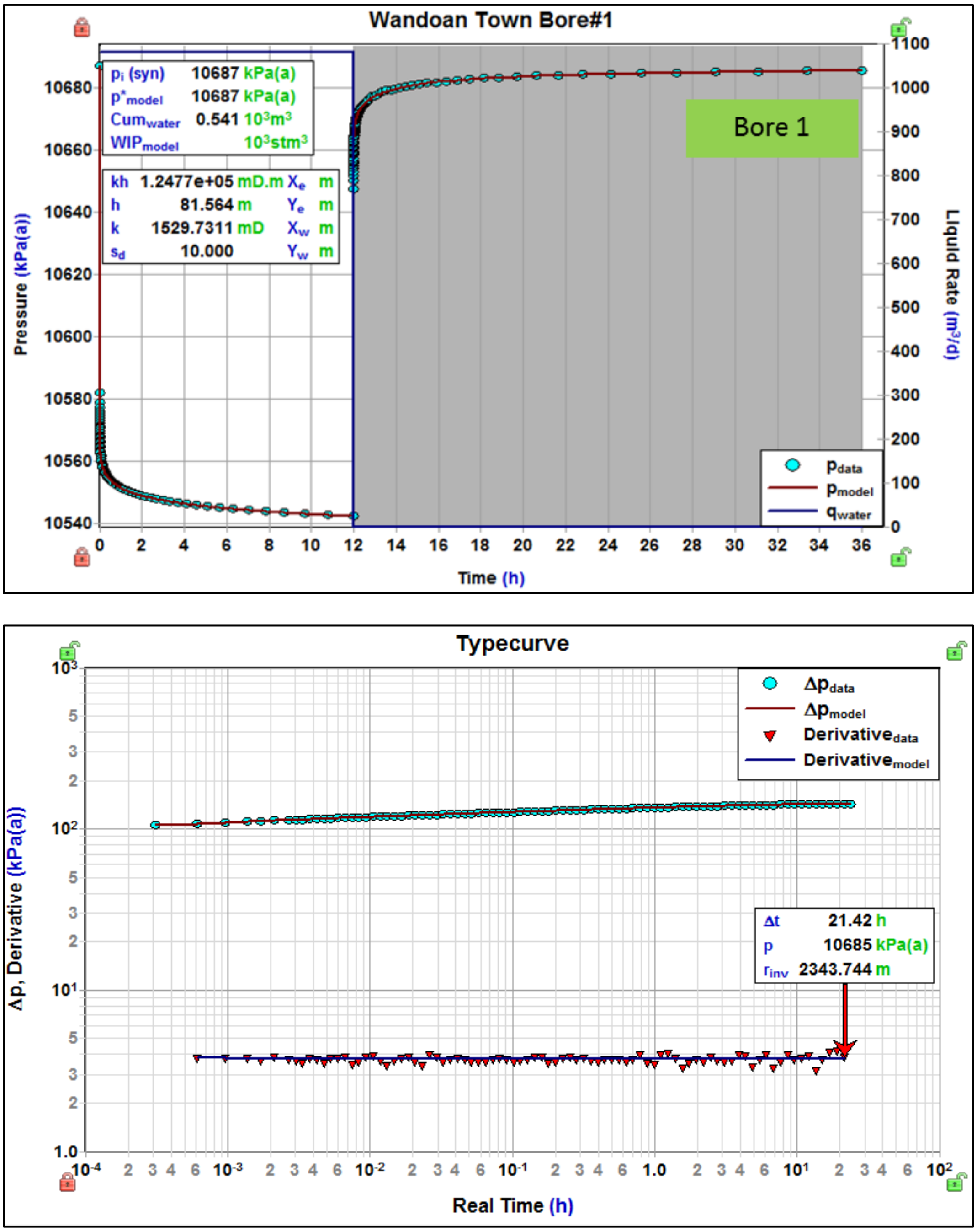
Figure 8 Wandoan bore locations.

Table 7 Water production rate and pumping and shut-in periods in Wandoan Bore 1.

Parameter	
Flow rate (bbl/day)	6800
Flow rate (ML/day)	1.08
DD duration (days)	0.5
Total produced water (ML)	0.54
BU duration (days)	1

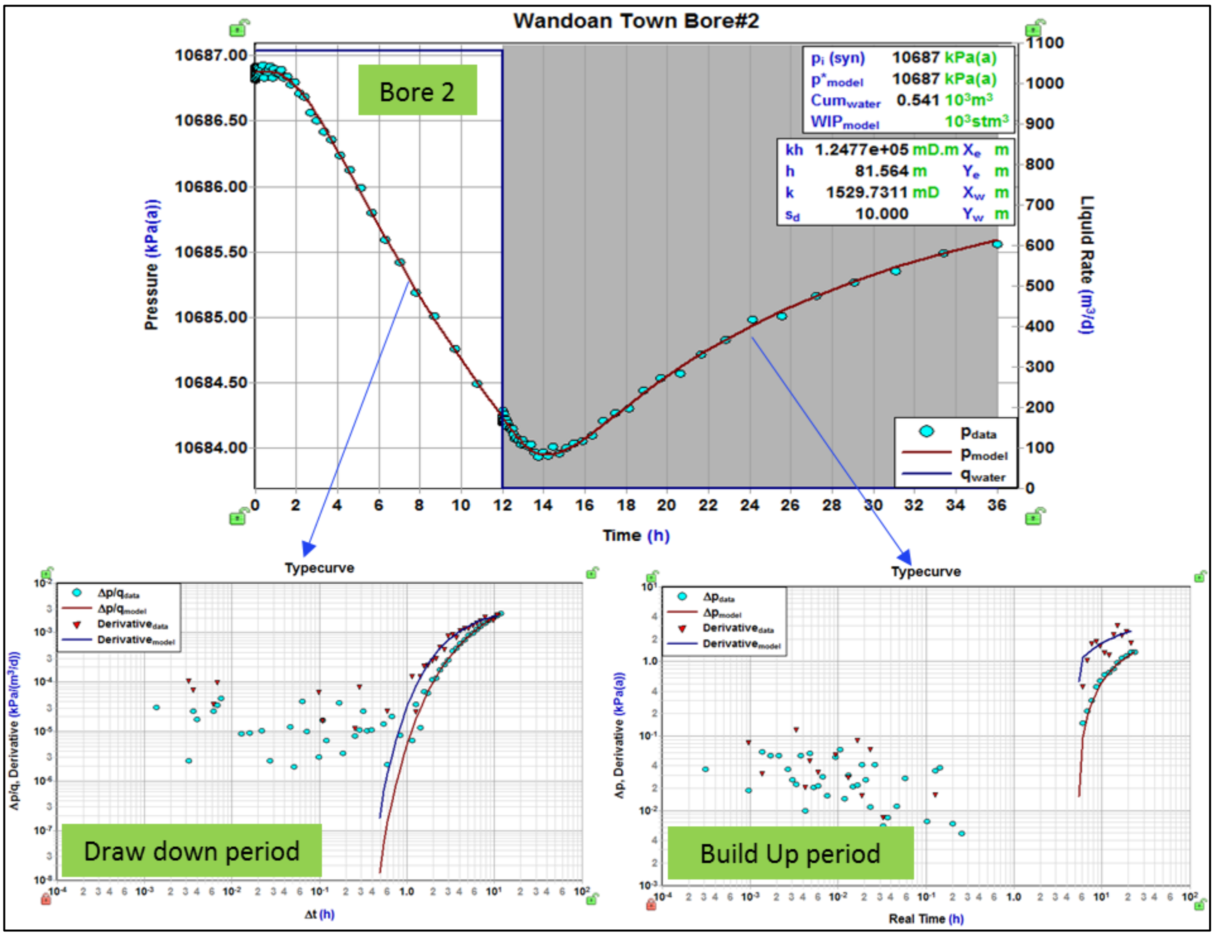
A pumping test with the sequences specified in Table 7 would create the pressure responses in Bore 1 as shown in Figure 9 with ROI of ~2340m. The process might be achieved simply and cheaply by relying on pumping of town bore in their normal operations and installing down-hole gauges in one of two of the other wells.

Figure 9 (Top) the pressure response in the Wandoan bore 1 as a result of pumping of water at rate of 1.08 ML/day for 12 hours and shut-in of 24 hours; (Bottom) the log-log derivative plot for the pumping test.



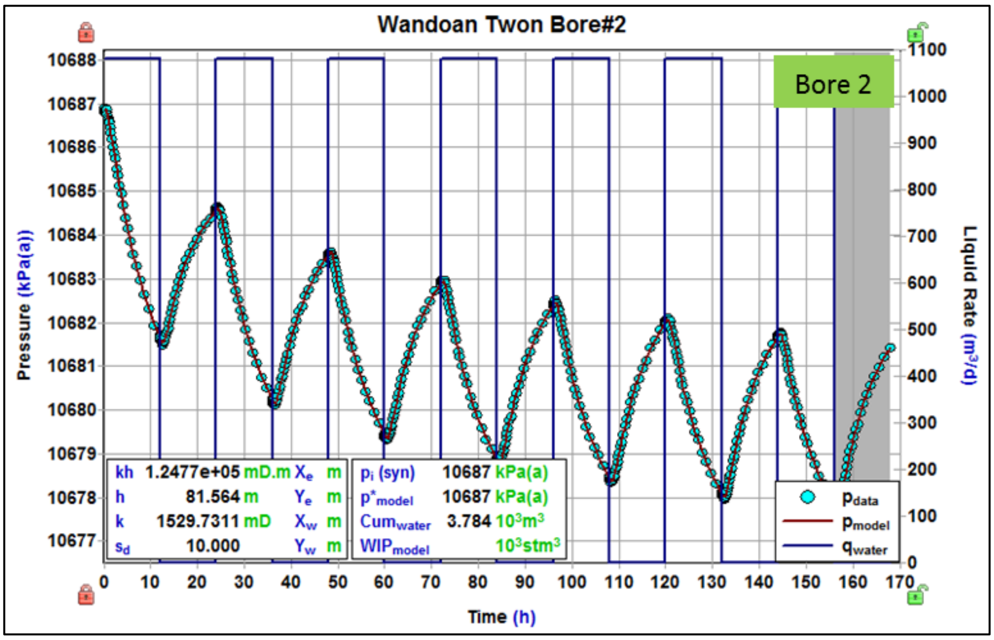
The pressure response in the Wandoan bore 2 (the monitoring bore), which is located further away from Bore 1, is shown in Figure 10. It indicates sufficient pressure change would be observed during the actual test to generate an interpretable response.

Figure 10 (Top) The pressure response in the Wandoan bore 2 (the monitoring bore) located 1105m away from Bore 1 (the pumping bore); (Bottom) the log-log derivative plots for Bore 2.



Due to the nature of the Wandoan Bore 1 supplying water for the town, sequential pumping and shut-in periods would be expected. Thus, a pulse test would be ideal in this situation to increase the ROI of the test. An example of pulse test pressure response for Wandoan bore 2 is illustrated in Figure 11. A detail of pulse test interpretation can be found in well test text books (e.g. Earlougher 1977).

Figure 11 Pulse test response in Bore 2 when water is producing from Bore 1 at the rate of 1.08 ML/day and the sequential pumping and shut-in periods of 12 hours.



2.4.2 Well test design in the Miles town bore

Figure 12 summarises the potential ROI that could be achieved based on the average petrophysical properties in the Miles area listed in Table 8.

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Figure 12 Radius of investigation in the Miles bore calculated at various build up times.

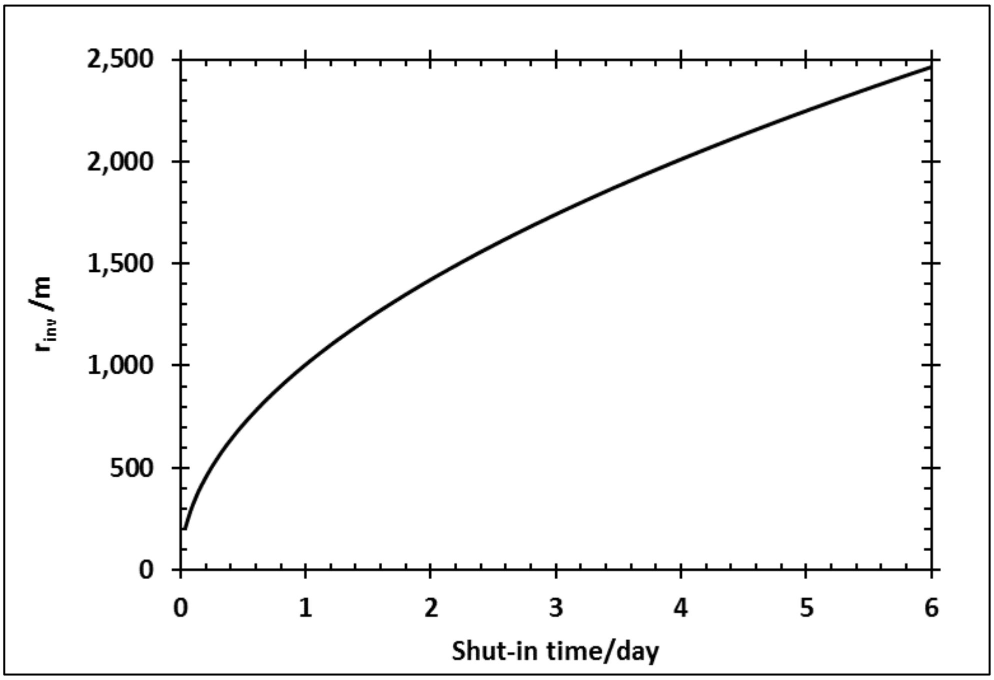


Table 8 Petrophysical-input data for Miles bore.

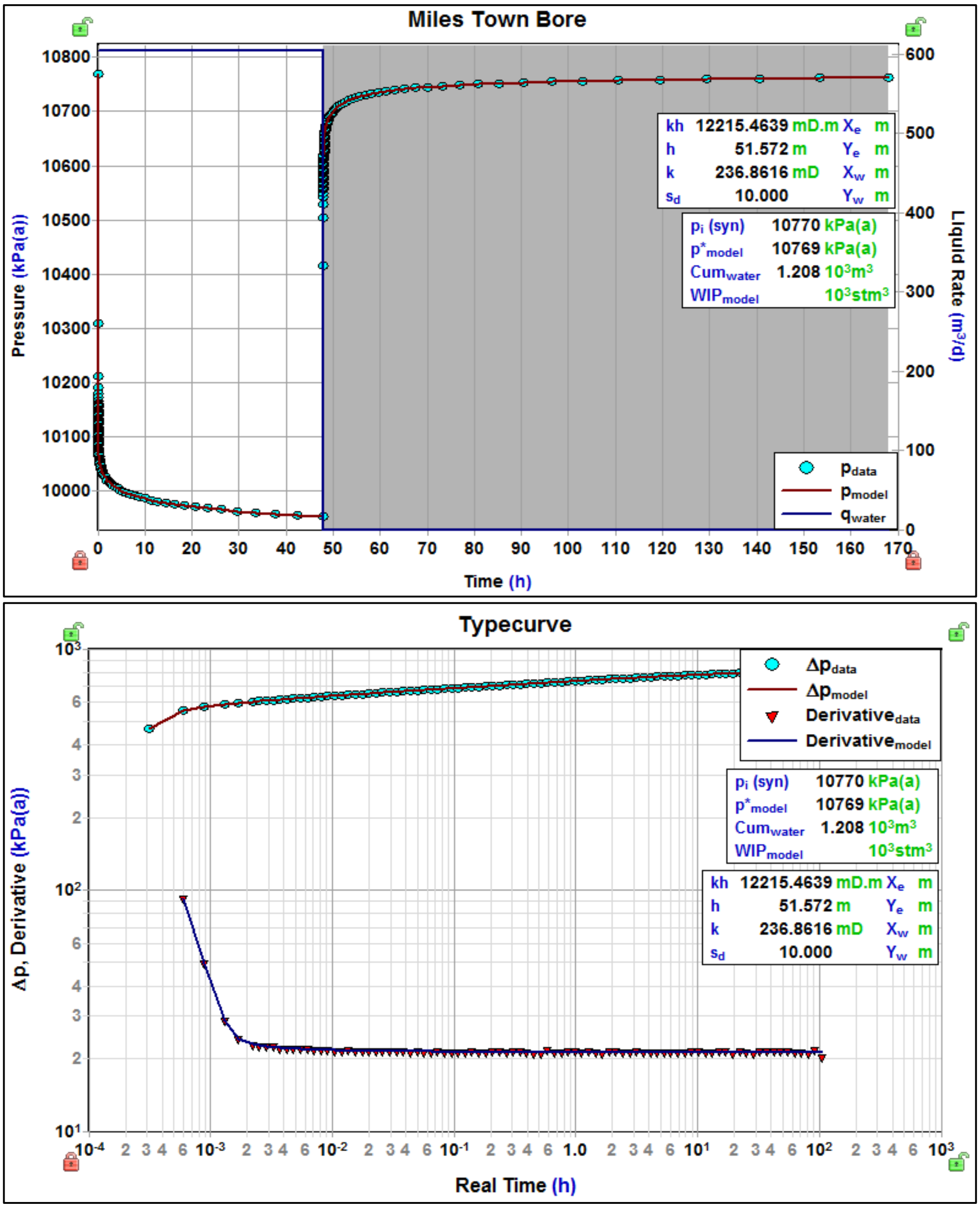
Input data		Comment
Pay zone (m)	51.6	Calculated from GR log with 35% shale cut-off
Porosity (%)	17	Zonal core data
Permeability (mD)	240	Zonal core data and DSTs
Reservoir temperature (°C)	60	From the log in nearby wells
Initial reservoir pressure (bar)	107.7	From DST data in nearby wells
Total compressibility (kPa^{-1})	1.03E-06	IHS WellTest software estimation
Viscosity (cp)	0.4622	Carr et al. correlation
Salinity (ppm)	250	
Skin	10	
Well radius (m)	0.107	Based on current well status
Gauge noise (psi)	0.03	Based on manufacturers' datasheet

Since the bore could be accessed for a relatively long period of time due to potential water supply from Creek, the only key limitation for the pump-out test would have been the maximum flow rate that the current pump could deliver. Thus, DD and BU time and rate in Table 9 were used as the basis of well testing scenarios, obtaining a maximum ROI of approximately 2.25km. The pressure response and derivative for the Miles bore test are illustrated in Figure 13.

Table 9 Miles town bore well testing scenario.

Parameter	
Flow rate (bbl/day)	3800
Flow rate (ML/day)	0.604
DD duration (days)	2
Total produced water (ML)	1.2
BU duration (days)	5
r_{inv}(m)	2248

Figure 13 Pressure vs. time (top) and derivative response (bottom) for the Miles town bore.

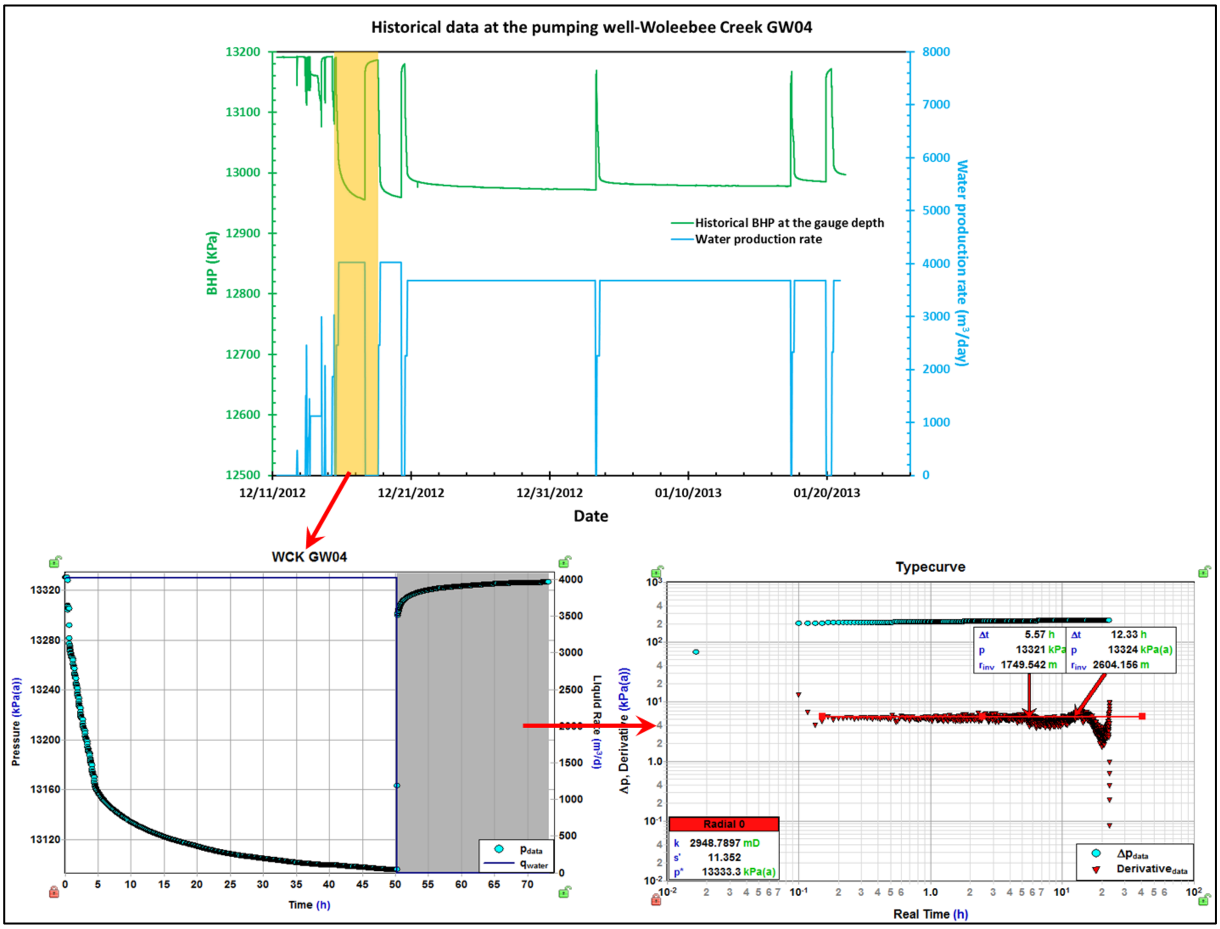


2.5 Well test in Woleebee Creek area

QGC (Shell) ran a series of well tests at Woleebee Creek in the Blocky Sandstone Reservoir in order to evaluate the feasibility of using managed aquifer recharge (MAR) in that area to provide pressure support for local groundwater dependant springs, should the coal seam gas development cause the water level in the aquifer to decline beyond a trigger point. A pumping trial was conducted between December 2012 and January 2013 where water was pumped out of the Woleebee Creek GW4 well with a flow rate of approximately 4022 m^3/day and the pressure response was measured both in the Woleebee Creek GW4 (producing well) and Woleebee Creek GW10 (monitoring well) located 3.28 km away.

As shown in Figure 14, there were several DD-BU sequences during this pump trial in which the longest DD and BU period was two days and 23 hours, respectively. This was the period chosen for UQ SDAAP pressure transient analysis. The analysis of the BU period resulted in the permeability and skin values of ~3000 mD and 11, respectively, which are in agreement with the values reported by Shell (Permeability of ~3200 mD and skin of 11). Conservatively, a ROI of ~1.75 km was estimated from the test. The ROI value could be increased to 2.6 km if the first “hump” in the log-log plot (i.e. 12 hours of the BU period) is included in the estimation.

Figure 14 The pressure response and historical water pumping rate at Woleebee Creek GW04 during the pump test trial (top); a subset of the data for the longest DD-BU periods achieved during the pump test (bottom left) and the pressure transient analysis for the selected BU period resulting in permeability, skin and ROI values (bottom right).



3. Summary

If oil and gas or similar well infrastructure can be accessed in a proposed CCS play, risk-critical data can be acquired via extended well testing. Well access remains complex and difficult to secure and confirm (Garnett 2019) and the value of information may ultimately be limited by the volumes of produced water that can be handled. Minimum production rates are determined by gauge accuracy, test duration and hence radius of investigation is constrained by water management infrastructure (and costs). More information on well tests for the lowest risk, notional injection sites, identified by UQ-SDAAP, is given in the main project report (Garnett et al, 2019).

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