7.0
Connectivity of aquifers and aquitards

7.0 Connectivity of aquifers and aquitards

#	Department Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
7	**49b**		Submission of aquifer connectivity studies progress report	April 2013	● (Commitments completed)
8	**49b**	**53B a**	Submission of Infrastructure Connectivity Report	October 2013	● (Commitments completed)
57		**53B a**	Submission of updated aquifer connectivity studies progress report	April 2014	● (Firm deliverables for that month)

● Commitments completed
○ Commitments work in progress
△ Evergreen Commitments
● Firm deliverables for that month

7.1 OVERVIEW OF CONNECTIVITY PROGRAM

QGC has embarked on a major program of investigation and assessment to understand the possible changes in inter-formation groundwater flow due to coal seam gas development of the Walloon Subgroup. This is in response to Commitment 7 of the Stage 2 WMMP. Commitment 7 addresses Condition 53(B)a which calls for 'a program and schedule for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity'.

Specific testing and characterisation of connectivity between the Walloon Subgroup, aquifers and intervening aquitards has been undertaken and are ongoing. This work is vital to a proper understanding of connectivity and to predictions of water level changes in key aquifers. Substantial progress has been made in characterising each unit and now actual testing has begun with pumping from the Walloon Subgroup and associated aquifer monitoring to measure pressure changes

The QGC June 2013 Aquifer Connectivity Progress Report (Appendix I) describes the work currently underway. This Stage 3 WMMP largely represents a summary of this report, an update on data collection up to June 2013, some further analysis and a detailed forward program.

Aquifer connectivity is best considered as a change in flux (i.e. a change in leakage rate) resulting from a change in hydraulic gradient between formations. This flux is generally considered at a formation to formation scale (i.e. it can be called inter aquifer connectivity). The overall objective is to look at the change in flux between the Walloon Subgroup and overlying and underlying aquifer formations. However in some specific cases a different scale and change in flux direction is considered. For example, potential leakage across a fault is generally a horizontal intra aquifer connectivity matter.

The possible change in flow directions and magnitudes as a result of different mechanisms is shown conceptually in Figure 7-1.

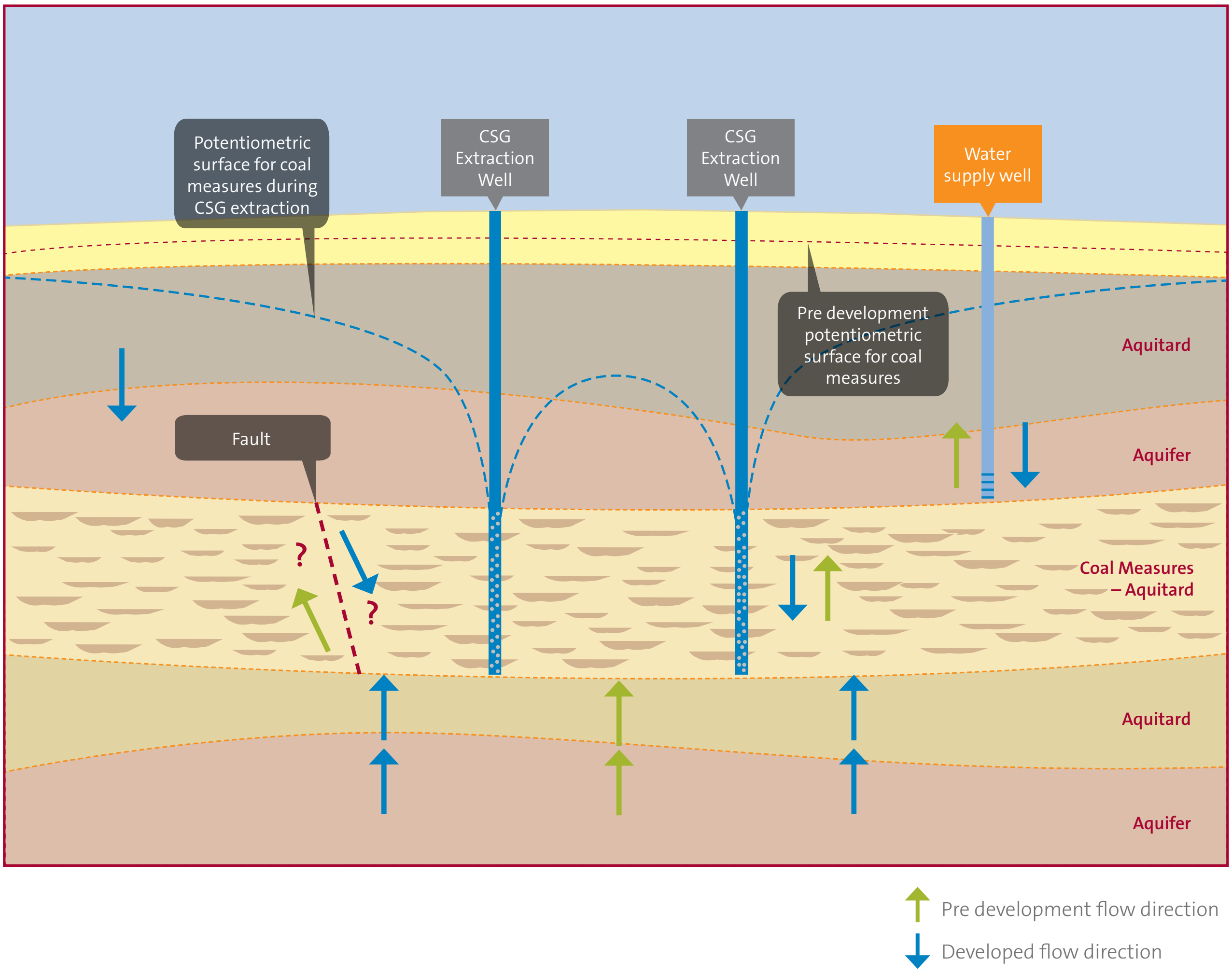


Figure 7-1 – Diagrammatic perspective of possible changes in flow directions and magnitudes as a result of CSG development

Aquifer connectivity is controlled by many different hydrogeological factors and processes. However it is generally recognised that the vertical hydraulic conductivity (Kv) is the most important factor. Consequently the Stage 2 WMMP included a detailed literature review of the feasible range of values. This is summarised in both permeability and hydraulic conductivity units in Figure 7-2. This illustrates the very broad possible range of values. The core of the connectivity program is to understand the spatial variability and most likely values for Kv and hence provide greater confidence in the prediction of possible impacts.

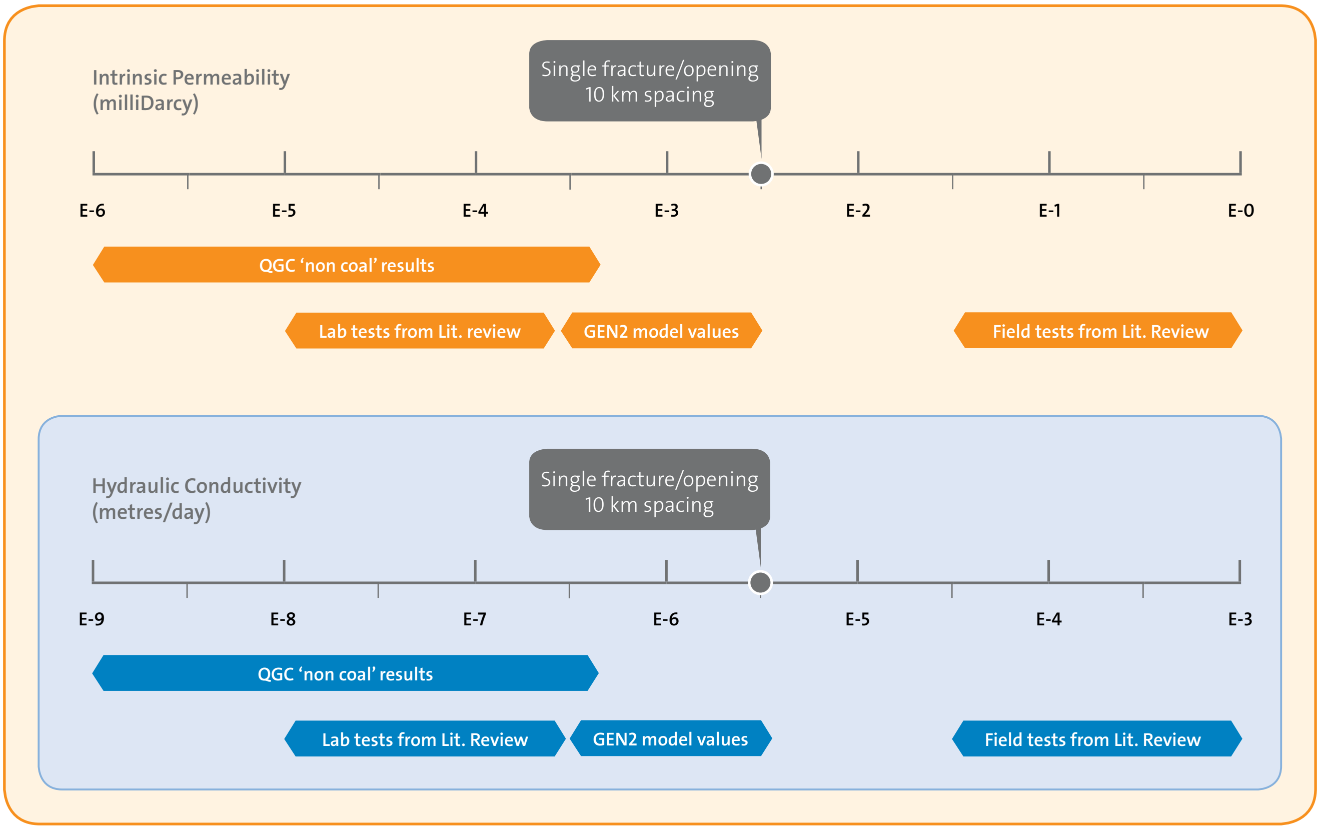


Figure 7-2 – Typical vertical hydraulic conductivities in sedimentary basins

7.2 AQUITARD AND AQUIFER CHARACTERISATION STUDIES

The lithologic and hydraulic properties of the major aquitards, and their spatial distribution, are the major factors influencing the rate and distribution of the regional depressurisation of the Walloon Subgroup and the adjacent aquifers. Consequently QGC has put in place a program to better understand the aquitards through core analysis and sedimentology studies. The results from the Walloon Subgroup and the Springbok Sandstone were reported in the Stage 2 WMMP. (Over the next 12 months the focus will be on the Eurombah and Westbourne Formations and the Springbok and Hutton Sandstones). Interpretation of the recent drilling data is underway and preliminary interpretations are presented in the June 2013 progress report (Appendix I).

One of the important conclusions in the June 2013 progress report is that the 'layer cake' geology of distinct homogeneous aquifer and aquitard formations, which forms the basis of mathematical groundwater flow models, can only be considered an approximate representation of groundwater flow processes. Further, many of the so called 'aquifers' are actually aquitards with relatively minor higher hydraulic conductivity zones. For example, this is illustrated with the Springbok Sandstone which generally behaves as an aquitard. Conversely some of the aquitards have higher hydraulic conductivity zones embedded in a generally low hydraulic conductivity sequence. It is planned that by December 2013 all the major stratigraphic units in the Central Development Area will be mapped to show both their thickness and hydraulic behaviour. It is anticipated that this will demonstrate regions with relatively higher and lower risks of leakage.

As part of ongoing groundwater investigation, QGC has undertaken a number of pumping tests. The results of these tests and other hydraulic testing in the Northern Gas Fields in the vicinity of Woleebee Creek are summarised in Table 7-1. These tests are considered the most appropriate method to determine subregional scale hydraulic properties.

The hydraulic testing in the vicinity of Woleebee Creek shows:

- The Gubberamunda Sandstone is a relatively poor aquifer with K values of typically 0.1 to 1 m/d;
- The Westbourne Formation and the Springbok Sandstone have similar and very low K values. The very low transmissivity values for the Springbok Sandstone add further weight to the conclusion that this formation in general acts as a very poor aquifer or an aquitard at this location;
- The Walloon Subgroup transmissivity values are generally greater than those of the Springbok Sandstone;
- The Hutton Sandstone is likely to be of relatively low transmissivity values indicating that it is a poor aquifer. Note this is based on analysis from a bore 25 km to north-east, however a low transmissivity appears to be a regional feature of the Hutton Sandstone in the Surat Basin; and
- The Precipice Sandstone is the only high yielding aquifer in the whole Surat Basin sequence at Woleebee Creek.

Bore/well name	Aquifer intersections (m bgl)	Screen location (m bgl)	Transmissivity[1] (m^2/day)	Indicative horizontal hydraulic conductivity Kh (m/day)	Comments
Gubberamunda Sandstone					
Woleebee Creek GW1	135 - 160 166 - 188	178 - 183	0.3 - 0.8[1]	0.08 - 0.16	Fine to coarse grained sandstone. 6-hr pump test at 0.45 L/s.
Woleebee Creek PB01[2]		165 - 185	5.5 - 12[1]	0.3 - 0.6	72-hr test pumping at 4 L/s
Woleebee Creek PB02[2]		181 - 199	7.3 - 20[1]	0.4 - 1.1	72-hr test pumping at 5.5 L/s
Woleebee Creek PB03[3]		215 - 233	10.5 - 20[1]	0.6 - 1.1	72-hr test pumping at 5.5 L/s
Woleebee Creek PB04[2]		189 - 208	6.6 - 22[1]	0.4 - 1.2	72-hr test pumping at 5 L/s
Westbourne Formation					
Kathleen MW03D		43.5 - 49.5		<0.037	Slug test
Kathleen MW08		59 - 65		<0.024	Slug test
Springbok Sandstone					
Woleebee Creek GW2	345 - 362 380 - 388 400 - 412 418 - 434	425 - 430	0.06	0.003	• Medium to coarse grained clayey sandstone • Fine to medium grained clayey sandstone • 49-minute test pumping at 0.9 L/s

Bore/well name	Aquifer intersections (m bgl)	Screen location (m bgl)	Transmissivity[1] (m^2/day)	Indicative horizontal hydraulic conductivity Kh (m/day)	Comments
Walloon Coal Measures (pilot tests)					
WCK_WH004			0.43		Multi-layer Unsteady state analysis for transmissivity (S = 0.0001). Extraction rate 125 m^3/d for less than 100 m pressure drop
WCK_WH004			0.54		Eden-Hazel equation analysis for transmissivity
WCK_WH005			0.02		Extraction rate 40 m^3/d with + 400 m pressure drop
WCK_WH006			0.07		Extraction rate 40 m^3/d with + 400 m pressure drop
Hutton Sandstone					
RN22117[3]	534.9 - 797.7		4.4	0.017	SWL 35.7 m bgl. Test pumping at 2 L/s on 31/08/2008. Open hole from 616.1 m to 707.6 m. Hence effective length in Hutton Sandstone is smaller than the aquifer intersection, and hence Kh is greater than calculated value
Precipice Sandstone					
WCK_GW4	1,465.5 - 1,573.7		480 482.3	4.7 4.7	MLU analysis Eden-Hazel Equation
WCK_GW10	1,399.7 - 1,503.7		520	5	MLU analysis (S=1.008 x 10^{-4})
Bundi Bore[4] RN123300	1,202 - 1,302		30.55	0.3	SWL 55.2 m bgl 24 hr test pumping 17/10/2004

Notes:
1. Transmissivity values calculated from step, constant rate and groundwater level recovery measurements
2. Bores located approximately 1.5 to 1.8 km west south-west of Woleebee Creek GW1
3. Approximately 8 km south west of Wandoan
4. Approximately 21.5 km north-west of Delga Park (Woleebee Creek block).

Table 7-1 – Groundwater hydraulic data in Northern Gas Fields

7.3 ANALYSIS AND INTERPRETATION OF PILOT PRODUCTION TESTS

The key activity of the connectivity program is the detailed monitoring of three CSG pilot tests with a monitoring network at variable depths in various geological strata. These tests generally involve up to six months of CSG water extraction, followed by six months recovery, from five wells in a cluster (termed a pilot). It is envisaged that the detailed monitoring of the overlying and underlying aquifers and aquitards will provide valuable information enabling an assessment of pressure changes and hence vertical leakage rates and thus vertical hydraulic conductivity (Kv). The analysis involves integrating three different sets of pressure data, from groundwater monitoring bores, from grouted vibrating wire piezometers and from the CSG extraction wells.

These monitoring networks will also provide an early indication of the actual groundwater responses under gas field operational conditions.

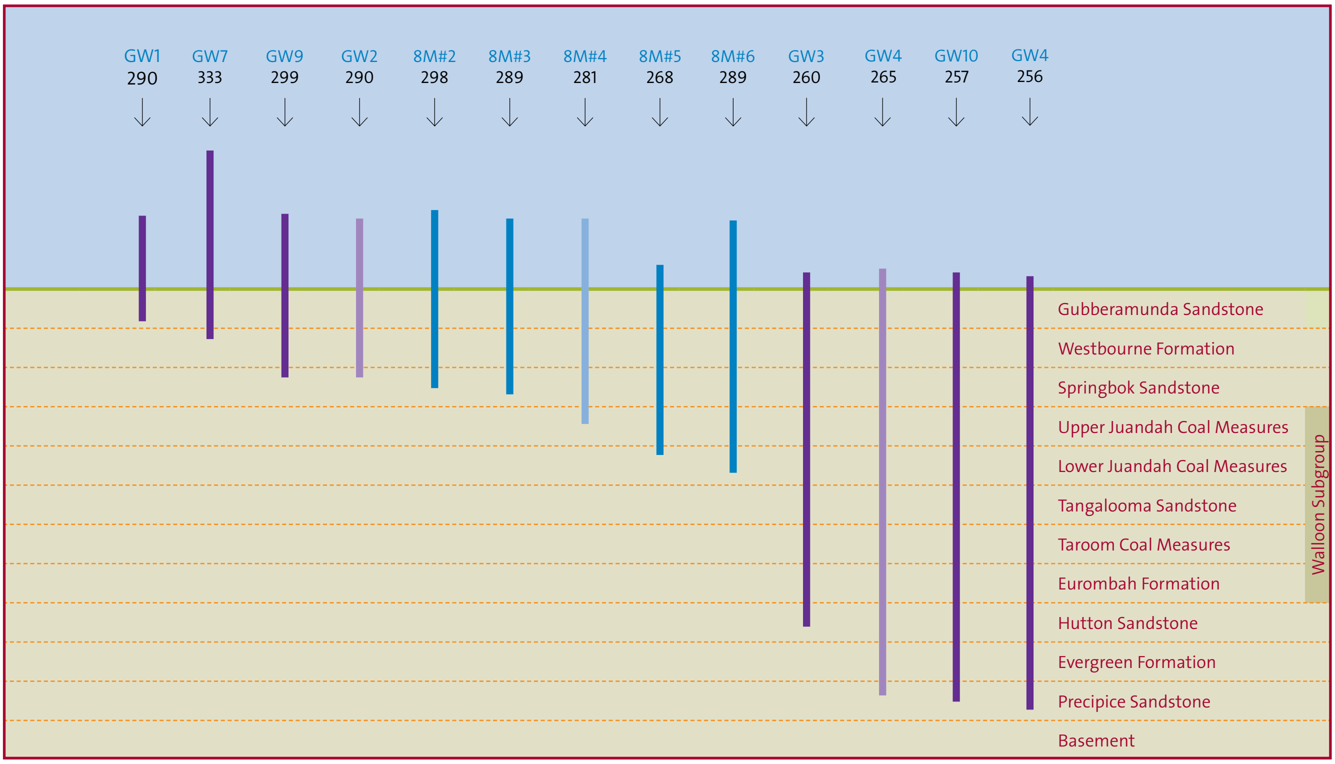


Figure 7-3 – Woleebee Creek P1 potentiometric surface levels (m AHD)

The three intensively monitored pilot test sites are Woleebee Creek P1, Kenya East P3 and Ruby Jo P2. All major formations have been monitored at these sites since December 2012 and are either undergoing baseline stabilisation or are actually monitoring the pilot tests underway. Background bore monitoring initially commenced at Woleebee Creek in December 2011, at Kenya East in June 2011 and at Ruby Jo in October 2012.

The June 2013 Connectivity Progress Report presented results up to 31 January 2013. This Stage 3 WMMP updates this data to June 2013 where it is available.

7.3.1 WOLEEBEE CREEK P1 PILOT TEST

Figure 7-3 presents a diagrammatic representation of the potentiometric levels from all the monitoring points at the Woleebee Creek P1 pilot test. This monitoring network represents the most comprehensive monitoring program at a specific site in the Surat Basin available to date. The data shown is in m AHD generally as at 16 October 2012, and the potentiometric levels have been temperature compensated. This date was adopted as the most complete data set available (as updated to June 2013) before commencement of the pilot test. The individual bore hydrographs are shown in Figure 7-4.

The Woleebee Creek pilot test has been underway intermittently since November 2012. Preliminary analysis of limited data at Woleebee Creek indicates no groundwater pressure response to date from the adjacent units.

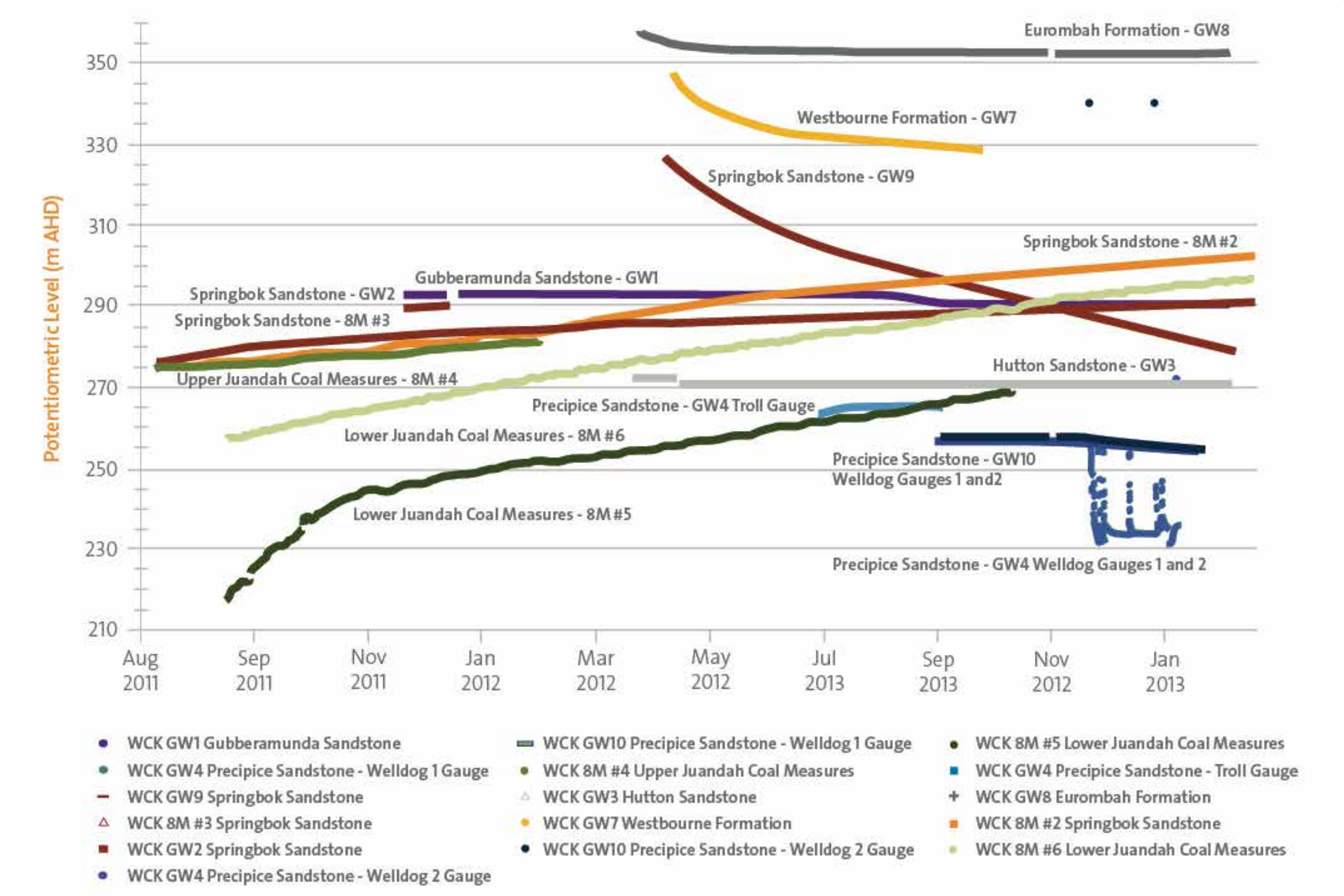


Figure 7-4 – Woleebee Creek P1 bore hydrographs

A numerical analysis of groundwater flow in layered aquifer systems was carried out for the Woleebee Creek CSG development block. Some of the output from this analysis is shown in Figure 7-5 and Figure 7-6. This is for the case of four wells pumping. This demonstrates, for a variety of cases of varying pumping stresses in the Walloon Subgroup, the juxtaposition between the time for a pumping response and the Kv of the bounded aquitards. This study indicates that the Kv of the aquitard layer underlying the Walloon Subgroup (the Eurombah Formation) should be greater than 2.5×10^{-5} m/d in order to get a discernible impact of 0.1 m in the underlying Hutton Sandstone within a reasonable pumping period of 100 days. This conclusion serves to demonstrate that the ability of a pilot testing program to measure the pumping response in the underlying Hutton Formation is strongly controlled by the values of Kv or, conversely that the ability of a field testing program to measure Kv is strongly controlled by the ability to impose sufficient pressure gradients on the system. As greater pressure difference is imposed, lower values of Kv can be discerned.

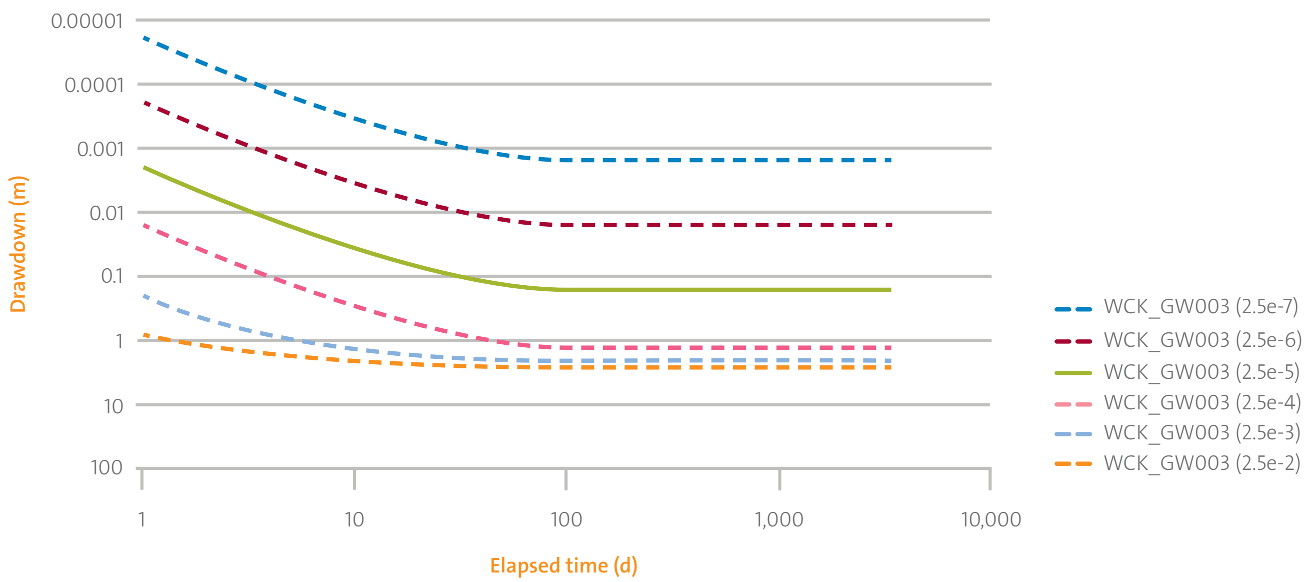


Figure 7-5 – Woleebee Creek, Case 2 analysis with varying Kv

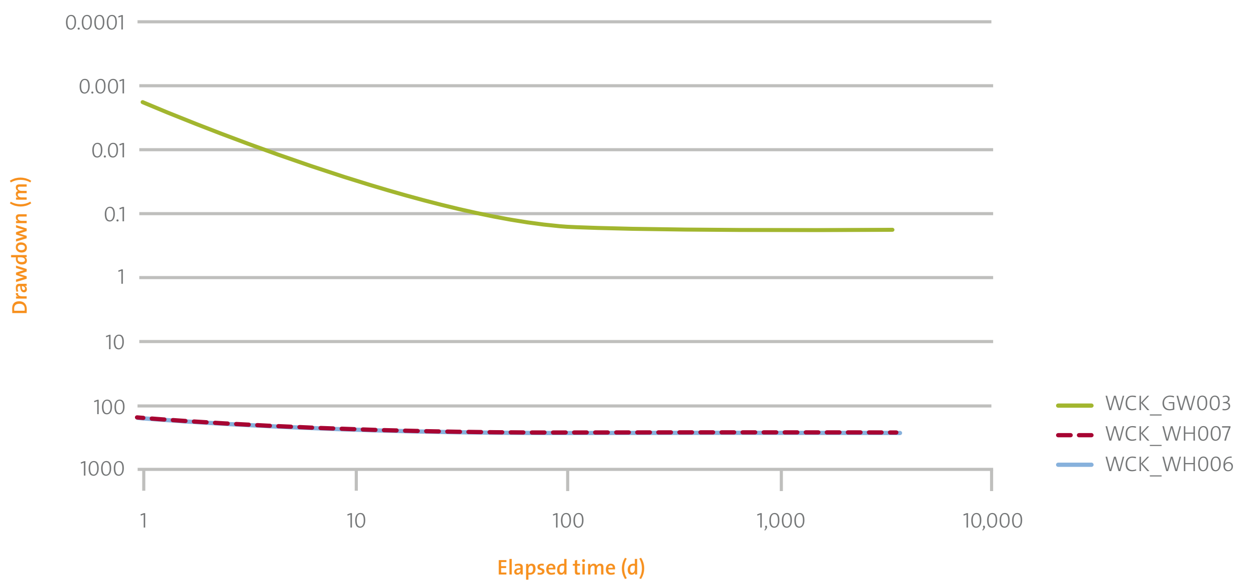


Figure 7-6 – Woleebee Creek, Case 2 with Kv of 2.5 X 10-5 m/d

7.3.2 KENYA EAST P3

Figure 7-7 presents a diagrammatic representation of the potentiometric surface levels from all the monitoring points at the Kenya East P3 pilot test. The data shown is in m AHD as at 18 October 2012, except for KEE_GW003, KEE_GW004 and KEE_GW007 where the data was measured on 17 December 2012. The potentiometric surface levels have been temperature compensated. The individual bore hydrographs are shown in Figure 7-8.

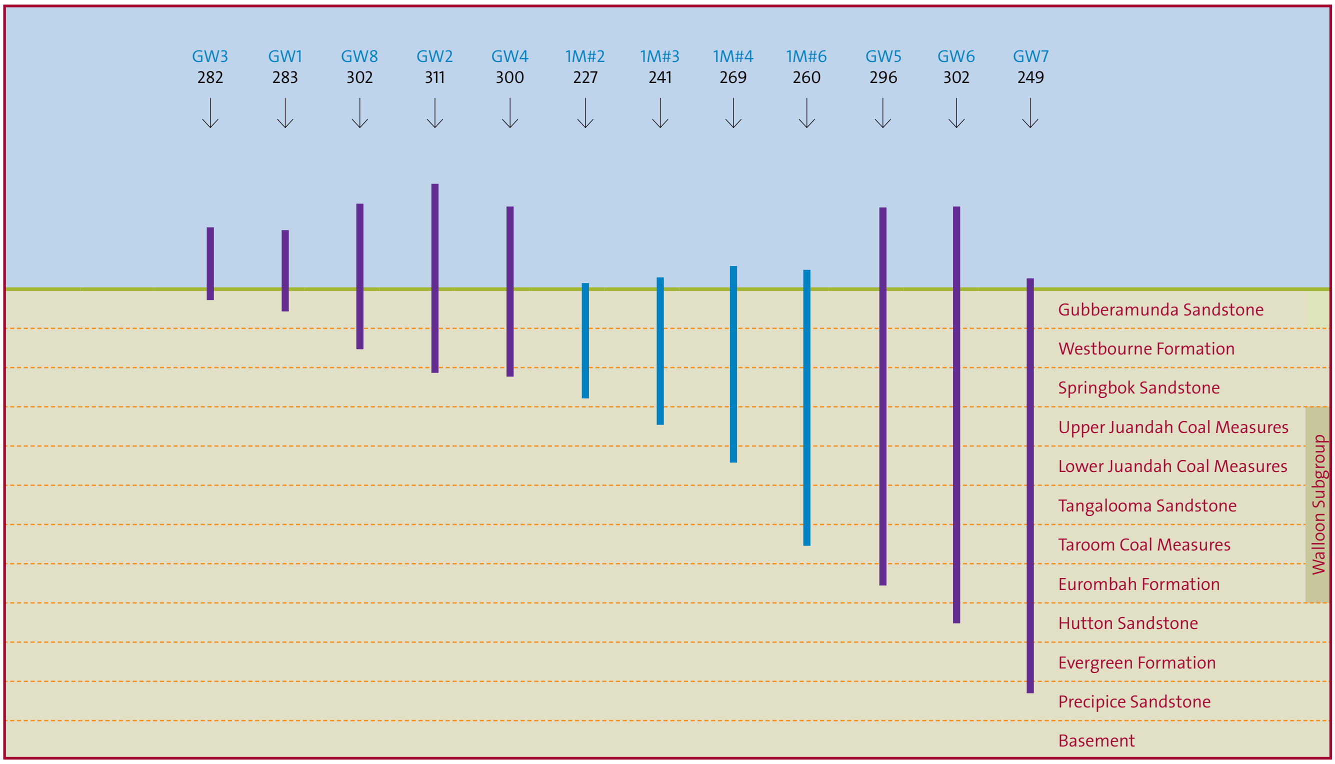


Figure 7-7 – Kenya East P3 potentiometric surface levels (m AHD)

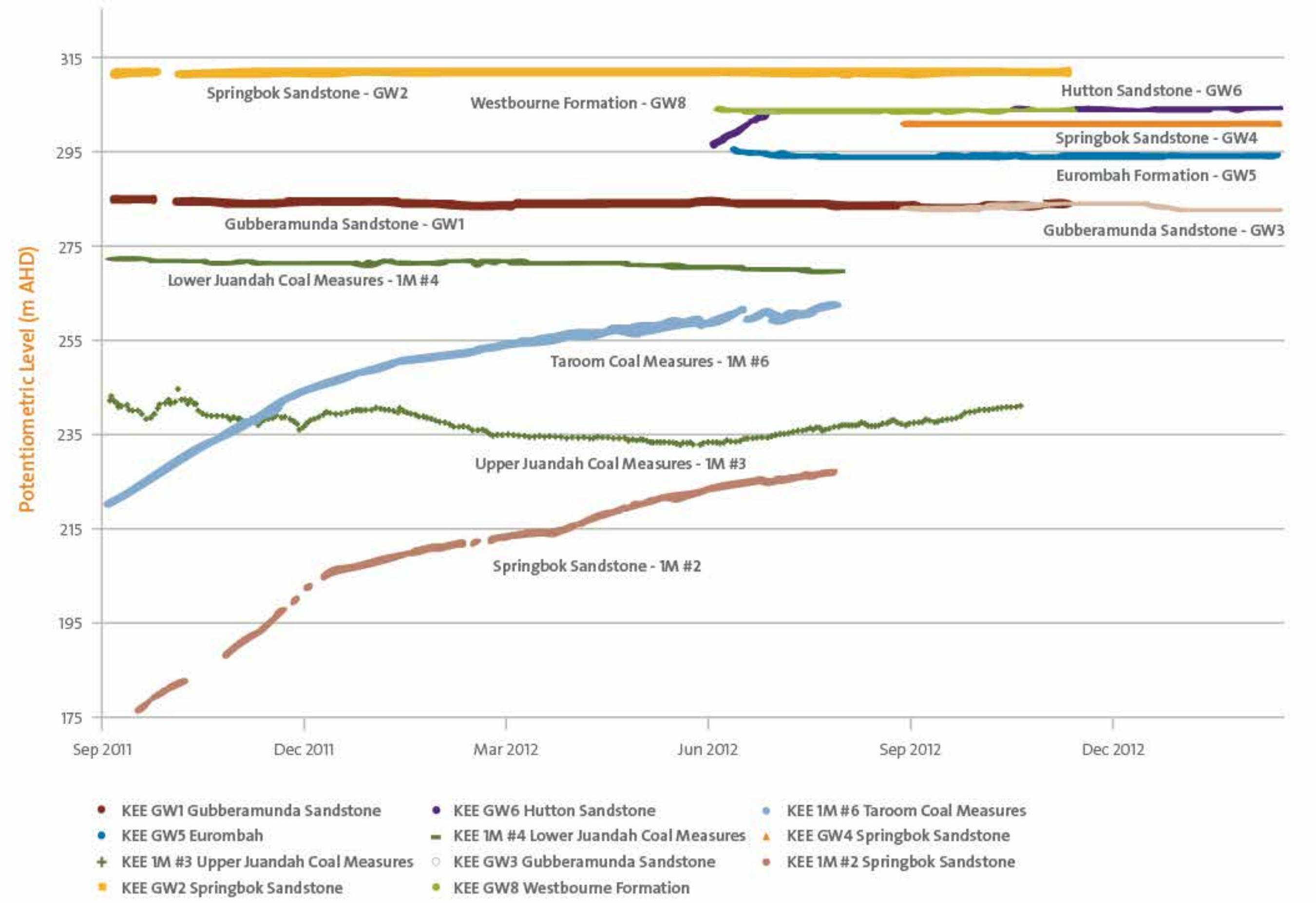


Figure 7-8 – Kenya East P3 hydrographs

Safety at work. Everyone has a duty to intervene to prevent accidents.

7.3.3 RUBY JO P2

Figure 7-9 presents a diagrammatic representation of the potentiometric surface levels from the monitoring points at the Ruby Jo P2 pilot test. The data shown is in m AHD as at 22 October 2012 for the VWP data and 23 February 2013 for the groundwater monitoring bores. The potentiometric surface levels have been temperature compensated. The individual bore hydrographs are shown in Figure 7-10.

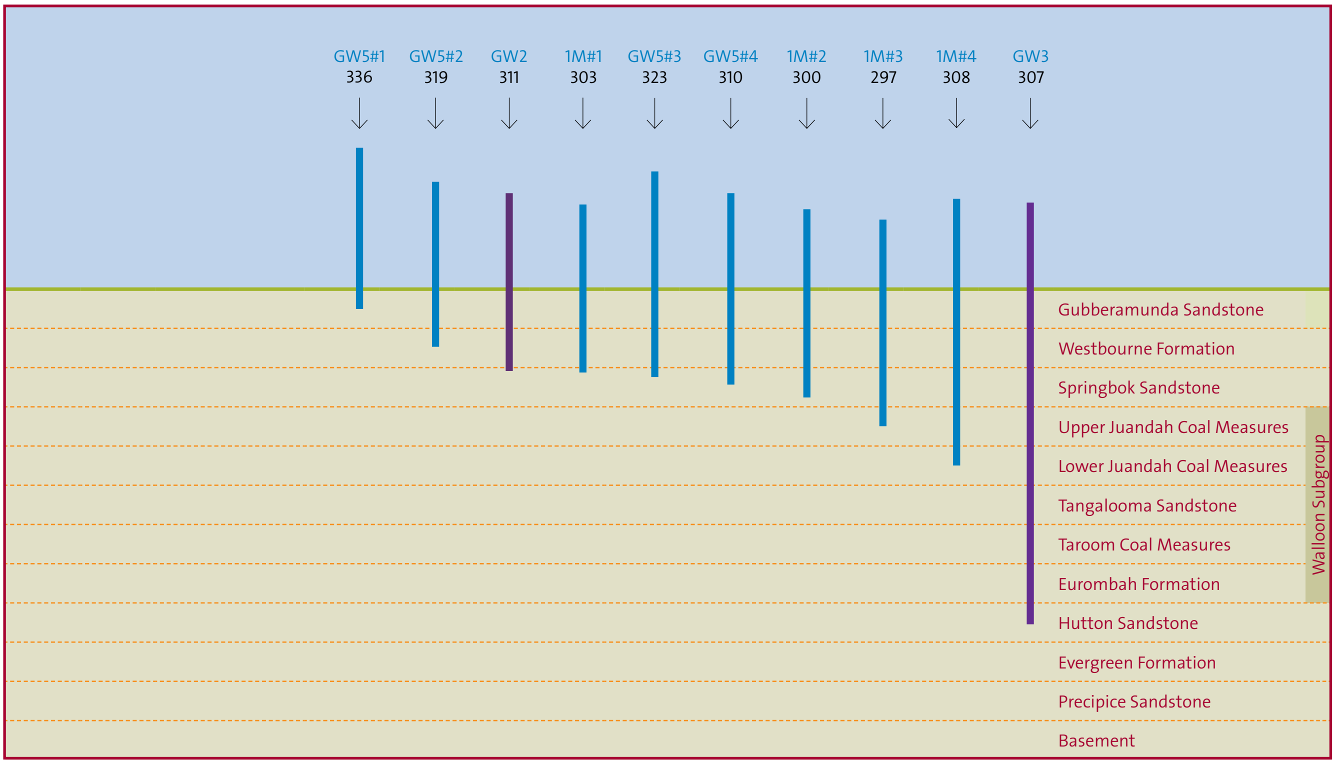


Figure 7-9 – Ruby Jo P2 potentiometric surface levels (m AHD)

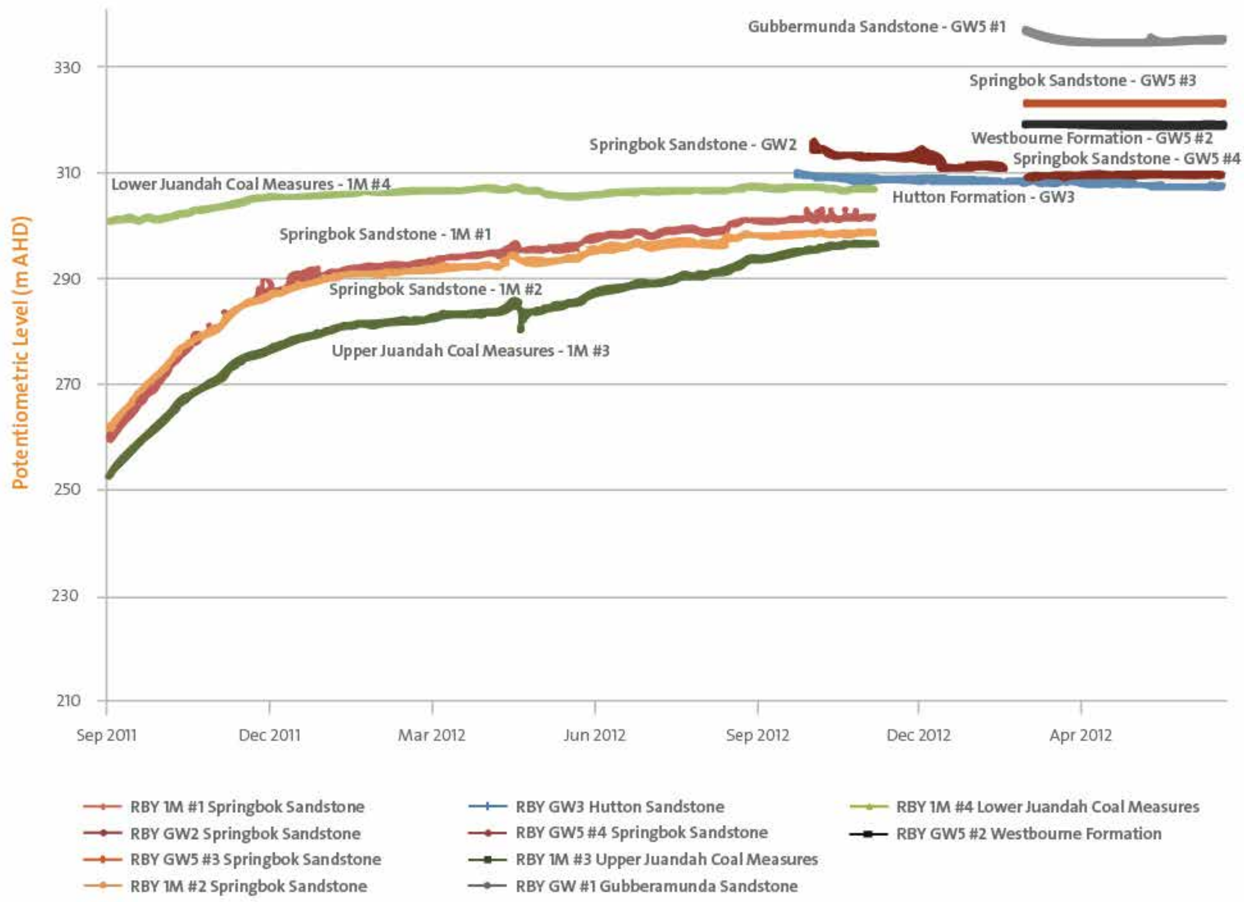


Figure 7-10 – Ruby Jo P2 hydrographs

7.4 EXISTING PRODUCTION FIELD MONITORING

Two producing gas fields are also included in the monitoring program. The Lauren field was chosen because significant pumping commenced in mid-2011. Aquifer monitoring bores were installed in late 2011. Although it may be considered that no groundwater level baseline is available, the limited monitoring of the upper aquifers to date indicates stable groundwater levels. It is noted that normal significant variation in groundwater levels due to a broad range of natural groundwater processes is occurring.

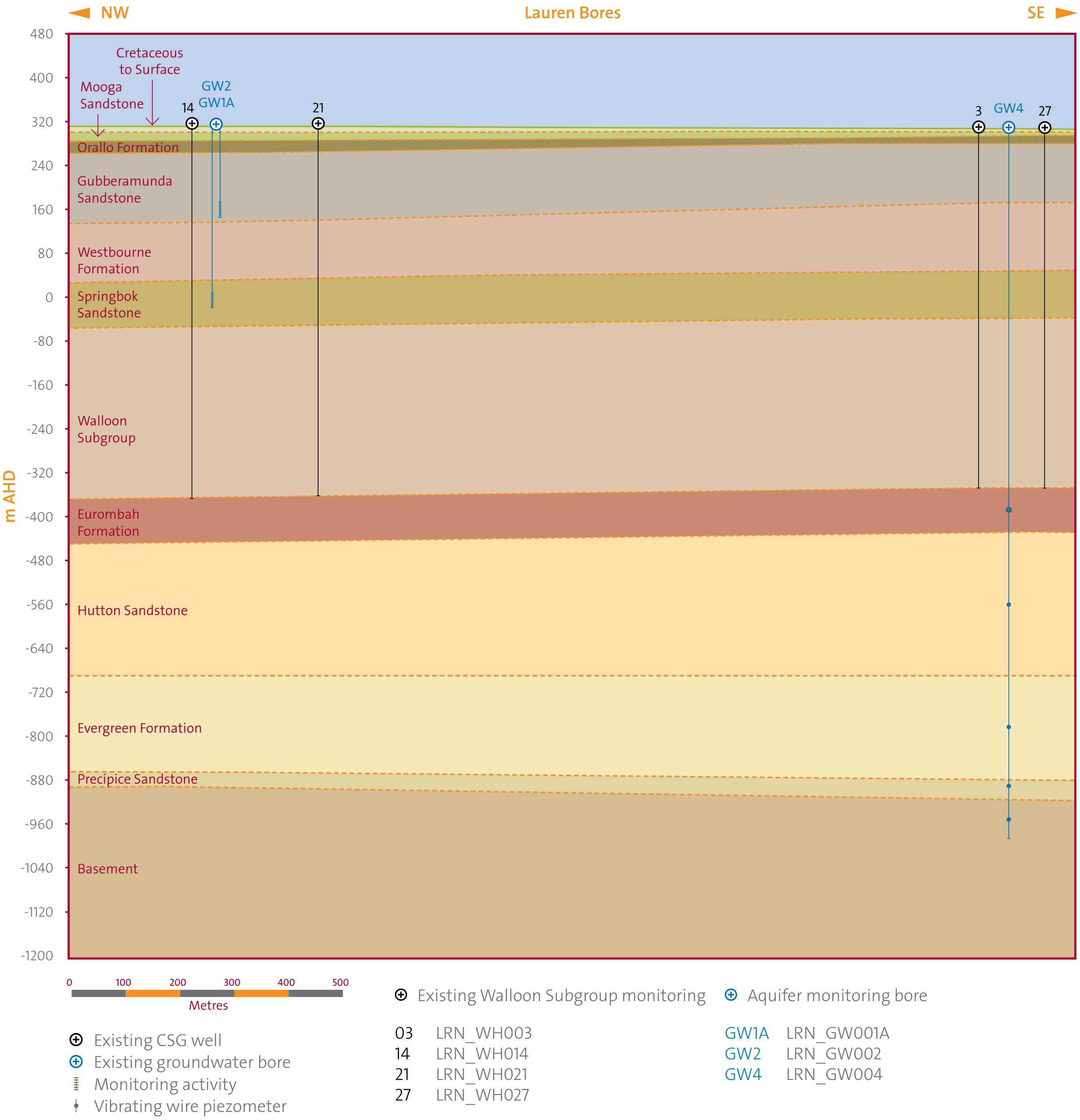


Figure 7-11 – Lauren cross-section

Figure 7-11 is a cross-section of the monitoring bores in the Lauren Field. Figure 7-12 and Figure 7-13 show the potentiometric surface data and the bore hydrographs for the groundwater monitoring bores up to June 2013. These demonstrate the strong upward hydraulic gradient between the Springbok and the Gubberamunda Sandstone, and the relatively stable behaviour.

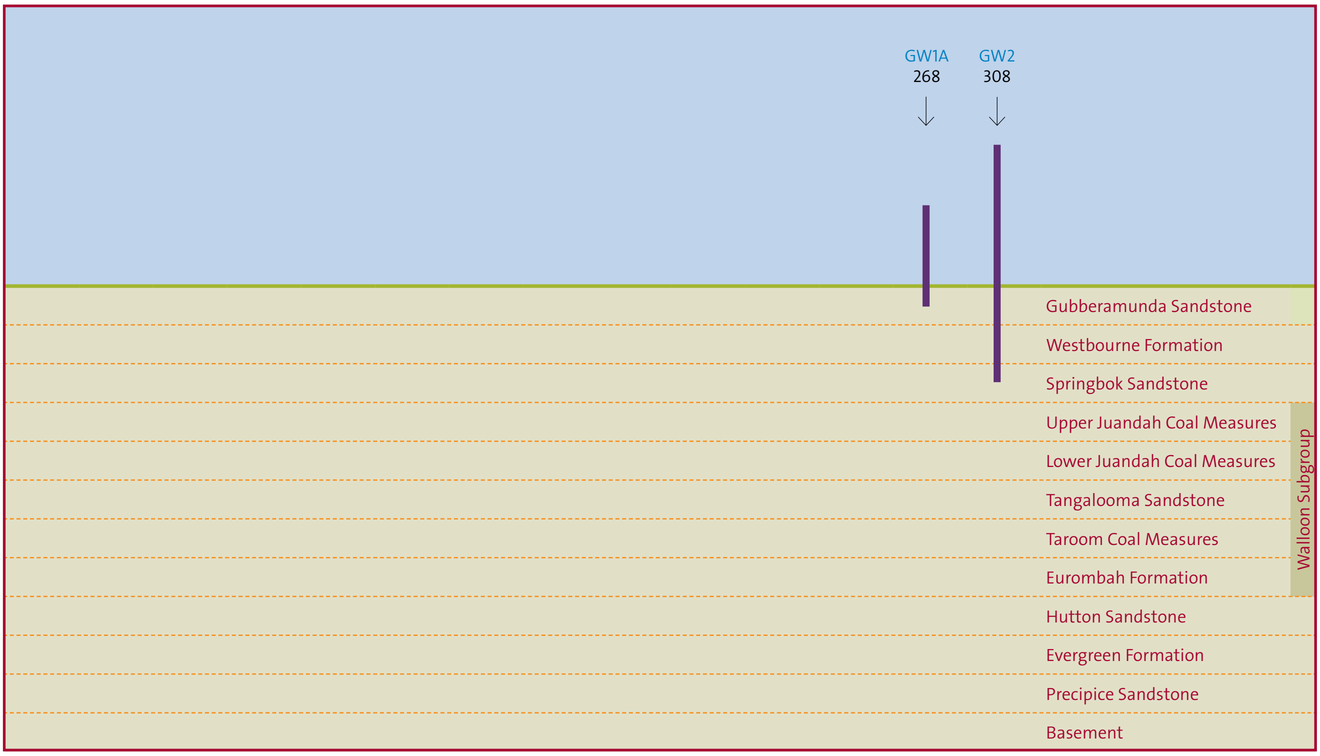


Figure 7-12 – Lauren potentiometric surface levels (m AHD)

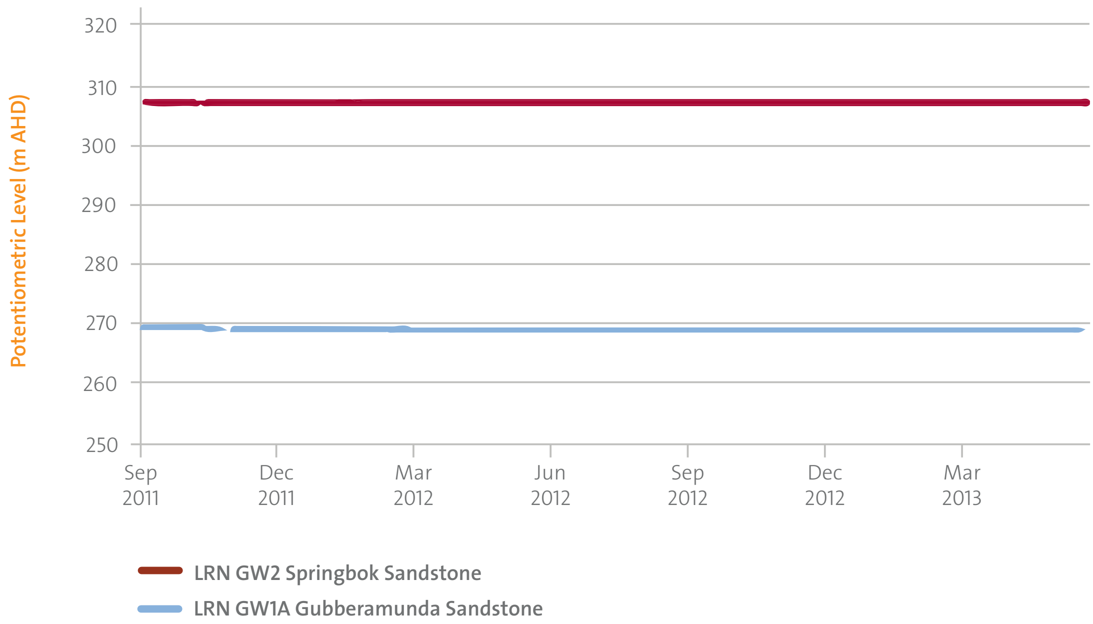


Figure 7-13 – Lauren bore hydrographs

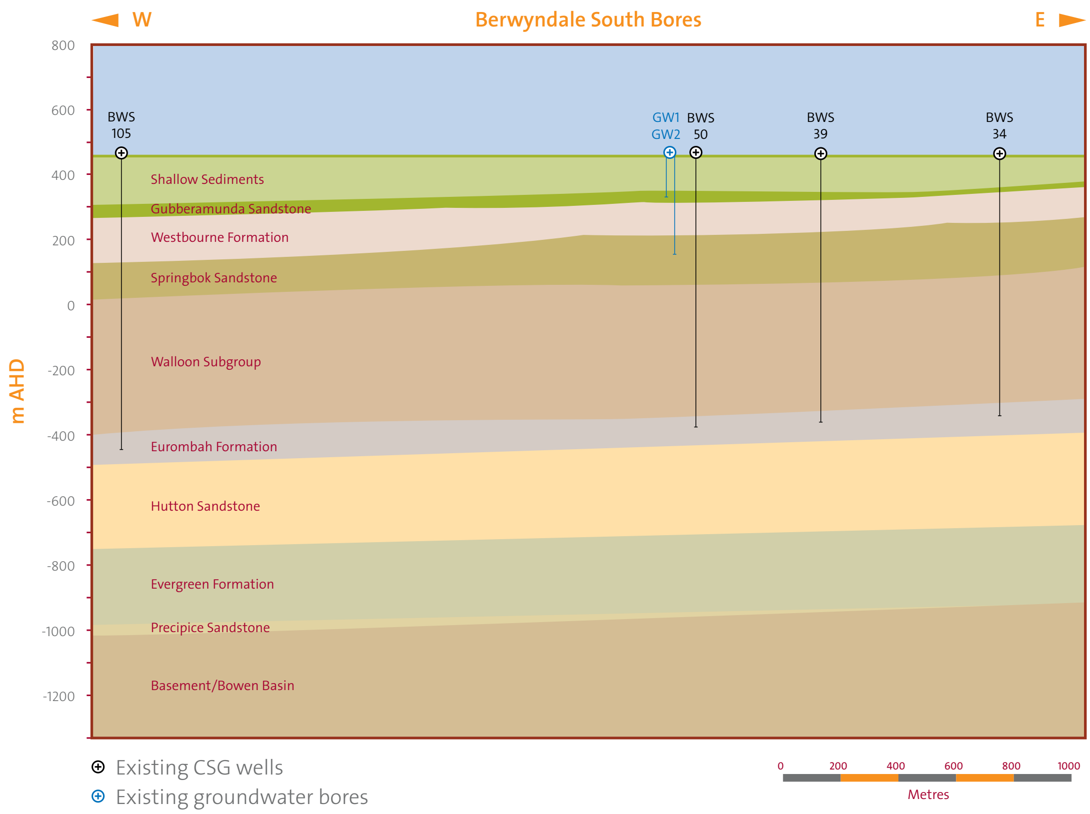
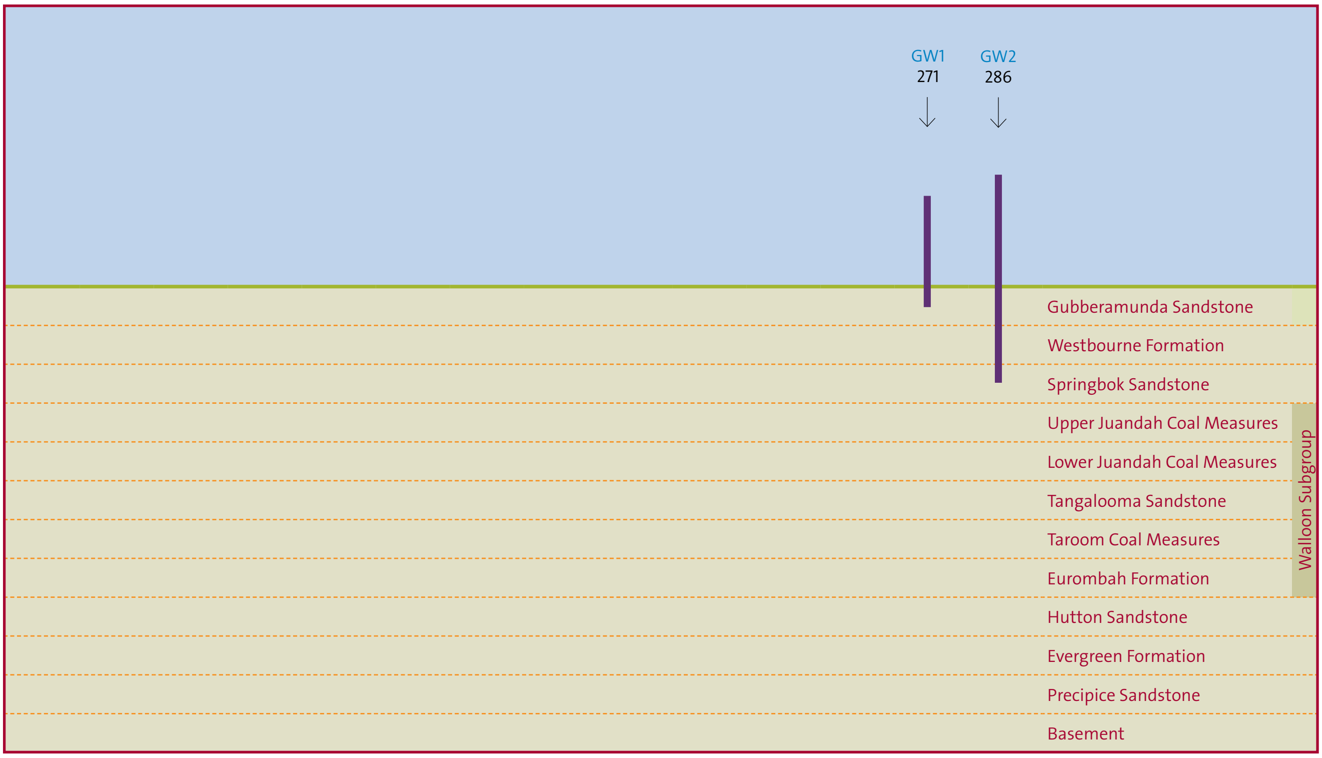


Figure 7-14 – Berwyndale South cross-section

The Berwyndale South field has also been chosen because commercial gas and associated water extraction has been underway since 2005, the oldest of the QGC blocks. Figure 7-14 is a cross-section of the monitoring bores in the Berwyndale South field. Two groundwater monitoring bores were constructed in 2011. Figure 7-15 and Figure 7-16 show the potentiometric surface data and the bore hydrographs for the groundwater monitoring bores in the Berwyndale South field up to June 2013. This monitoring shows a similar behaviour to the Lauren field (i.e. a strong upward hydraulic gradient between the Springbok and the Gubberamunda Sandstone, and relatively stable levels, albeit clearly influenced by rainfall).



Notes:
Data available 21/09/2011 – 26/02/2013
Data represented from 26/02/2013

Figure 7-15 – Berwyndale South potentiometric surface levels (m AHD)

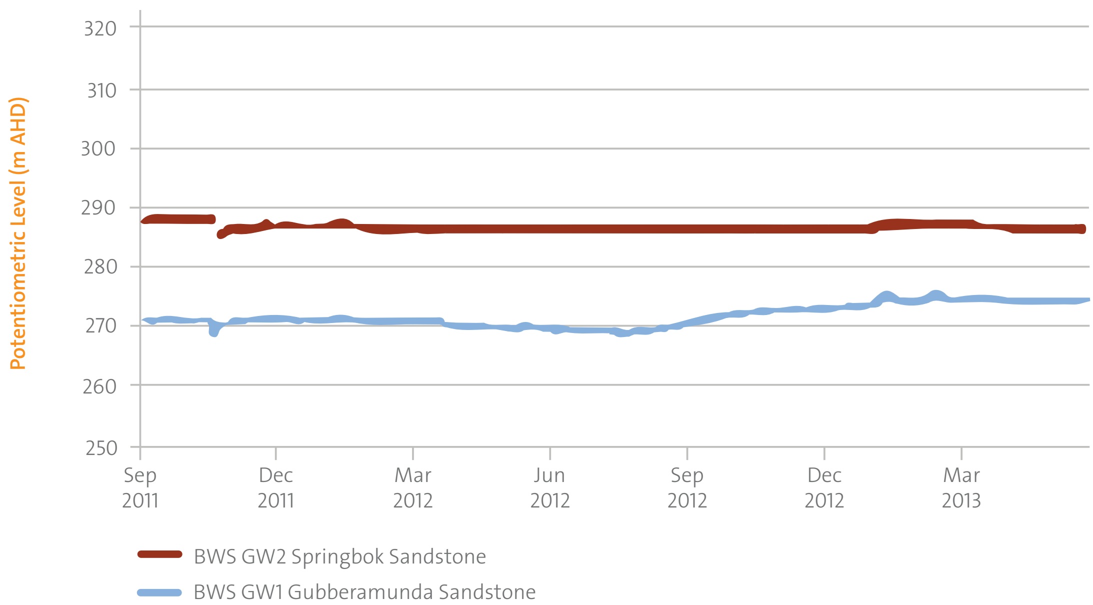


Figure 7-16 – Berwyndale South bore hydrographs

7.5 REGIONAL HYDROCHEMISTRY PRELIMINARY RESULTS

Hydrochemistry can also help characterise vertical connectivity. The preliminary regional hydrochemistry results are described in the Preliminary Hydrochemistry Model which forms Appendix K (QGC, 2013a) and summarised in Chapter 9. Based on the sampling and testing to date the initial conclusion is that under the relatively unstressed (quasi steady state) current conditions, horizontal flow processes dominate. Nonetheless a range of hypotheses for inter-formation flow are postulated that will be tested as more data becomes available.

7.6 CONDAMINE ALLUVIUM MONITORING

Monitoring on QGC tenements of the Condamine Alluvium and underlying formations is commencing. These results will be used in conjunction with Arrow Energy's studies to investigate the hydraulic relationship between the Condamine Alluvium and the underlying Walloon Subgroup. Arrow is planning several pumping tests in the Condamine Alluvium and will use the results from the adjacent QGC monitoring bores in the analysis.

7.7 EFFECTS OF INFRASTRUCTURE ON AQUIFER CONNECTIVITY

In addition to the potential for leakage between formations and along structures, it is recognised that inadequately constructed or poorly abandoned bores pose a possible route for vertical flow. In accordance with Commitment#8, a Stage 1 risk assessment has been carried out to determine the likelihood of potential leakage paths in the QCLNG project area due to any existence of poor bore and well integrity (Appendix I). The Stage 2 risk assessment report, which will be delivered in April 2014, will comprise the consequences of poor bore and well integrity on regional leakage rates. Together these two components will comprise the risk assessment. Additionally, a modelling methodology is described herein to incorporate the results of the Stage 1 risk assessment into the Stage 2 program and hence quantify the impacts of vertical leakage of these bores and wells on regional hydraulic heads using the GEN3 dual phase hydrogeological model.

Categorisation of the bore and well types and the results of the Stage 1 risk assessment are presented in Table 7-2. This table presents the assessed likelihood of the bore or well construction and condition to provide a vertical leakage path (regardless of the length of the leakage path).

Base or well type	Total number within QCLNG Project Area	Likelihood of potential leakage paths			Number of bores in surrounding areas
		High	Medium	Low	
Baselined groundwater bores	226	104*1	44	78	N/A
Non-baselined groundwater bores	107	73	10	24	N/A
Inherited conventional oil and gas and CSG wells	305	0	268	37	N/A
Legacy conventional oil and gas and CSG wells	44	32	11	1	N/A
Coal exploration bores	941	941*2	0	0	2,424
Total (excluding QGC CSG wells)	**1,623**	**1,150**	**333**	**140**	
QGC CSG production wells	6,000*3	0	0	6,000	
Total (including QGC CSG wells)	**7,623**	**1,150**	**333**	**6,140**	

Notes:
**1 12 of these are in the Walloon Subgroup or deeper (17 are of unknown depth)*

**2 Note that even though these bores have high likelihood of potential leakage paths, it is likely that the consequences of this leakage is generally low on QCLNG tenements as they are often drilled into the Springbok Sandstone and then into the Walloon Subgroup. It is believed that these penetrate the base of the Walloon Subgroup by exception. The impact of the Coal Exploration bores will be assessed in Stage 2.*

**3 As per EPBC 2008/4398 approval 22/10/2010*

N/A = Not Available

Table 7-2 – Bore and well types on QCLNG tenements and the likelihood of potential leakage paths

The likelihood of potential leakage pathways is defined primarily as a function of age for the casing as defined in Table 7-3.

Criteria	Risk of failure		
	Low	Medium	High
Mild Steel: Age	0-10 years	10-30 years	>30 years
PVC: Age	0-30 years	30-60 years	>60 years

Table 7-3 – Bore failure risk assessment criteria

An important aspect of this assessment is to define which bores and wells QGC is legislatively responsible for, namely:

- QGC is responsible for groundwater bores on QGC owned land and for CSG wells and water bores drilled by or for QGC or its related bodies corporate;
- QGC is also responsible for inherited wells drilled by companies which have been purchased by QGC (“Inherited Wells”);
- Conversely, the State of Queensland is responsible for water bores, old oil and gas and CSG wells (not part of QGC predecessors) and coal exploration bores located on QCLNG tenements which have not been drilled by QGC or its related bodies corporate. The wells are termed “legacy wells” in this report.

- QGC wells constructed after November 2008 are rated as low likelihood of failure as they are expected to have been constructed to high standards, as described in Section 3.4.2. Nonetheless it is recognised that a small percentage may have construction issues and QGC has procedures in place to identify and rectify these issues.

The determined likelihood of bore failure was primarily based on the age and casing material of the bore or well, and bore condition observations where available. Based on these criteria, each bore and well was assigned a likelihood of failure rating of low, medium or high. This methodology included the QGC inherited conventional oil and gas and CSG wells, which received a medium and low rating depending upon recent P&A activities.
Coal exploration bores received a high rating.

Bore failure risk was determined by assessing the age of the bore or well, the casing material, and for groundwater bores with a completed bore baseline assessment, bore condition comments provided in the baseline assessment forms and observations of bore condition made by reviewing photographs collected during the baseline assessments. The risk of failure for each bore and well was assigned a value of low, medium or high risk based on the criteria in Table 7-3. These ages have been developed based on general subjective experience.

If bore condition comments and/or observations indicated that despite the age, the bore was heavily or severely corroded, the risk level was increased a level. If age was unknown, but photographs and/or bore condition comments provided insight into its age and condition, these were used for ranking. Where information was missing to confidently assign a risk value, the default value assigned was medium risk.

Bores and wells that were assigned a low rating have not been included in the modelling methodology, which has been designed to assess the vertical leakage impacts on regional hydraulic heads. A specified percentage of bores and wells with medium rating and high rating will be included in the regional modelling based on a randomised selection for three modelling scenarios of minor, moderate and major leakage.

Regional modelling of leakage due to integrity failures includes 83 unique cases of vertical leakage scenarios based on risk rankings and construction types for the data sets. Vertical leakage rates from along the bore/well annulus are estimated based on a continuous effective flow area (%) that is represented in the model as a 'micro' bore/well of equivalent diameter. This effective flow area was considered across defined vertical zones (Z1 and/or Z2) for each bore/well. The modelling scenarios will be evaluated over the next few months and will be reported in April 2014, Commitment #57.

7.8 KEY FINDINGS TO DATE

- The conceptual hydrogeological model developed in Chapter 5 highlights the distinction between local flow systems and regional flow systems. This includes the clear confirmation of northerly flow directions into the Dawson River Catchment.
- The downward hydraulic gradient at the Woleebee Creek pilot test site is consistent with the regional flow direction being the opposite of the dip of the strata. This suggests that groundwater recharge to the Walloon Subgroup in the Northern Surat Basin has occurred by rainfall infiltration and vertical leakage from the overlying formations.
- The hydrochemistry analysis of pre CSG development systems suggests a predominantly horizontal flow component. There is also a promising use of isotopes to differentiate the Gubberamunda Sandstone from the Springbok Sandstone (see Chapter 9).

- The lack of stabilisation of some of the monitoring bores and VWPs even 12 months after construction is testament to both the very low hydraulic conductivity of the aquitards and also to the problem of ideally having a very long period to establish the baseline. The open standpipe bores in general provide good stabilised data in all aquifer formations.
- A major groundwater monitoring program at the three pilot test sites is in place to assess future impacts. Very preliminary data analysis demonstrates that within a reasonable pumping period of 100 days and with a discernible impact of approximately 0.1 m, the Woleebee Creek P1 pilot test may be able to demonstrate an effect in the underlying Hutton Sandstone if the Kv is approximately equal to or greater than 2.5×10^{-5} m/d. This conclusion serves to demonstrate that the ability of a field testing programme to measure varying values of Kv is strongly controlled by the ability to impose sufficient stress on the system. As greater stress is imposed, lower values of Kv can be discerned, or conversely at the typical stresses imposed by a pilot test, only the mid to higher values of Kv (if present) can be measured.
- The pilot test monitoring networks will also provide an early indication of the actual groundwater responses under operational conditions.
- There is growing evidence of no flow across a well-defined fault at the Jen Block pilot location, within the spatial and temporal scale of a pilot test.
- Limited preliminary monitoring at Lauren and Berwyndale South (September 2011 to January 2013) suggests no drawdown response in the overlying Springbok Sandstone from domestic CSG water extraction.
- Comprehensive groundwater level and quality monitoring infrastructure is now almost in place to enable the measurement of vertical leakage for aquifer connectivity assessment at six locations on QCLNG tenements.
- A screening level assessment of bores and wells on QGC tenements has been completed and old oil and gas wells and privately owned water bores have been identified as the potentially greatest at risk categories. A risk based approach and groundwater modelling has been carried out to assess the magnitude of potential leakage impacts of at risk bores.
- An approach for understanding and predicting any possible impact on the Condamine Alluvium has been developed.

These findings are explained in detail in Appendix I.

7.9 ONGOING CONNECTIVITY PROGRAM

The comprehensive connectivity assessment program will comprise 10 major tasks over the timeframe shown in Figure 7-17, as follows:

Analysis of formation tests

Three steps will be taken to integrate the data from the formation tests (DST, DFIT, MFT and FRT) of the Surat Basin.

- The data collection phase occurs during the drilling of the bore and will continue until January 2014;
- Data analysis consists of pressure and permeability analysis of the drawdown measurements made with each tool; and
- Data interpretation is the third step where the results of the analysis are used to compare and calibrate petrophysical logs and current geological models to produce more accurate conceptualisation of groundwater flow units in the system.

Analysis of aquitard and aquifer properties

The hydrostratigraphic characterisation and interpretation study is to collate data, interpret, and evaluate Surat Basin hydrostratigraphy in the Central Development Area (CDA). One objective is to review and enhance current QGC hydrogeological conceptual thinking of those formations proximal to the Walloon Subgroup and therefore could be affected by CSG development. The second objective is to build a strong foundation of aquifer and aquitard classifications utilizing stratigraphy, petrophysics, core and wireline logs. The deliverables of this study are:

- Identify formational and intra formational units and features with significant flow potential; and
- Identify areas with a semi-quantified leakage risk.

The evaluation will be on the Westbourne Foundation, the Springbok Sandstone, Eurombah Formation and the Hutton Sandstone due to the proximity of the formations to the Walloon Subgroup in the Surat Basin Jurassic sequences. Well and seismic data will undergo data quality control. Within a lithostratigraphic framework, the study will define depositional sequences and parasequences in a continental setting. Petrophysical modelling will provide property values. Risking methodology inputs could include thickness, a range of permeabilities aligned with GEN3 modelling results, lateral extent, and lithological changes. The deliverables can then be compared with pressure and hydrochemistry information for proof of concept.

Woleebee Creek P1, Ruby Jo P2, and Kenya East P3 Pilot test data assessment, modelling and interpretation

The three pilot tests will take about 12 months to be completed (including six months of recovery), followed by analysis, analytical modelling and possibly numerical modelling, as described in the June 2013 Progress Report. It is planned to produce a progress report in April 2014 which will present the pilot test results for the first six months of pumping.

Lauren and Berwyndale South Production Fields

Ongoing groundwater monitoring data from these two gas production fields will be progressively analysed to identify any possible effects of depressurisation of the Walloon Subgroup.

Regional Hydrochemistry Characterisation

The hydrochemistry and isotope characterisation program, which is discussed in Chapter 9, will be used to develop hypotheses on the potential and magnitude of inter-aquifer mixing across flux boundaries.

Condamine Alluvium assessment

The possible impact of QGC depressurisation of the Walloon Subgroup on the Condamine Alluvium involves the construction of further monitoring bores, ongoing monitoring, active liaison with Arrow Energy in relation to their pumping tests on tenements adjacent to QGC's tenements, and the analysis of all relevant data on the Condamine Alluvium and underlying formations. This is expected to lead to a revised conceptual hydrogeological model of the region. After this it is planned to develop a local scale numerical model so that the possible effects of QGC's activities can be predicted.

Effects of Infrastructure on aquifer connectivity

As described in the June 2013 Connectivity Progress Report, this assessment will involve two stages, as follows. A leaking bore risk assessment will be initially undertaken. This will involve identifying all those high risk wells and bores which might increase the regional scale Kv. This will be followed by using the GEN3 model to quantify the possible effects.

Task	Activity	Completion date	2013							2014											
			Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Analysis of formation tests: DST, DFIT, MFT, FRT	Oct 2014																			
2	Aquitards. Further geological data assessment and interpretation	Dec 2013																			
3	Woleebee Creek P1 Pilot Test. • Progress report • Data assessment modelling and interpretation	 Apr 2014 Oct 2014																			
4	Ruby Jo P2 Pilot Test. • Progress report • Data assessment modelling and interpretation	 Apr 2014 Oct 2014																			
5	Kenya East P3 Pilot Test. • Progress report • Data assessment modelling and interpretation	 Apr 2014 Oct 2014																			
6	Lauren and Berwyndale South production field. Further analysis of monitoring data	Apr 2014																			
7	Regional hydrochemistry characterisation. Further assessment of potential and magnitude of inter-aquifer mixing across flux boundaries	Jul 2014																			
8	Condamine alluvium. • Broadwater block bore construction, data gathering and analysis of all relevant Condamine alluvium data and revised conceptual model • Local scale Condamine Alluvium model	 Apr 2014 Oct 2014																			
9	Effects of infrastructure on aquifer connectivity: • Leaking bore risk assessment • Modelling of impacts of leaking bores on connectivity	 Oct 2013 Apr 2014																			
10	Connectivity Report, followed by three-yearly reviews	Oct 2014																			

Figure 7-17 – Aquifer connectivity forward program

The status of the Commitments relevant to Connectivity is as follows:

#	SEWPaC Condition		Description	Completion date	Status
	Pre-Dec 2012	Post-Dec 2012			
7	**49b**		Submission of aquifer connectivity studies progress report	April 2013	● (green)
8	**49b**	**53B a**	Submission of Infrastructure Connectivity Report	October 2013	● (green)
57		**53B a**	Submission of updated aquifer connectivity studies progress report	April 2014	● (red)

● (green) Commitments completed
○ (green) Commitments work in progress
△ (green) Evergreen Commitments
● (red) Firm deliverables for that month