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# SHELL CANADA LIMITED

## Quest Carbon Capture and Storage Project

## FIFTH ANNUAL STATUS REPORT

**Prepared By:**
Shell Canada Limited
Calgary, Alberta

March 31, 2017

Revision: May 5, 2017

The Fifth Annual Status Report addresses the AER application approval referenced in the Carbon Dioxide Disposal Approval No. 11837C the "Approval", issued on May 12th, 2015 to Shell Canada Limited [1]. This report addresses Conditions 10 and 17 of the Approval.

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# 1. SPECIFIC REQUIREMENTS

The following Table 1-1 lists the requirements for Annual Reporting as listed in the AER QUEST Project Approval No 11837C [1], and the corresponding Section in this report:

Table 1-1: Concordance Table.

| Requirement as listed in the Alberta Energy Regulator (AER) Quest Project Approval No 11837C | Section |
|---|---|
| 10) The Approval Holder must provide annual status reports and presentations. The reports must be aligned with the most current MMV plan and submitted to ResourceCompliance@aer.ca. The report must be in metric units and include: | |
| a) a summary of scheme operations including, but not limited to, | 2 |
| i) any new project wells drilled in the reporting period, | 2.2 |
| ii) any workovers/treatments done on the injection and monitoring wells including the reasons for and results of the workovers/treatments, | 2.3 |
| iii) changes in injection equipment and operations, | 2.3 |
| iv) identification of problems, remedial action taken, and impacts on scheme performance. | 2.3<br>4 |
| b) complete pressure analysis including but not limited to stabilized shut-in formation pressures and a discussion on how the pressure compares with the formation pressure expected for the cumulative volume of $CO_2$ injection, along with an updated estimate of what the actual cumulative injection volume will be at the maximum shut-in formation pressure specified in clause 5) a), | 3 |
| c) discussion of the overall performance of the scheme, including: how the formation pressure is changing over time; updated geological maps; and updated $CO_2$ plume extent and pressure distribution models, if needed. The updated models should be based on all new data obtained since the last model run including the cumulative $CO_2$ injected to the end of the reporting period. | 3<br>3.4 |
| d) a summary of MMV Plan activities, performance and results in the reporting period, including, but not limited to: | 4 |
| i) a report on any event that exceeded the approved operating requirements or triggered MMV activities, | 4 |
| ii) comparison of measured performance to predictions, | 3.3<br>4.1 |
| iii) summary of operations and maintenance activities conducted, | 4.1 |

| Requirement as listed in the AER Quest Project Approval No 11837C | Section |
|---|---|
| iv) details of any performance or Measurement, Monitoring, and Verification (MMV) Plan issues that require attention, | 4.5 |
| v) pressure surveys, corrosion protection, fluid analyses, logs and any other data collected that would help in determining the success of the scheme, and | 2.3 |
| vi) discussion of the need for changes to the MMV plan. | 5 |
| e) a table for all wells listed in clause 3)(1) a), showing the following injection data for each month of the reporting period: | 3.1 |
| i) mole fraction of the $CO_2$ and impurities in the injection stream, | 3.1 |
| ii) volume of the $CO_2$ injected at standard conditions, | 3.1 |
| iii) formation volume factor of the injected $CO_2$ stream (not applicable since $CO_2$ is in dense phase), | N/A |
| iv) cumulative volume of the injected $CO_2$ at standard conditions following the commencement of the scheme, | 3.1 |
| v) volume of the $CO_2$ injected at reservoir conditions, | 3.1 |
| vi) hours on injection, | 3.1 |
| vii) maximum daily injection rate at standard conditions, | 3.1 |
| viii) average daily injection rate at standard conditions, | 3.1 |
| ix) maximum wellhead injection pressure (MWHIP) and corresponding wellhead injection temperature, | 3.1 |
| x) average wellhead injection pressure, corresponding average wellhead injection temperature, | 3.1 |
| xi) maximum bottom hole injection pressure (MBHIP) at the top of injection interval and the corresponding bottom hole injection temperature, and | 3.1 |
| xii) average bottom hole injection pressure at the top of injection interval and the corresponding average bottom hole injection temperature. | 3.1 |
| f) a table showing the volumes of injected $CO_2$ on a monthly and cumulative basis, | 3.1 |
| g) Hall Plots of constant average reservoir pressure where unexplained anomalous injection rate and pressure data could indicate fracturing. | 3.2 |
| h) a plot showing the following daily average data at standard conditions versus time since the commencement of $CO_2$ injection: | 3.1 |
| i) daily $CO_2$ injection rate, | 3.1 |
| ii) wellhead and bottom hole injection pressure, and | 3.1 |

| Requirement as listed in the AER Quest Project Approval No 11837C | Section |
|---|---|
| iii) estimated or measured average reservoir pressure in the Basal Cambrian Sandstone (BCS) formation. | 3.1 |
| i) the potential need for installing additional monitoring towards the periphery of the pressure build up area later in the project life, | 5.4 |
| j) evaluate the need for additional deep monitoring wells adjacent to the four legacy wells in the approval area. Based on the information provided the ERCB may require the Approval Holder to drill one or more such deep monitoring wells, and | 5.4 |
| k) discussion of stakeholder engagement activities in the reporting period. | 6 |
| 17) The Approval Holder must provide ongoing annual reports beginning March 31, 2016 through to March 31, 2040. The report must include all the requirements listed in clause 10. The Approval Holder must provide a report and presentation of general performance of prior calendar year, identification of operations problems, and discussion of the need for MMV changes. Include updates, conclusions and review of: | |
| a) need for additional deep monitoring wells adjacent to the four legacy wells in the approval area, | 5.4 |
| b) results from well testing including data from annual hydraulic isolation logging, | 2.3 |
| c) need for further hydraulic isolation logging beyond the first five years of injection, | 2.3 |
| d) projected timing for additional 3D surface seismic surveys, | 5 |
| e) required frequency of time-lapse seismic surveys, | 5 |
| f) update of $CO_2$ plume and pressure front models including the results of the prescribed BCS Formation reservoir pressure fall-off test two years after the start-up of each injection well, | 3.4 |
| g) need for ongoing BCS Formation fall-off shut-in reservoir pressure tests in all injection wells, | 5.4 |
| h) updated geology, and | 3.4.1 |
| i) potential need for additional monitoring wells towards the periphery of the pressure build up area. | 5.4 |

N/A means that the specific requirement is not applicable at this time.

# 2. CONSTRUCTION AND SCHEME OPERATIONS UPDATE

## 2.1. Capture and Pipeline Construction

Capture and pipeline construction was completed in 2015 [5], and on 29th September 2015, the commercial operations' certificate for Quest was issued .

## 2.2. Project Wells / SCVF

Shell completed drilling all the wells currently planned for the operations phase of the Project in 2012 and 2013. Table 2-1 is a synopsis of all the completed drilling activity for the Quest Project. No more wells are expected to be drilled for this project unless required as per the conditions in AER approval 11837C [1].

Post drilling, surface casing vent flows (SCVF) were identified in all deep monitoring and injection wells, as well as gas migrations (GM) in IW 7-11 and IW 5-35.

As required, annual testing was completed in 2016 for surface casing vent flow (SCVF) and Gas Migration (GM) at the injection pads. Reports were sent to AER in June 2016.

The SCVF flow test results for both IW 5-35 and IW 7-11 are summarized in Figure 2-1. Measurements at IW 5-35 are at similar levels to those observed in June 2015. There is an increase at IW 7-11 though the overall level is still very low. No gas was detected on the SCVF measurements on IW 8-19, indicating that the surface casing vent flow on this well has declined to zero. (Figure 2-1). The compositional results indicate that the SCVF gas in the IW wells is predominately methane.

Gas Migration testing (as per AER Directive 20) was performed on both wells. Previously the gas migrations observed on IW 5-35 and IW 7-11 occurred as bubbles in the well cellars. The air gas concentration measurements were sampled along the 4 cardinal directions, starting 30cm from each wellhead and then every 1m with 6 points acquired in every direction. In June 2016 no gas bubbles were observed in the IW 7-11 cellar, and gas bubbles were observed in the IW 5-35 cellar.

No gas was detected around IW 7-11 and gas migration appears to have declined to zero. At IW 5-35 the gas measurements 30 cm from the wellhead declined from 57% to 31% relative to 2015. At IW 5-35, the gas measurements 130 cm from the wellhead increased marginally from 4.3% to 4.8% relative to 2015, and 230 cm from the wellhead the measurements declined from 0.86% to 16 ppm. The gas migrations have limited impact and no potential for concern beyond the lease.

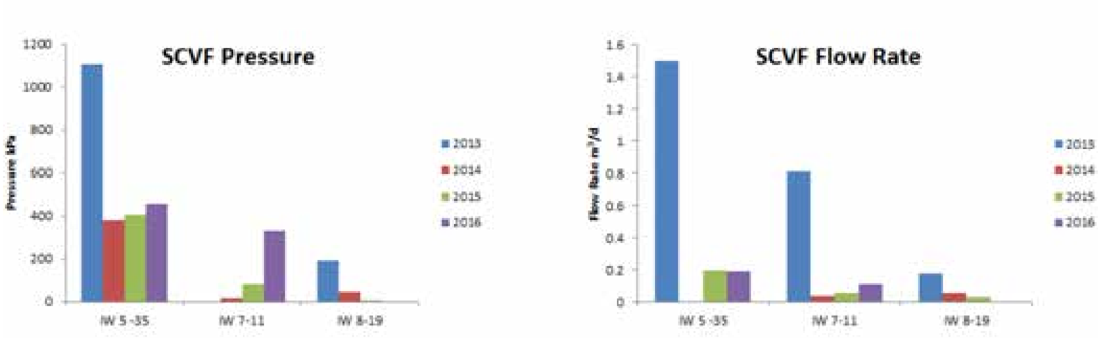



Figure 2-1: SCVF Pressure and Flow rate summary graphs for IW 5-35, IW 7-11, and IW 8-19.

## 2.3. Well Workovers and Treatments

### *2.3.1. Injection Wells*

No new wells have been drilled since completion of the 2012-2013 drilling campaign. During 2016, the following activities were executed in the Injector wells:

IW 8-19:

- Wellhead Integrity Test and Packer Isolation Test: passed.
- Tubing integrity logging (caliper) and hydraulic isolation logging (PNx).
- Pull G-Pack off and install Avalon plug.
- SCVF and Gas Migration Test

IW 7-11:

- Wellhead Integrity Test and Packer Isolation Test: passed.
- Tubing integrity logging (caliper) and hydraulic isolation logging (PNx).
- Pull G-Pack off and install Avalon plug.
- SCVF and Gas Migration Test

IW 5-35:

- Wellhead Integrity Test and Casing Shoe Inspection test: passed.
- Pressure logging and hydraulic isolation logging (PNx).
- Pull G-Pack off and install Avalon plug.
- SCVF and Gas Migration Test

The results and interpretation of the 2016 PNx hydraulic isolation logging are included in Appendix B, and the logs are submitted through the standard log submission process.

Table 2-1: 2016 Quest Well Summary.

| UWI | Well type | Well name in this report | Spud date [d/m/y] | Rig release [d/m/y] | Total Depth [m MD] | TD formation |
|---|---|---|---|---|---|---|
| 1AA/11-32-055-21W400 | Appraisal (Abandoned) | Redwater 11-32 | 10/11/2008 | 02/01/2009 | 2240.6 | Precambrian |
| 100/03-04-057-21W400 | Observation | Redwater 3-4 | 23/01/2009 | 18/03/2009 | 2190.0 | Precambrian |
| 100/081905920W4/00 | Injection | IW 8-19 | 01/08/2010 | 08/09/2010 | 2132.0 | Precambrian |
| 102/081905920W4/00 | Deep Monitoring | DMW 8-19 | 30/09/2012 | 15/10/2012 | 1696.0 | Ernestina Lake |
| 102/053505921W4/00 | Injection | IW 5-35 | 21/10/2012 | 20/11/2012 | 2143.0 | Precambrian |
| 100/053505921W4/00 | Deep Monitoring | DMW 5-35 | 24/11/2012 | 06/12/2012 | 1710.0 | Ernestina Lake |
| 103/071105920W4/00 | Injection | IW 7-11 | 14/12/2012 | 20/01/2013 | 2105.0 | Precambrian |
| 102/071105920W4/00 | Deep Monitoring | DMW 7-11 | 23/01/2013 | 05/02/2013 | 1664.5 | Ernestina Lake |
| 1F1/081905920W4/00 | Groundwater | GW 1F1/8-19 | 08/12/2010 | 08/01/2011 | 201 | Lea Park |
| UL1/081905920W4/00* | Groundwater | GW UL1/8-19 | 14/01/2011 | 17/01/2011 | 101.0 | Foremost |
| UL2/081905920W4/00* | Groundwater | GW UL2/8-19 | 12/01/2011 | 13/01/2011 | 62.8 | Foremost |
| UL3/081905920W4/00* | Groundwater | GW UL3/8-19 | 09/01/2011 | 10/01/2011 | 37.5 | Foremost |
| UL4/081905920W4/00* | Groundwater | GW UL4/8-19 | 11/01/2011 | 11/01/2011 | 20.0 | Oldman |
| 1F1/053505921W4/00 | Groundwater | GW 1F1/5-35 | 08/02/2013 | 17/02/2013 | 200 | Lea Park |
| UL1/053505921W4/00* | Groundwater | GW UL1/5-35 | 17/02/2013 | 18/02/2013 | 23 | Foremost |
| 1F1/071105920W4/00 | Groundwater | GW 1F1/7-11 | 19/02/2013 | 26/02/2013 | 180 | Lea Park |
| UL1/071105920W4/00* | Groundwater | GW UL1/7-11 | 26/02/2013 | 27/02/2013 | 30.7 | Foremost |

**Legend:** * well name used in Shell but not official UWIs as these wells do not require a well licensed because they are less than 150m depth.

### *2.3.2. Deep Monitoring Wells*

See Section 4.3 for the report on the Microseismic array installed in the DMW 8-19.

No well workovers or operations occurred in 2016 at the four deep monitoring wells.

### *2.3.3. Groundwater Wells*

The groundwater well drilling and completion campaign was completed in 2013. A full report can be found in the Second Annual Status Report [3].

No new project groundwater wells have been drilled since the 2012-2013 drilling campaign.

## 2.4. Well Integrity Summary

This section includes a discussion on the status of the Quest injection well integrity and well leak detection methodology.

Well integrity assurance is supported by, but not limited to, the data in Table 2-2. In 2014 an independent well integrity review was submitted to support the suitability of the Quest injection wells for long-term $CO_2$ storage and the MMV Plan activities [8].

As of 2016, there is no indication of integrity issues in IW 7-11 and IW 8-19. The following is a summary of the evidence of the integrity of the Quest injection wells.

The SCVF and GM testing that occurred and were reported in 2016 (Section 2.2) continue to indicate low flow levels. DTS data continue to behave in a manner similar to typical wells without any leaks; no expected leak profiles have been identified in the data (discussion in Section 4.3). Tubing integrity logging (caliper) does not show any indication of corrosion in the tubing strings. Hydraulic isolation logging (PNx) in the injection wells demonstrate the containment of the $CO_2$ in the BCS (Section 4.3 and Appendix B). Packer isolation tests were performed in the injection wells and all wells passed.

Injection well monitoring occurs continuously using tubing head pressure (THP), casing head pressure (CHP) and tubing head temperature (THT). Data are summarized in Table 3-6 and Table 3-7.

Table 2-2: Well integrity activities (modified from the 2017 MMV Plan [7], Table 4-1).

| Monitoring technology | Areal coverage | Frequency |
|---|---|---|
| SCVF testing as per AER ID 2003-01 | DMWs and IWs, as required | annually by June 30th |
| Gas migration testing as per AER Directive 020 | DMWs and IWs, as required | annually by June 30th |
| Wellhead pressure-temperature monitoring | IWs | continuous |
| Downhole pressure-temperature monitoring | IWs | continuous |
| Annulus pressure monitoring | IWs | continuous |
| Time-lapse ultrasonic casing imaging | active IWs | every 5 years |
| Time-lapse electromagnetic casing imaging | active IWs | every 5 years |
| Time-lapse cement bond log | active IWs | every 5 years |
| Mechanical well integrity testing (packer isolation test) | IWs | every 5 years |
| Tubing caliper log | active IWs | every 5 years |
| Injection rate monitoring | IWs | continuous |
| Temperature and RST logs | active IWs | as per AER Approval No. 11837C condition 5c and associated logging extension request granted on March 22, 2016 |
| Distributed temperature sensing | IWs | continuous |

Table 2-3: Well integrity logging activities.

| | IW 8-19 | IW 7-11 | IW 5-35 |
|---|---|---|---|
| **2010** | CBL-VDL-USIT | | |
| **2012** | | | CBL-VDL-USIT |
| **2013** | | CBL-VDL-USIT<br>EMIT | CBL-VDL-USIT<br>EMIT |
| **2015** | RST | RST | RST |
| **2016** | PNx<br>Tubing Caliper | PNx<br>Tubing Caliper | |

The injection wells have a Drillsol filled annulus with an $N_2$ cushion on top. Figure 2-2 and Figure 2-3 show an example of the annulus pressure variations (teal) alongside the wellhead temperature (yellow) and pressure measurements (green). The annular pressure seasonal variations correlate with injected $CO_2$ temperature. Seasonal temperatures affect the amount of cooling that the $CO_2$ undergoes in the Quest pipeline. The injected $CO_2$ temperature then warms or cools the annular fluid thereby affecting the annular pressure. To date the magnitude of seasonal changes in annulus pressure varies by 1-2 MPa.

Under current typical injection conditions, the injection tubing head pressure is 9 MPa with an annular pressure of 11 MPa. The annular pressures are higher than injection pressures and injected $CO_2$ cannot leak into the annulus due to the pressure differential. The $CO_2$ is a liquid under current typical injection conditions (9 MPa and below 30°C).

Monitoring the change in annular pressure over 24 hour periods under stable injection conditions effectively isolates the temperature effects from daily temperature variations. In addition to the continuous pressure monitoring, the annular liquid level is measured annually and before/after service rig workovers.

The combination of monitoring annular pressure with injected $CO_2$ temperature trends, measuring annular liquid levels and monitoring annular pressure changes over 24 hour periods provides a comprehensive analysis to distinguish between small packer leaks and seasonal changes in annular pressure

From a well integrity management perspective, leaks through the packer and tubing are mitigated by monitoring the well annulus pressure and maintaining an annulus pressure above the injection tubing head pressure (as explained above).

A lower pressure limit is in place on Quest injection well flowlines as there is a low pressure ESP at 8 MPa. The BCS reservoir quality is very good (see Section 3.2: Injectivity) and consequently the bottomhole injection pressure is only a few hundred kPa above the reservoir pressure. As such, any changes in the reservoir pressure due to a theoretical leak could not physically cause a significant drop in the IW tubing head pressure.

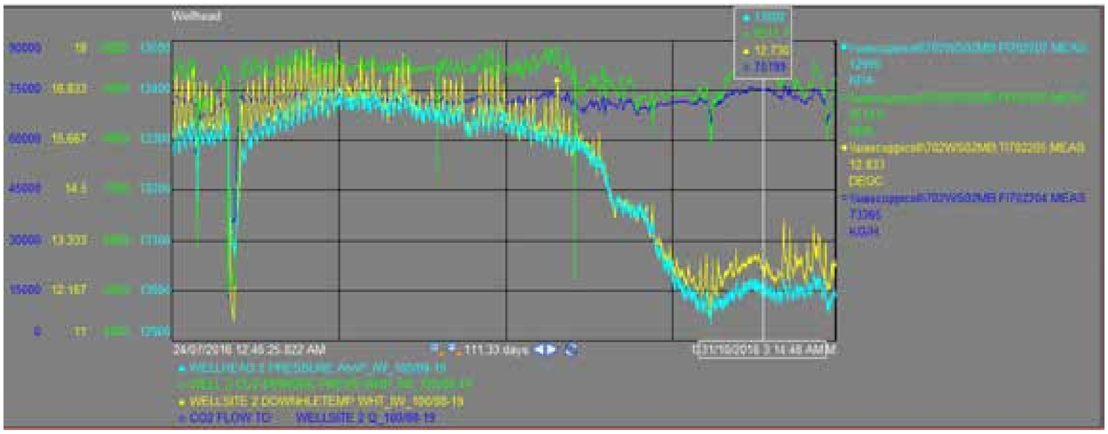



Figure 2-2: Annulus pressure monitoring in IW 8-19. Annulus pressure variations (teal), wellhead temperature (yellow) and pressure measurements (green).

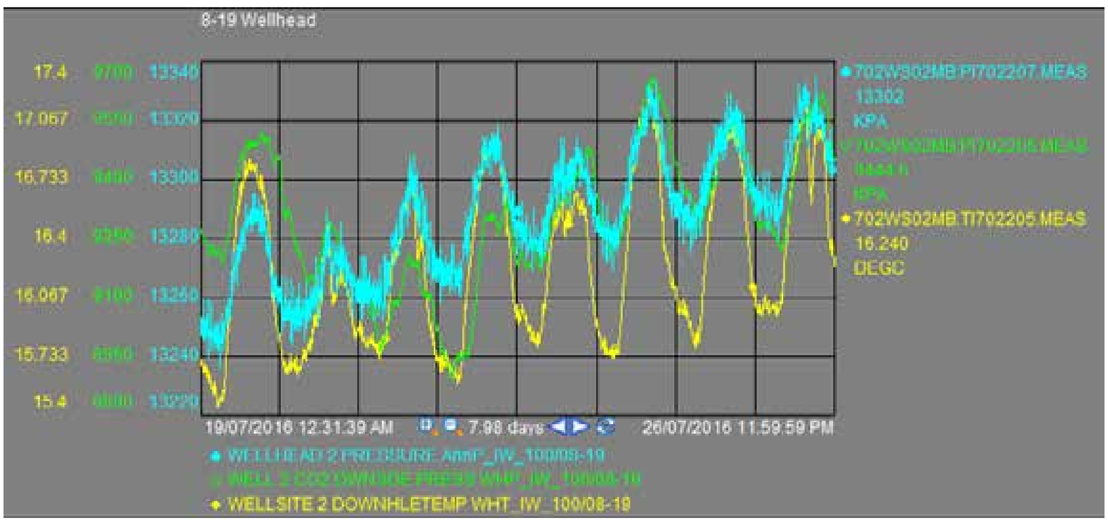



Figure 2-3: Annulus pressure monitoring in IW 8-19 demonstrating the correlation with the diurnal variations associated with the injected fluid temperatures. Annulus pressure variations (teal), wellhead temperature (yellow) and pressure measurements (green).

# 3. INJECTION WELL PERFORMANCE

## 3.1. Injection Data Reporting

The monthly totals for the Quest operations demonstrate rate changes primarily as a consequence of capture facility optimizations (Table 3-1, Table 3-2). Volume reductions from late March to early May 2016 reflect outages from the Scotford planned turn around.

To date, no $CO_2$ has been injected into IW 5-35. It has remained in observation mode.

Table 3-1: 2016 Quest $CO_2$ Injection Summary.

| Mass of Injected $CO_2$ (thousand-tonnes) in 2016 | | | | | |
|---|---|---|---|---|---|
| onth | 05-35 | 08-19 | 07-11 | Monthly Total | Cum Total for 2016 |
| Jan-16 | - | 52 | 50 | 101 | 101 |
| Feb-16 | - | 49 | 41 | 90 | 191 |
| Mar-16 | - | 52 | 29 | 82 | 273 |
| Apr-16 | - | 28 | 24 | 52 | 325 |
| May-16 | - | 29 | 47 | 76 | 401 |
| Jun-16 | - | 50 | 51 | 101 | 502 |
| Jul-16 | - | 50 | 52 | 102 | 604 |
| Aug-16 | - | 52 | 54 | 107 | 711 |
| Sep-16 | - | 52 | 53 | 105 | 816 |
| Oct-16 | - | 53 | 40 | 93 | 910 |
| Nov-16 | - | 53 | 54 | 107 | 1017 |
| Dec-16 | - | 48 | 44 | 91 | 1108 |

Table 3-2: Total Quest $CO_2$ Injection Summary.

| TOTAL Mass of Injected $CO_2$ (thousand-tonnes) | | | | | |
|---|---|---|---|---|---|
| Year | 05-35 | 08-19 | 07-11 | Total | Cum Total |
| 2015 | - | 210 | 161 | 371 | 371 |
| 2016 | - | 568 | 540 | 1108 | 1479 |

## 3.2. Injectivity

Overall the Quest project has more than sufficient injectivity, demonstrated by the utilization of only two of the three injection wells, despite full project rates up to 150t/hr. Therefore, with the inclusion of IW 5-35 the existing wells are capable of sustaining injectivity greater than the project goal of 140t/hr (1.2Mt/year) for the duration of the project life and no infill well development will be needed to meet injectivity requirements.

IW 8-19 well has been injecting consistently at approximately 70 t/hr over this time period (Figure 3-1). IW 7-11 has been receiving the remaining available volumes which averages to approximately 60 t/hr over this time period (Figure 3-2). IW 5-35 has remained in observation mode.


Figure 3-1: Flow Rate for 8-19 over time.


Figure 3-2: Flow Rate for 7-11 over time.

The injectivity stability is illustrated in the Dynamic Injectivity Index plots shown in Figure 3-3 and Figure 3-4. Both wells were shut-in for logging in April and thereby induced some overriding pressure transients. Beyond the transient affects, the plot illustrates that IW 8-19 and IW 7-11 appear to have an inverse relationship to injection temperature. This phenomenon is well recognized in the CCS community, and research is ongoing. Further data collection and evaluation of this relationship will be ongoing in 2017.

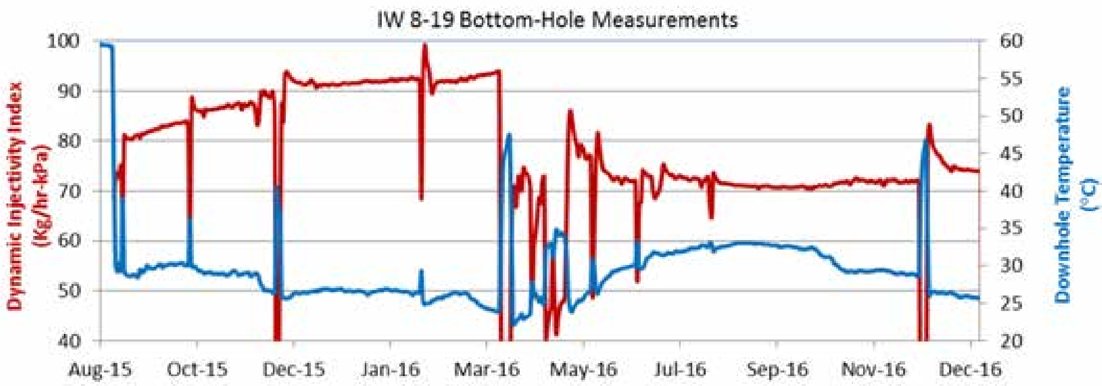



Figure 3-3: Dynamic Injectivity Index and BHT for 8-19 over time.


Figure 3-4: Dynamic Injectivity Index and BHT for 7-11 over time.

Injection stream compositions and variations are shown in Table 3-3. These values are within design scope and have not impacted operations. There are no concerns on reactivity of the impurities or impact on the phase behavior.

2016 monthly injection data summaries for rate, mass and pressures are reported in Table 3-3, Table 3-4, Table 3-5, Table 3-6, and Table 3-7.

Table 3-3: 2016 Quest $CO_2$ Injection Summary: Injection Stream

| MONTHLY DATA | Injection Stream Content (Volume %) | | | | |
|---|---|---|---|---|---|
| | $CO_2$ | $H_2$ | $CH_4$ | CO | $H_2O$ |
| Jan-16 | 99.44 | 0.48 | 0.05 | 0.02 | 0.006 |
| Feb-16 | 99.46 | 0.48 | 0.06 | 0.02 | 0.006 |
| Mar-16 | 99.38 | 0.51 | 0.06 | 0.02 | 0.006 |
| Apr-16 | 99.28 | 0.56 | 0.06 | 0.02 | 0.006 |
| May-16 | 99.31 | 0.55 | 0.06 | 0.02 | 0.006 |
| Jun-16 | 99.52 | 0.46 | 0.06 | 0.02 | 0.006 |
| Jul-16 | 99.31 | 0.55 | 0.06 | 0.02 | 0.006 |
| Aug-16 | 99.41 | 0.51 | 0.06 | 0.02 | 0.006 |
| Sep-16 | 99.41 | 0.49 | 0.05 | 0.02 | 0.006 |
| Oct-16 | 99.45 | 0.48 | 0.05 | 0.02 | 0.005 |
| Nov-16 | 99.41 | 0.44 | 0.05 | 0.02 | 0.005 |
| Dec-16 | 99.17 | 0.62 | 0.06 | 0.02 | 0.004 |

Table 3-4: 2016 Quest $CO_2$ Injection Summary: Injection data – Mass.

| MONTHLY DATA | INJECTION WELLS | | |
|---|---|---|---|
| Mass of $CO_2$ Injected[1] (kt) | IW 7-11 | IW 8-19 | IW 5-35 |
| Jan-16 | 50 | 52 | - |
| Feb-16 | 41 | 49 | - |
| Mar-16 | 29 | 52 | - |
| Apr-16 | 24 | 28 | - |
| May-16 | 47 | 29 | - |
| Jun-16 | 51 | 50 | - |
| Jul-16 | 52 | 50 | - |
| Aug-16 | 54 | 52 | - |
| Sep-16 | 53 | 52 | - |
| Oct-16 | 40 | 53 | - |
| Nov-16 | 54 | 53 | - |
| Dec-16 | 44 | 48 | - |
| Cumulative Mass of $CO_2$ Injected [1] (kt) | | | |
| 2015 | 161 | 210 | |
| Jan-16 | 210 | 262 | - |
| Feb-16 | 252 | 311 | - |
| Mar-16 | 281 | 363 | - |
| Apr-16 | 305 | 391 | - |
| May-16 | 352 | 420 | - |
| Jun-16 | 403 | 470 | - |
| Jul-16 | 455 | 520 | - |
| Aug-16 | 509 | 573 | - |
| Sep-16 | 563 | 625 | - |
| Oct-16 | 603 | 678 | - |
| Nov-16 | 657 | 731 | - |
| Dec-16 | 700 | 778 | - |

[1]Volume of $CO_2$ is reported in standard units for $CO_2$, i.e. mass.

Table 3-5: 2016 Quest $CO_2$ Injection Summary: Injection data.

| MONTHLY DATA | INJECTION WELLS | | |
|---|---|---|---|
| Total Monthly Hours on Injection (hours) | IW 7-11 | IW 8-19 | IW 5-35 |
| Jan-16 | 744 | 744 | - |
| Feb-16 | 696 | 692 | - |
| Mar-16 | 744 | 744 | - |
| Apr-16 | 654 | 574 | - |
| May-16 | 744 | 744 | - |
| Jun-16 | 711 | 711 | - |
| Jul-16 | 744 | 744 | - |
| Aug-16 | 744 | 744 | - |
| Sep-16 | 720 | 720 | - |
| Oct-16 | 744 | 744 | - |
| Nov-16 | 720 | 720 | - |
| Dec-16 | 634 | 641 | - |
| Maximum Daily Injection Rate (t/h) | | | |
| Jan-16 | 76 | 71 | - |
| Feb-16 | 87 | 90 | - |
| Mar-16 | 109 | 120 | - |
| Apr-16 | 86 | 84 | - |
| May-16 | 75 | 77 | - |
| Jun-16 | 120 | 90 | - |
| Jul-16 | 90 | 75 | - |
| Aug-16 | 90 | 74 | - |
| Sep-16 | 82 | 82 | - |
| Oct-16 | 78 | 76 | - |
| Nov-16 | 79 | 77 | - |
| Dec-16 | 82 | 80 | - |
| Average Daily Injection Rate (t/h) | | | |
| Jan-16 | 67 | 69 | - |
| Feb-16 | 59 | 70 | - |
| Mar-16 | 40 | 71 | - |
| Apr-16 | 33 | 39 | - |
| May-16 | 64 | 39 | - |
| Jun-16 | 71 | 70 | - |
| Jul-16 | 70 | 68 | - |
| Aug-16 | 73 | 71 | - |
| Sep-16 | 74 | 72 | - |
| Oct-16 | 54 | 72 | - |
| Nov-16 | 75 | 74 | - |
| Dec-16 | 59 | 64 | - |

[1]Maximum of the daily averages.

Table 3-6: 2016 Quest $CO_2$ Injection Summary: Well Head Pressures and Temperatures.

| MONTHLY DATA | IW 7-11 | | IW 8-19 | | IW 5-35 | |
|---|---|---|---|---|---|---|
| Maximum[1] WHIP and WHIT | WHIP (kPa-g) | WHIT (°C) | WHIP (kPa-g) | WHIT (°C) | WHIP (kPa-g) | WHIT (°C) |
| Jan-16 | 7976 | 14 | 7513 | 9 | - | - |
| Feb-16 | 8865 | 14 | 10083 | 9 | - | - |
| Mar-16 | 8384 | 15 | 7618 | 9 | - | - |
| Apr-16 | 9476 | 10 | 9855 | 8 | - | - |
| May-16 | 8692 | 17 | 8679 | 11 | - | - |
| Jun-16 | 9433 | 19 | 9375 | 15 | - | - |
| Jul-16 | 9513 | 20 | 9457 | 17 | - | - |
| Aug-16 | 9669 | 20 | 9615 | 17 | - | - |
| Sep-16 | 9768 | 20 | 9721 | 17 | - | - |
| Oct-16 | 9629 | 17 | 9576 | 16 | - | - |
| Nov-16 | 9573 | 17 | 9515 | 13 | - | - |
| Dec-16 | 8886 | 14 | 9162 | 12 | - | - |
| | IW 7-11 | | IW 8-19 | | IW 5-35 | |
| Average WHIP and WHIT | WHIP (kPa-g) | WHIT (°C) | WHIP (kPa-g) | WHIT (°C) | WHIP (kPa-g) | WHIT (°C) |
| Jan-16 | 7593 | 13 | 7463 | 8 | - | - |
| Feb-16 | 6640 | 12 | 7591 | 8 | - | - |
| Mar-16 | 5391 | 6 | 7478 | 8 | - | - |
| Apr-16 | 4582 | 2 | 4693 | 3 | - | - |
| May-16 | 7117 | 11 | 5239 | 4 | - | - |
| Jun-16 | 8911 | 18 | 8760 | 14 | - | - |
| Jul-16 | 8970 | 19 | 8700 | 15 | - | - |
| Aug-16 | 9425 | 20 | 9281 | 17 | - | - |
| Sep-16 | 9530 | 19 | 9482 | 16 | - | - |
| Oct-16 | 6887 | 13 | 9058 | 13 | - | - |
| Nov-16 | 9286 | 16 | 9240 | 12 | - | - |
| Dec-16 | 7406 | 9 | 8296 | 6 | - | - |

[1]Maximum of the daily averages.
Note: kPa-g refers to gauge pressure.

Table 3-7: 2016 Quest $CO_2$ Injection Summary: Bore Hole Pressures and Temperatures.

| MONTHLY DATA | IW 7-11 | | IW 8-19 | | IW 5-35 | |
|---|---|---|---|---|---|---|
| Maximum[1] BHIP and BHIT | BHIP (kPa-g) | BHIT (°C) | BHIP (kPa-g) | BHIT (°C) | BHIP (kPa-g) | BHIT (°C) |
| Jan-16 | 20318 | 34 | 20635 | 27 | - | - |
| Feb-16 | 20348 | 34 | 20827 | 29 | - | - |
| Mar-16 | 20347 | 36 | 20686 | 26 | - | - |
| Apr-16 | 20384 | 46 | 21127 | 47 | - | - |
| May-16 | 20401 | 34 | 20823 | 35 | - | - |
| Jun-16 | 20477 | 38 | 21003 | 33 | - | - |
| Jul-16 | 20497 | 37 | 20939 | 33 | - | - |
| Aug-16 | 20546 | 37 | 20981 | 33 | - | - |
| Sep-16 | 20587 | 37 | 21017 | 33 | - | - |
| Oct-16 | 20580 | 37 | 21033 | 32 | - | - |
| Nov-16 | 20601 | 35 | 21043 | 29 | - | - |
| Dec-16 | 20563 | 48 | 21015 | 47 | - | - |
| | IW 7-11 | | IW 8-19 | | IW 5-35 | |
| Average BHIP and BHIT | BHIP (kPa-g) | BHIT (°C) | BHIP (kPa-g) | BHIT (°C) | BHIP (kPa-g) | BHIT (°C) |
| Jan-16 | 20300 | 33 | 20629 | 27 | - | - |
| Feb-16 | 20263 | 32 | 20652 | 26 | - | - |
| Mar-16 | 20176 | 34 | 20670 | 25 | - | - |
| Apr-16 | 20113 | 32 | 20516 | 29 | - | - |
| May-16 | 20323 | 30 | 20408 | 29 | - | - |
| Jun-16 | 20437 | 36 | 20883 | 30 | - | - |
| Jul-16 | 20466 | 37 | 20870 | 32 | - | - |
| Aug-16 | 20512 | 37 | 20945 | 33 | - | - |
| Sep-16 | 20570 | 37 | 20991 | 33 | - | - |
| Oct-16 | 20410 | 35 | 20984 | 30 | - | - |
| Nov-16 | 20580 | 34 | 21018 | 29 | - | - |
| Dec-16 | 20446 | 34 | 20874 | 29 | - | - |

[1]Maximum of the daily averages.
Note: kPa-g refers to gauge pressure.

## 3.3. Model to Performance Conformance

Figure 3-5 illustrates that the actual pressure build up in the reservoir (solid lines) to date has been less than the model-predicted expectation case (dashed lines). Note that no injection has occurred at IW 5-35, but reservoir pressure is being monitored. This implies that the modelled reservoir properties are likely better than the previous expectation case.

The key implication is that lower injection pressures are required to meet injection/rate targets over the life of the project. More importantly, the lower than predicted end-of-life reservoir pressures significantly increases our confidence that it is extremely improbable for $CO_2$ leakage to occur via fracturing or fault reactivation.

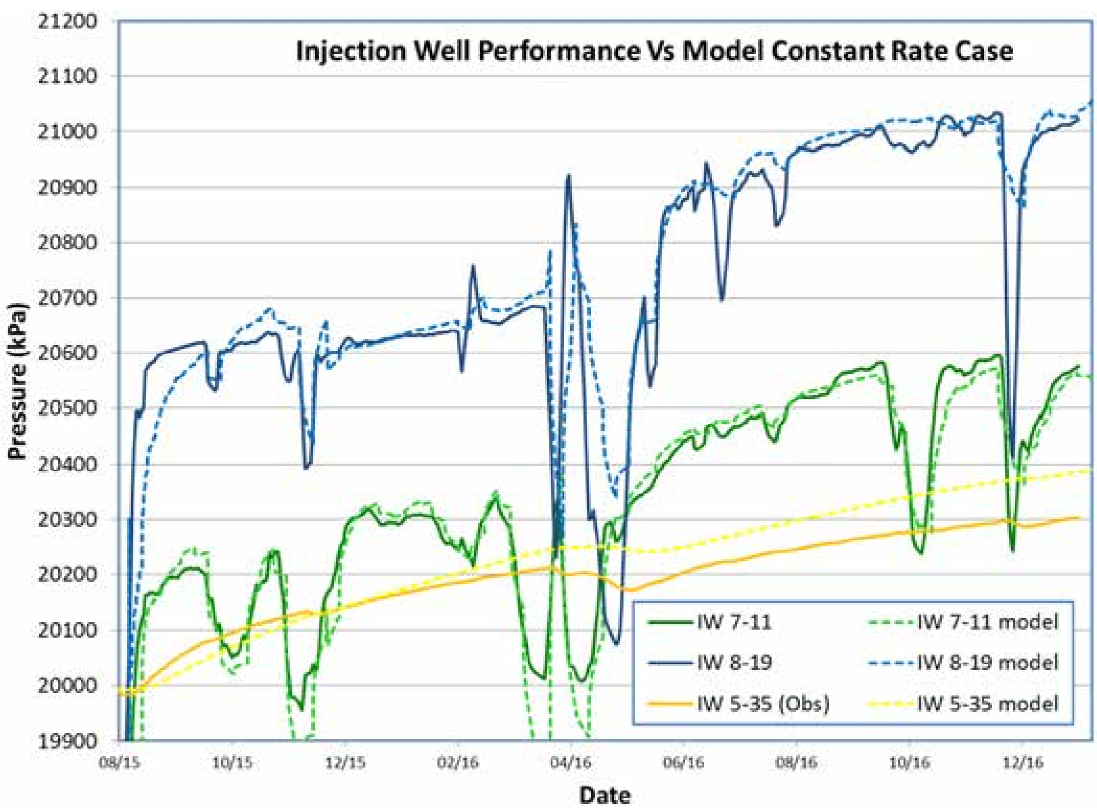



Figure 3-5: Actual BH Gauge Response vs Modeled Pressure Response.

## 3.4. Reservoir Modelling

### *3.4.1. Modelling Updates*

No significant update to the reservoir model occurred in 2016 as no new wells were drilled, and the early performance is close to our expectation case. The weekly well rate history has been incorporated into the model controls as illustrated in Figure 3-5. The correlation between injectivity and temperature has been accounted for with seasonal skin factors. Higher reservoir properties were used to better align with both the 2016 VSP results and the pressure response observed to date. Going forward, work will include tuning the model to a growing performance data set including the second monitor VSPs, and injectivity sensitivity to temperature.

### *3.4.2. Pressure Prediction*

By the end of project life, the pressure build-up in the BCS is forecasted to be less than 2 MPa of differential pressure (DeltaP) at the injection wells (Figure 3-6). This pressure increase represents less than 12% of the delta pressure required to exceed the BCS fracture extension pressure and less than 25% of the pressure increase required to exceed the AER Approval operating constraint on bottom hole pressure [1].

The assumption for the 2017 forecast below is that from 2017 onward an equal amount of $CO_2$ will be injected in each well for the remainder of the life of the project. Note that the pressure incline observed at IW 5-35 is responding to the injection at IW 8-19.

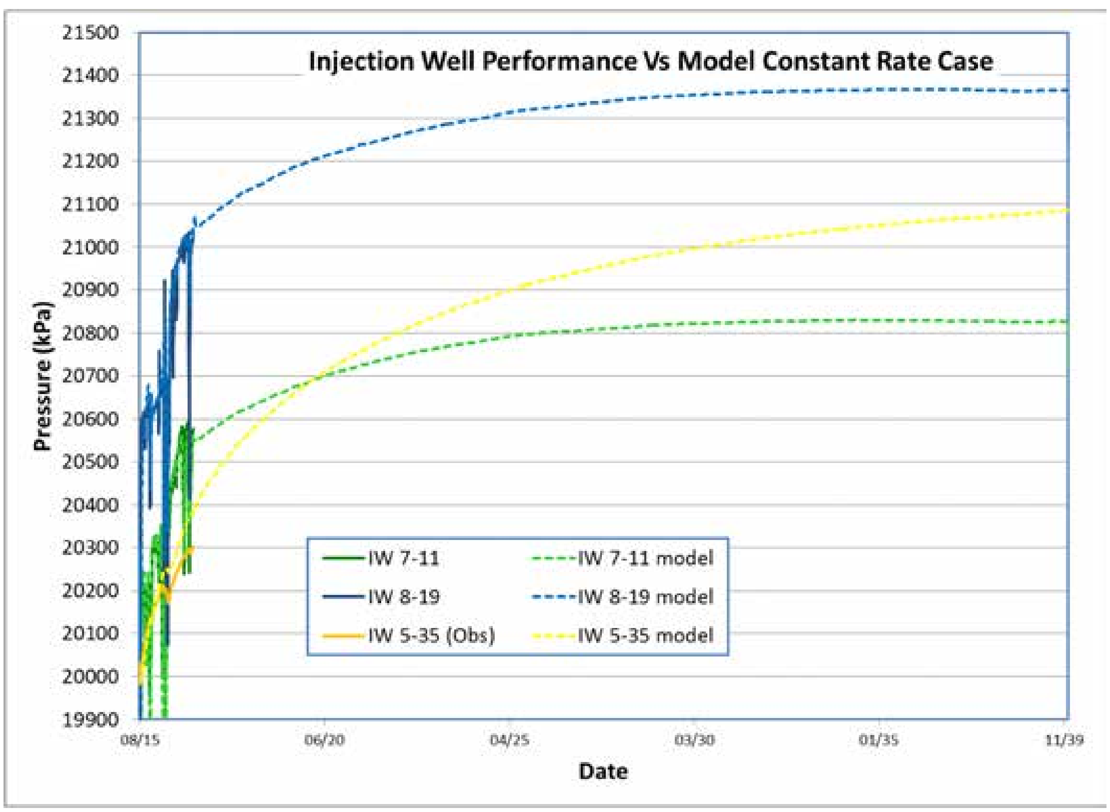



Figure 3-6: Well by well expected pressure build forecast.

### *3.4.3. Plume Prediction*

The current dynamic model incorporates injection well rates & pressure data to the end of 2016, and the 1st monitor VSP results. Assuming we continue to only inject into IW 8-19 and IW 7-11 (as per 2016 operations) the modelling shows maximum plume lengths in 2040 of 2 to 4 km. The resulting end-of-life plumes are illustrated in Figure 3-7. The most significant impact on $CO_2$ plume size will be whether or not IW 5-35 is required for injection. Additional uncertainty will be reduced in 2017 as the model is tuned to additional pressure data, the 2nd monitor VSP interpretation, and injectivity temperature dependence.

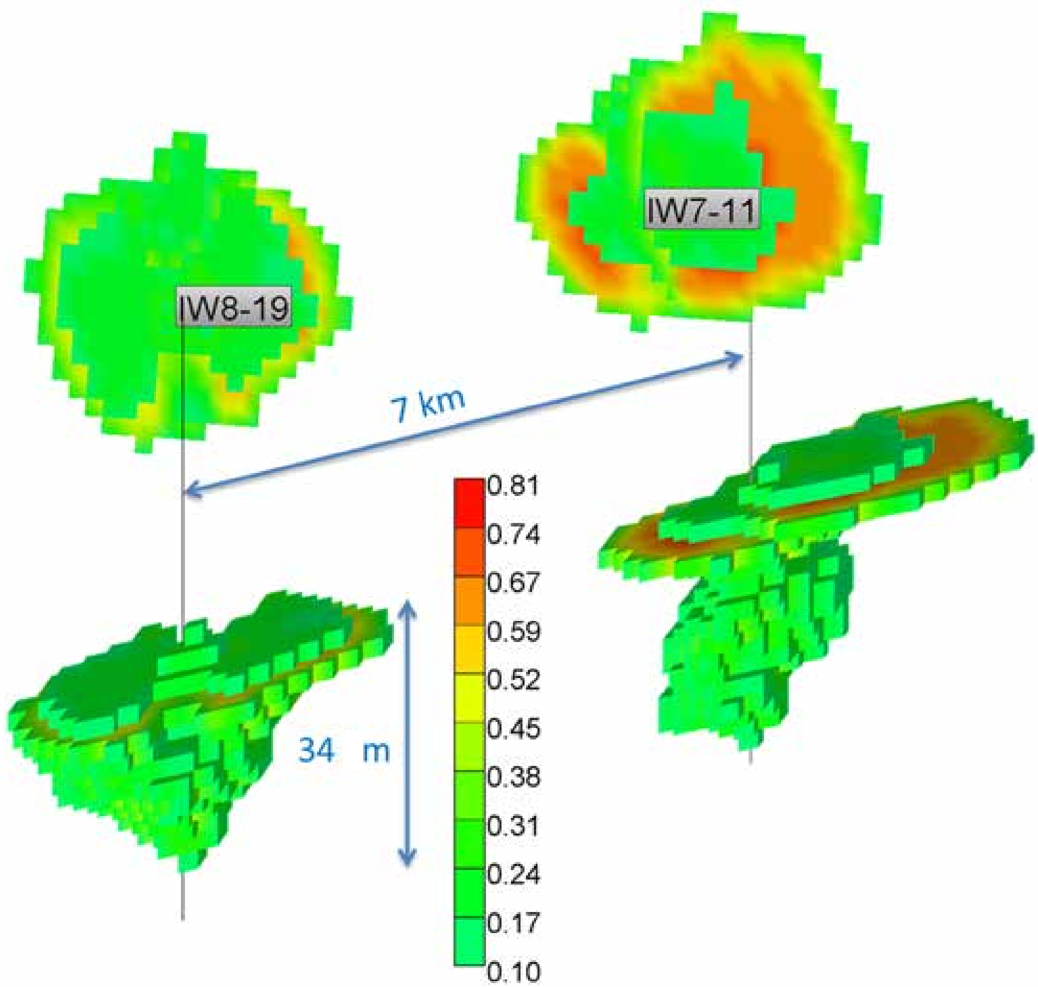



Figure 3-7: Map view and 3D views of the $CO_2$ plume in 2040.

## 3.5. Reservoir Capacity

A base case pore volume of 14.3 billion $m^3$ within the SLA could store 27 Mt of $CO_2$ at just under 70% potential storage capacity. This is an extremely conservative calculation because displacement of water outside the SLA relieves all of the pressure over time. Dynamic pressure modeling indicates that 27 Mt of $CO_2$ can be injected while keeping the reservoir pressure below 23 MPa (compared to the BHP limitation of 28 MPa).

Table 3-8: BCS Pore Volume within the Sequestration Lease Area.

| Case | Reservoir Connectivity | Reservoir Quality | Sum Pore Volume in the SLA (m3) |
|---|---|---|---|
| P90 | High | High | 1.62E+10 |
| P50 | Mid | Mid | 1.43E+10 |
| P10 | Low | Low | 1.08E+10 |

Using a material balance calculation:

$$G_{CO2} = A\ h_g\ f_{tot}\ r\ (c_p + c_w)\ (p\text{-}p_0)$$

Using the mid-case properties:

Pres = 20 Mpa, Pmax = of 28 MPa, Temp = 60°C,

Cp = 1.45 E-7, Cw = 2.78 E-7, r = 814 kg/$m^3$

The full 27 Mt of $CO_2$ is still expected to be sequestered without ever approaching the limit specified in clause 5) a) of the Approval [1]. The First Annual Status Report [2] states that the Quest project will not raise the stabilized reservoir pressure at any injector beyond the AER approved 26 MPa limit within the life of the project. This has not changed as there is no expectation for the flowing bottomhole pressure to ever approach the 26 MPa maximum shut-in formation pressure.

Based on injection volumes since inception and the pressure limitations, the remaining capacity of the Quest Sequestration Lease Area is reported in Table 3-9, as per the data from Table 3-1.

Table 3-9: Remaining capacity in the Sequestration Lease Area as of end 2016

| Estimated Total Capacity | Year | Yearly Injection Total | Remaining Capacity |
|---|---|---|---|
| 27Mt | 2015 | 0.371Mt | 26.629 Mt $CO_2$ |
| 27Mt | 2016 | 1.108 Mt | 25.521 Mt $CO_2$ |

# 4. OPERATIONAL MMV PLAN ACTIVITIES AND PERFOMANCE

## 4.1. Summary of Operational MMV Activities in 2016

In 2016, MMV activities included: atmosphere, biosphere, hydrosphere, geosphere, and well-based monitoring. Please refer to Table 4-1 for a list of the various monitoring activities that took place.

- Atmosphere Domain: Monitoring of $CO_2$ levels within the atmosphere continued using the LightSource and EC systems.
- Hydrosphere Domain: Four discrete sampling events (Q1, Q2, Q3, Q4) were executed at all the project groundwater wells located on the 3 injection well pads, and the landowner groundwater wells within 1 km of the well pads 7-11 and 8-19. Three distinct sampling events (Q1, Q3, Q4) were executed at the landowner wells within 1 km of well pad 5-35. Note that additional groundwater well testing/sampling was undertaken in conjunction with the Q1 1st monitor VSP campaign.

Further details on these activities can be found in Appendix A.

- Biosphere Domain: Two sampling events (June, October) of soil gas and soil surface $CO_2$ flux measurements were undertaken on each injection pad.
- Geosphere Domain: The first monitor VSP campaign was executed in Q1 around well pads 7-11 and 8-19. In addition, monthly satellite image collection for assessing InSAR continued, and all Radarsat-2 satellite images collected between 3 June 2011 and 9 December 2016 were processed.
- Well based Monitoring: ongoing data collection via wellhead gauges, downhole gauges, downhole microseismic geophone array, and DTS lightboxes.

## 4.2. MMV Infrastructure

A web-based toolkit was implemented which interfaces directly with the PI database and displays these data online in real-time at any Shell location. This system was fully operational in Q1 2015, and in the Fourth Annual Report it was mentioned that changes to this system were expected in 2016 due to software upgrades [5]. The web-based toolkit has been replaced with desktop based software without any loss to real-time data visualization functionality.

During June to August timeframe, new groundwater downhole water quality gauges were installed in all of the nine project groundwater wells.

In 2016 DTS data were stored locally at a pad. Dedicated computers were installed at each of the well pads to facilitate ultimate automated on-line data access/retrieval. Some work remains to address the latter.

Some upgrades were done to the LightSource systems, as well as some repairs to address outage related to severe weather (e.g. thunderstorms). Development of the LightSource code for locating and quantifying $CO_2$ emissions was completed.

Table 4-1: Summary of MMV activities planned and executed in 2016.

| Domain | Activity planned for 2016 ^ | Executed | Comment |
|---|---|---|---|
| *Atmopshere* | | | |
| | LightSource measurements at pads 8-19, 7-11, & 5-35 | ✓ | system upgrades |
| *Biosphere* | | | |
| | Targeted soil gas and soil surface $CO_2$ flux measurements at each of the injection well pads | ✓ | completed two sampling events: June and October |
| *Hydrosphere* | | | |
| | Downhole pH & EC monitoring at Project groundwater wells | ✓ | around mid-year downhole gauges were replaced |
| | Discrete water and gas (if possible) sampling at Project groundwater wells | ✓ | quarterly sampling events |
| | Discrete water and gas (if possible) sampling at landowner wells within 1km of each injection well pad | ✓ | quarterly sampling events (when possible); except for wells around well pad 5-35 where three sampling events took place ((Q1, Q3, Q4) |
| | Once per year for landowner wells located within expected $CO_2$ plume size | ✓ | covered under 'landowner wells within 1km of each injection well pad', as $CO_2$ plume size < 1km |
| | Landowner wells associated with VSP surveys | ✓ | pre- and post-VSP campaigns |
| *Geopshere* | | | |
| | Injection rate monitoring | ✓ | |
| | Annulus pressure monitoring | ✓ | |
| | DHPT monitoring at all 3 DMWs | ✓ | |
| | DHPT monitoring at all 3 IWs | ✓ | |
| | DHP monitoring at Redwater 3-4 | ✓ | |
| | WHPT monitoring at all 3 IWs | ✓ | |
| | Mechanical well integrity testing (packer isolation test) and tubing caliper log of IWs | ✓ | |
| | Routine well maintenance, including Temperature & RST logs and measurement of hold-up depths (HUD) of IWs at which injection started | ✓ | completed in Q2 2016 |
| | MSM at DMW 8-19 | ✓ | |
| | DTS monitroing at IWs | ✓ | work in progress to move towards automated data download; currently, field visits required to download data |
| | DAS monitoring at IWs | ✓ | used for VSP survey data collection in Q1 |
| | InSAR: monthly satellite image collection | ✓ | |
| corrosion probes | at injection skids | ✓ | all OK |
| SCVF/GM | annually by June 30th | ✓ | |
| Injected $CO_2$ | analysis of captured $CO_2$ at Scotford Upgrader | ✓ | |
| Notes: | ^ list of MMV activities as per MMV plan update from January 31, 2015 | | |

## 4.3. Assessment of MMV objective 'Containment'

No trigger events were identified during 2016 that would indicate a loss of containment (Table 4-2). In other words, data to-date indicate that no $CO_2$ has migrated outside of the Basal Cambrian Sands (BCS) injection reservoir during 2016.

Reasons for this observation are described below for the technologies that were used as part of the assessment during 2016.

Note that as the project progresses, it is expected that based on current performance the assessment of 'containment trigger events' will be focused on a limited and/or reduced number of monitoring technologies.

Table 4-2: Overall assessment of trigger events used to assess loss of containment in 2016.

| Domain | Technology ^ | Trigger Event indicating loss of containment | 2016 |
|---|---|---|---|
| Atmosphere | LightSource | Sustained locatable anomaly above background levels | |
| Biosphere | Soil Gas | Outside established baseline range | |
| | Surface CO2 Flux | Outside established baseline range | |
| Hydrosphere | Tracer | Outside established baseline range | |
| | WPH | Sustained decrease in baseline pH values | |
| | WEC | Sustained increase in baseline WEC values | |
| | Geochemical Analyses | Outside established baseline range | |
| Geosphere | DHPT CKLK | Pressure increase 200 Kpa above background levels | |
| | DHMS | Sustained clustering of events with a spatial pattern indicative of fracturing upwards | |
| | DTS | Sustained temperature anomaly outside casing | |
| | VSP2D | Identification of a coherent and continuous amplitude anomaly above the storage complex | |
| | SEIS3D | Identification of a coherent and continuous amplitude anomaly above the storage complex | not applicable yet |
| | InSAR | Unexpected localized surface heave | |

^ based on Table 7-4 from the MMV plan dated January 31st, 2015

| Legend | |
|---|---|
| | no trigger event |
| | trigger event |
| | not evaluated |

A pulsed neutron logging run was executed in Q2 for IW 8-19 and IW 7-11 (post-start of injection). The results indicate that $CO_2$ is contained within the perforated interval of the BCS reservoir (Figure 4-1). A copy of these logs is also found in Appendix B: Results of 2016 PNX Logging (Hydraulic Isolation Logs).

Wellsite #1 (IW 7-11):

Wellsite #2 (IW 8-19):

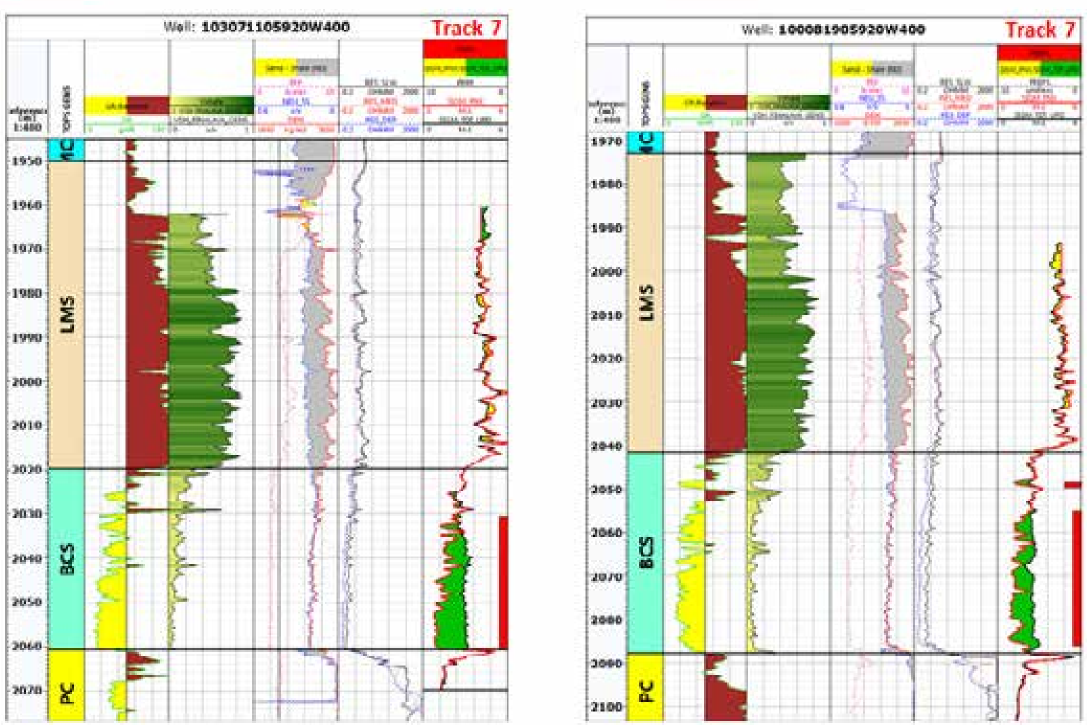



Figure 4-1: Pulsed Neutron log for IW 8-19 and IW 7-11.

- LightSource

On each well pad the LightSource system includes one laser beam installed in one of the pad's corners that can scan across the pad, as well as three reflectors installed in the three remaining corners of the pad. To-date no evidence has been found of a trigger event indicative of leakage.

Figure 4-2 shows a time series plot for path averaged $CO_2$ concentration difference by beam recorded at the three well pads. As can be seen data are behaving similar between all 3 wells pads whether injection is occurring or not. Changes in the magnitude of the path averaged $CO_2$ concentration difference are expected as $CO_2$ concentrations vary daily, seasonally, and are impacted by agricultural activities (among others). The larger changes seen in Figure 4-2 occurred during the growing season.

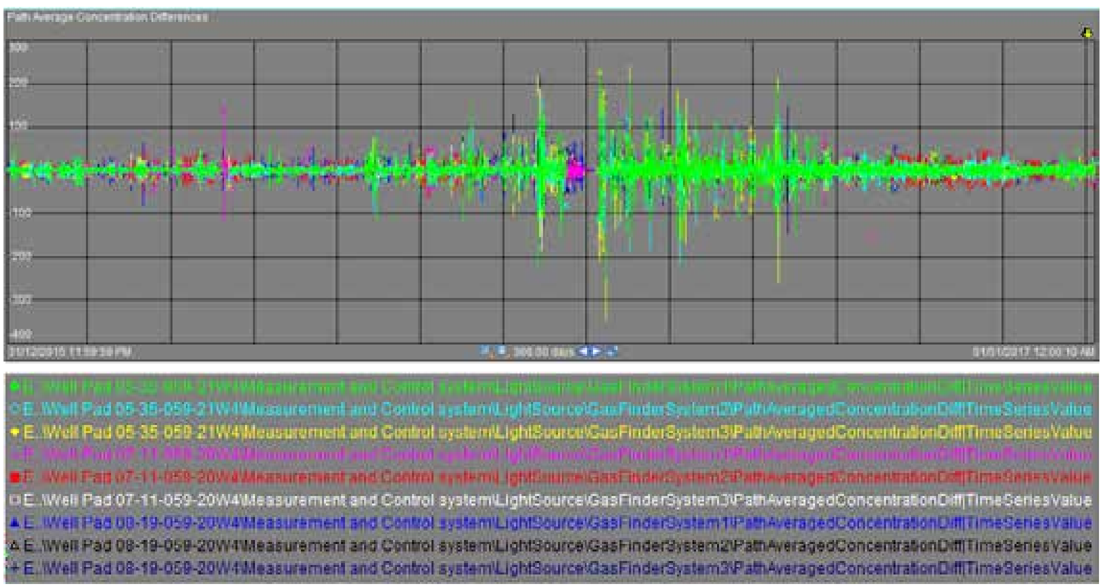



Figure 4-2: Time series plot of path averaged $CO_2$ concentrations difference [ppm] recorded at pads 5-35, 7-11 and 8-19 between June 2015 and December 2016.

- **Soil Gas**

In June and October 2016, field work was undertaken to collect soil gas $CO_2$ concentrations. Figure 4-3 shows soil gas $CO_2$ concentrations for pad 7-11 and pad 8-19 for all sampling campaigns completed in 2015 and 2016. Overall, soil gas $CO_2$ concentrations in June and October 2016 are similar. There was no indication of loss of containment. It can be noted though that at pad 7-11, soil gas concentrations were slightly higher in 2016 compared to 2015. Complimentary data collected during the fieldwork suggest that this is related to oxidation of $CH_4$, based on the following observations.

- While CO2 concentrations were slightly higher, CH4 concentrations on the other hand indicate an overall decreasing trend from June 2015 to October 2016 (Figure 4-4)
- A concurrent increase in $\delta^{13}C\text{-}CH_4$ and decrease in $\delta^{13}C\text{-}CO_2$ can also be observed.

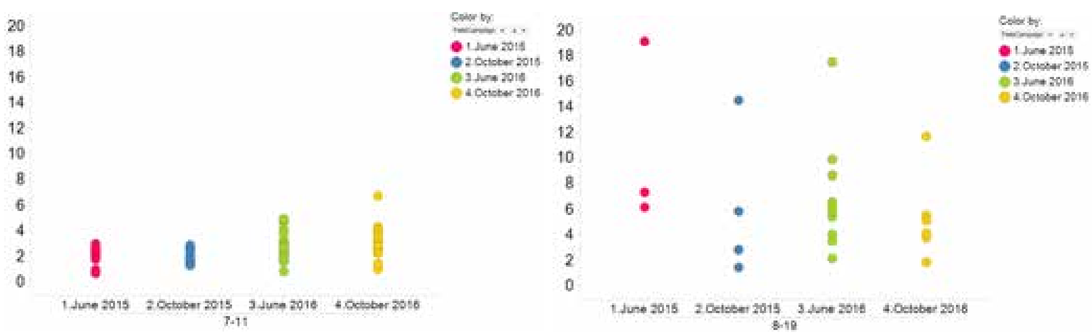



Figure 4-3: Soil gas $CO_2$ concentrations (mole %, laboratory analysis) for soil gas probes sampled at pads 7-11 and 8-19 in June 2015 (pre-injection), October 2015 (post start of injection), June 2016, and October 2016.

- **Surface $CO_2$ Flux**

In June, field work was undertaken to collect soil surface $CO_2$ flux measurements. Another sampling campaign took place in October. Due to site conditions (unusually heavy snow fall, subsequent snow melting) it was not possible to collect any soil surface $CO_2$ flux measurements as the flux chamber collars were flooded.

Available data on soil surface CO2 flux are presented in Figure 4-5 and results from June 2016 fall within the range observed for previous sampling events (e.g. the pre-injection event from June 2015). There was no indication of loss of containment.

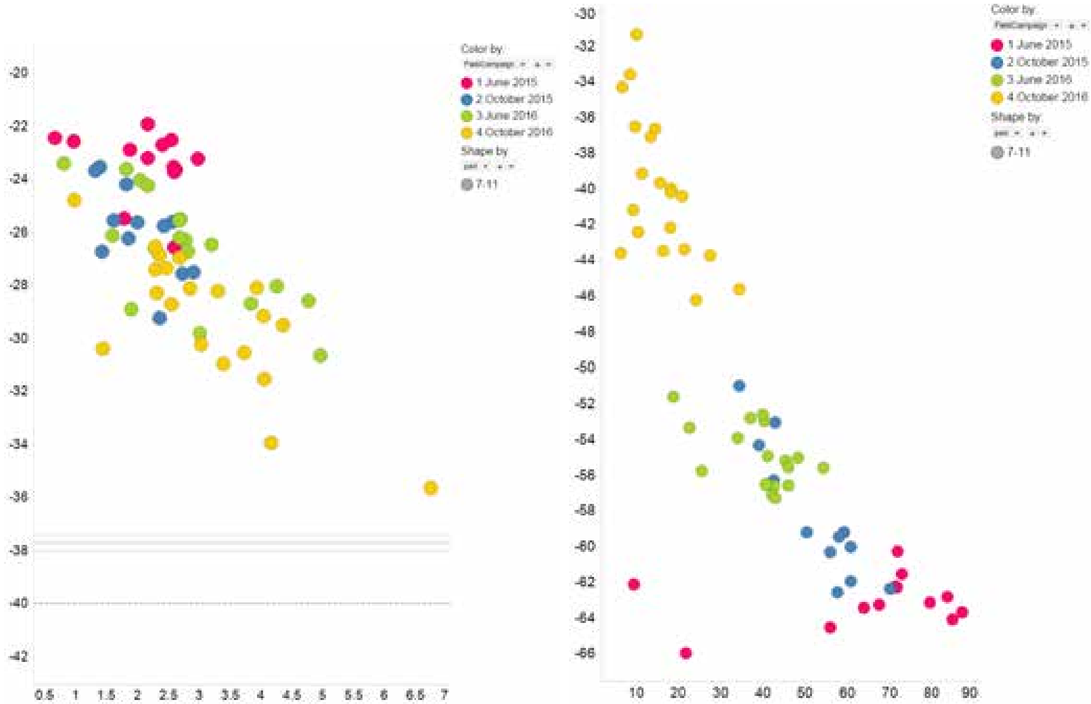



Figure 4-4: Left plot: δ$^{13}$C-$CO_2$ (‰) versus $CO_2$ concentration (mole %) for laboratory analyses at pad 7-11 for the three sampling events.

Notes: gray band represents estimated δ$^{13}$C-$CO_2$ value of injected $CO_2$ based on δ$^{13}$C-$CO_2$ values of gas sample which is closest to the injected $CO_2$ collected at Scotford prior to completion of capture facility, and taking into consideration potential isotope fractionation effects due to adsorption and desorption; gray dashed line represents 'October 2015' δ$^{13}$C-$CO_2$ value of captured $CO_2$. Right plot: δ$^{13}$C-$CH_4$ (‰) versus $CH_4$ concentration (mole %) for laboratory analyses at pad 7-11 for the four sampling events.

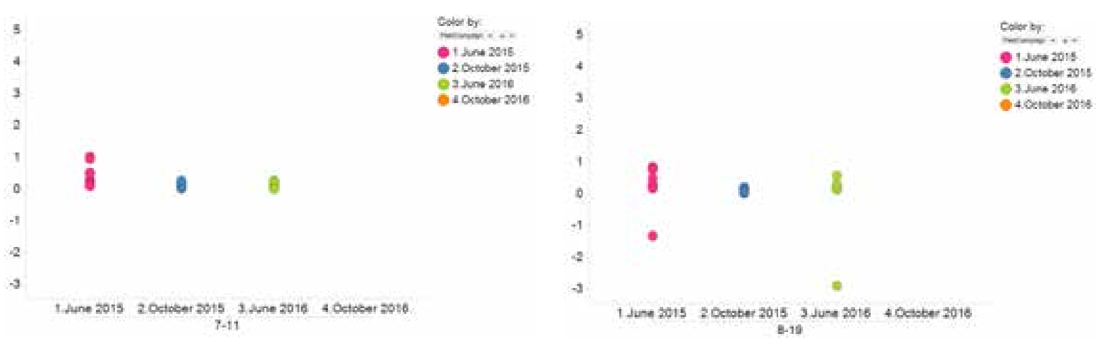
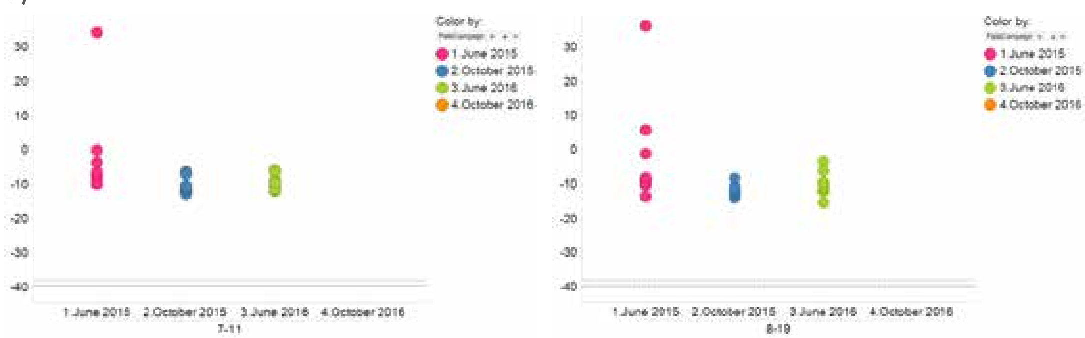



Figure 4-5: Soil surface $CO_2$ flux (μmol m$^{-2}$ s$^{-1}$) versus sampling events measured at pads 7-11 and 8-19 in June 2015 (pre-injection), October 2015 (post start of injection), and June 2016.

- **Tracer**

In June and October, field work was undertaken to collect $\delta^{13}C$-$CO_2$ values for soil gas $CO_2$ and soil surface $CO_2$ flux. Note that no data are available for soil surface $CO_2$ flux from the October, 2016, field work due to site conditions (unusually heavy snow fall, subsequent snow melting). Results are presented in Figure 4-6. There was no indication of loss of containment. Please refer to section 'Soil gas' above for comments regarding $CH_4$ oxidation.

a)




b)

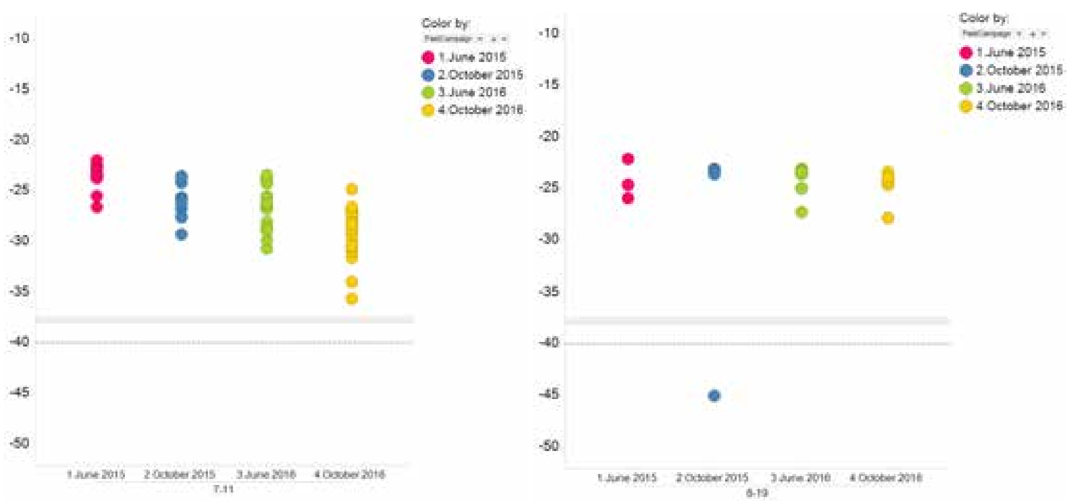



Figure 4-6: $\delta^{13}C$-$CO_2$ values for pads 7-11 and 8-19 in June 2015 (pre-injection), October 2015 (post start of injection), June 2016, and October 2016 for a) soil surface $CO_2$ and b) soil gas CO.

Notes: gray band represents estimated $\delta^{13}C$-$CO_2$ value of injected $CO_2$ based on $\delta^{13}C$-$CO_2$ values of gas sample which is closest to the injected $CO_2$ collected at Scotford prior to completion of capture facility, and taking into consideration potential isotope fractionation effects due to adsorption and desorption; gray dashed line representative of $\delta^{13}C$-$CO_2$ value of captured $CO_2$.

- WPH (water pH)

Groundwater pH values above the base of the groundwater protection zone at the injection well pads are measured using downhole gauges deployed within the project groundwater wells. No trigger events indicating loss of containment have been noted during 2016, as there has been no indication of a sustained decrease in pH values (Figure 4-7). Note that some of the pH readings were 'less stable', indicate some kind of interference, since June-July. This is being investigated. Further details will be provided in next year's annual report. Field pH measurements collected during quarterly sampling events indicate that pH readings are still within previously recorded ranges, and that there is no indication of a loss of containment (Figure 4-8).

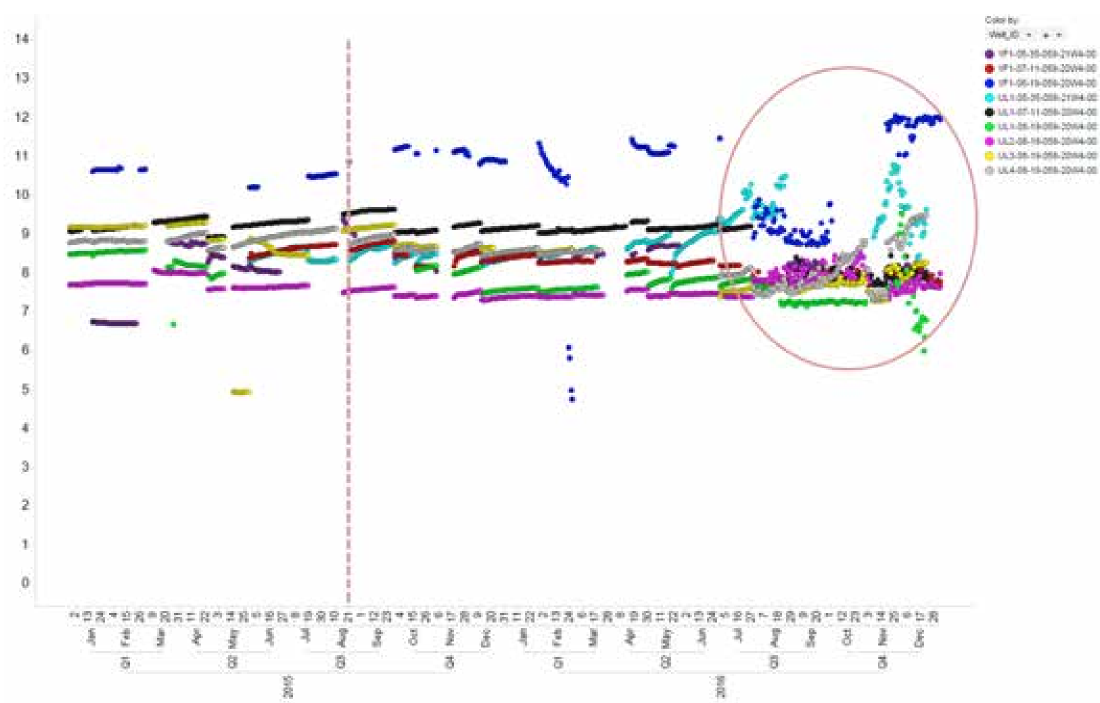



Figure 4-7: pH values recorded between January 2015 and December 2016 based on downhole gauges deployed within the project groundwater wells at pads 8-19, 7-11, and 5-35. The red vertical dashed line indicates start of $CO_2$ injection; oval represents time period of data collection after replacement of downhole gauges.

- **WEC (Water electrical conductivity)**

Groundwater EC values above the base of the groundwater protection zone at the injection well pads are measured using downhole gauges deployed within the project groundwater wells. No trigger events indicating loss of containment have been noted during 2016, as there has been no indication of a sustained increase in EC values (Figure 4-8).

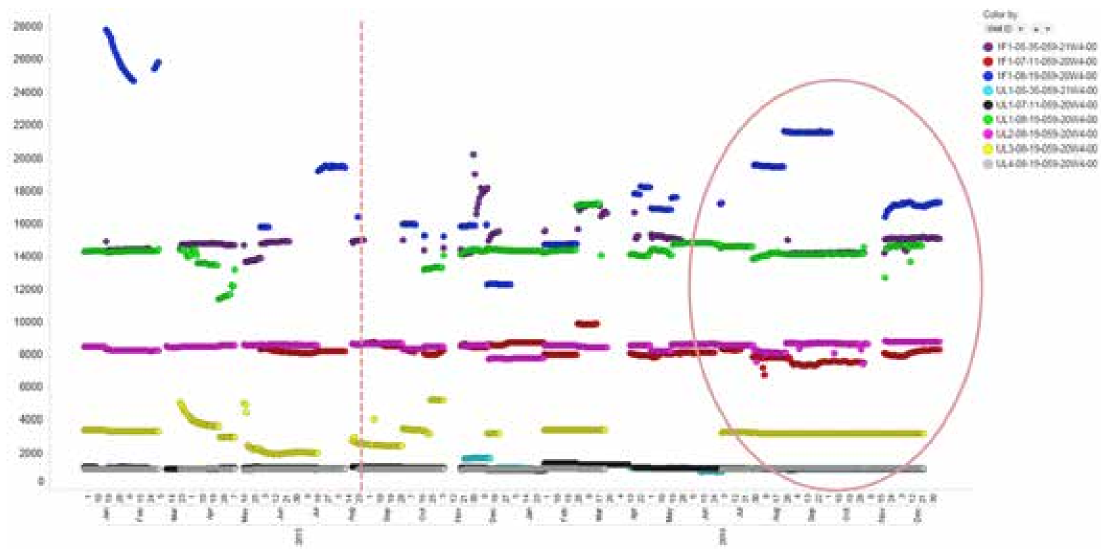



Figure 4-8: Actual conductivity values (μS/cm) recorded between January 2015 and December 2016 based on downhole gauges deployed within the project groundwater wells at pads 8-19, 7-11, and 5-35. The red vertical dashed line indicates start of $CO_2$ injection; oval represents time period of data collection after replacement of downhole gauges.

- **Geochemical Analyses**

During 2016, project groundwater wells and landowner groundwater wells within a 1km radius of an injection well were sampled. There was no indication of loss of containment. Results are similar between 2015 and 2016, as illustrated for select analytes of the project groundwater well samples (Figure 4-9).

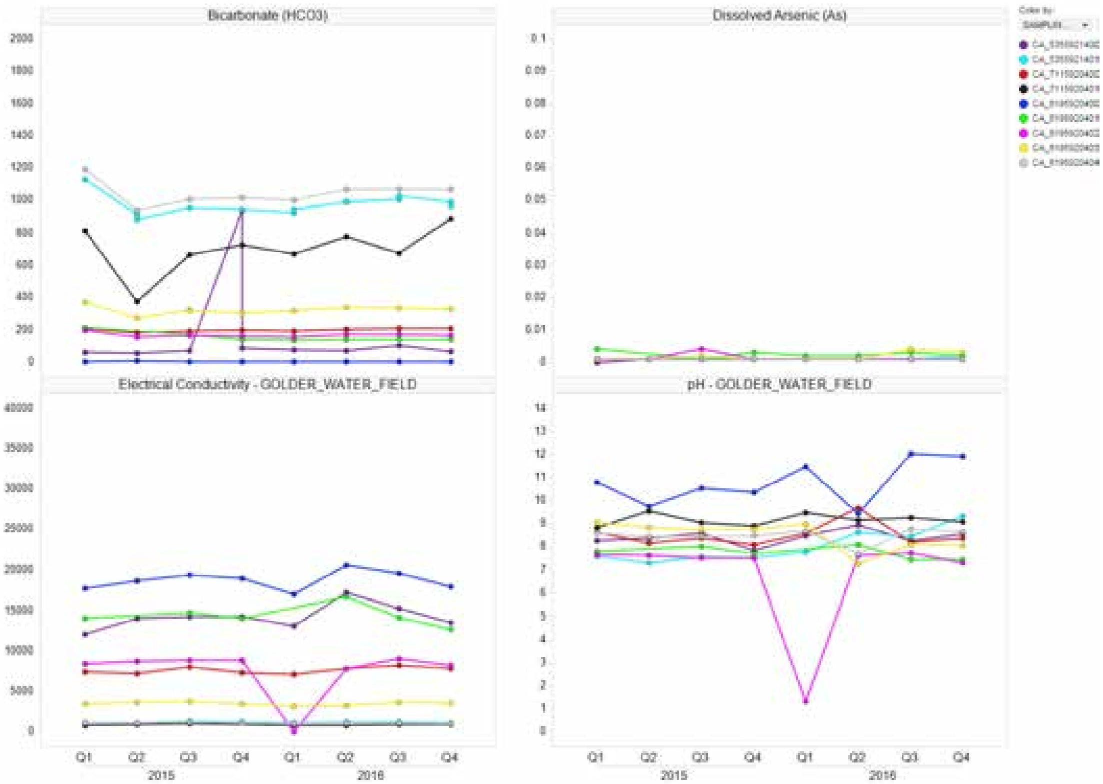



Figure 4-9: Results for bicarbonate (mg/L), dissolved Arsenic (mg/L), Electrical Conductivity (μS/cm), and pH for quarterly samples collected from the project groundwater wells at pads 8-19, 7-11, and 5-35 during 2015 and 2016.

- DHPT Cooking Lake

Continuous pressure data in the Cooking Lake Formation via three monitoring wells, DMW 7-11, DMW 8-19, and DMW 5-35 are plotted in Figure 4-10. A pressure fluctuation greater than 200 kPa is the threshold for indication of a leak in the 2015 MMV Plan. Thus far pressure data have been very steady. This provides evidence that a leak path from the BCS to the Cooking Lake near IW 7-11 and IW 8-19 does not exist.

Pressure data in the Cooking Lake Formation (Figure 4-11) is also collected at DMW 3-4.

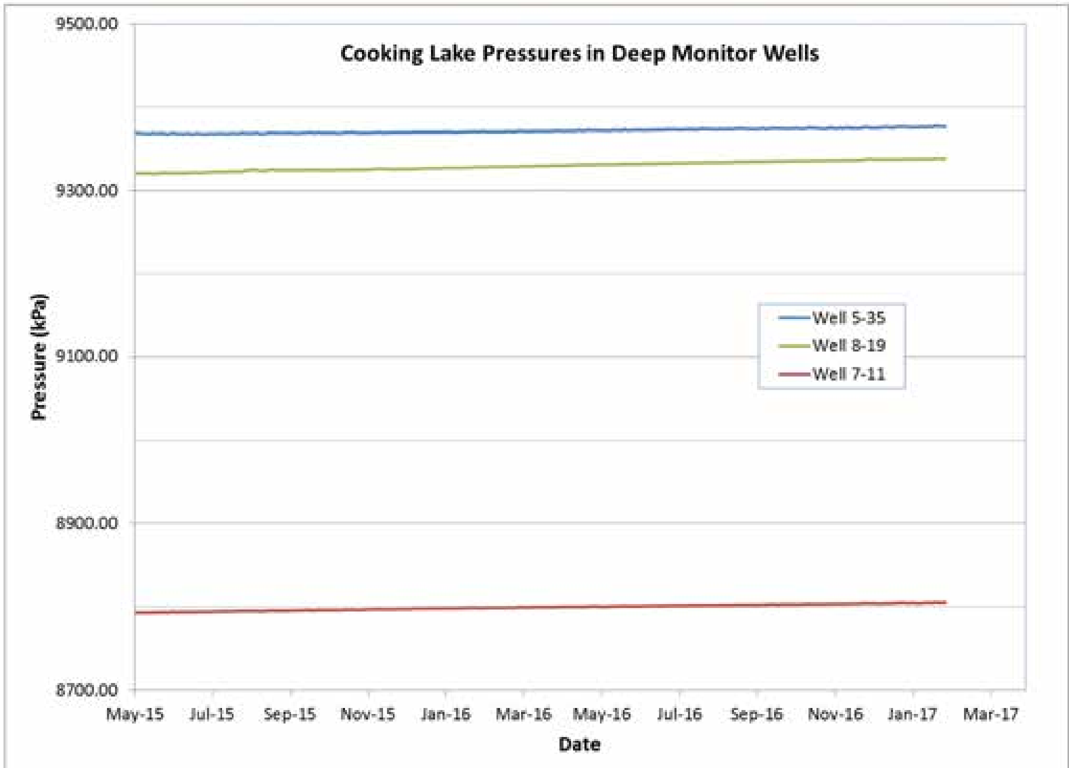



Figure 4-10: Quest deep monitoring well pressure history before and after injection.

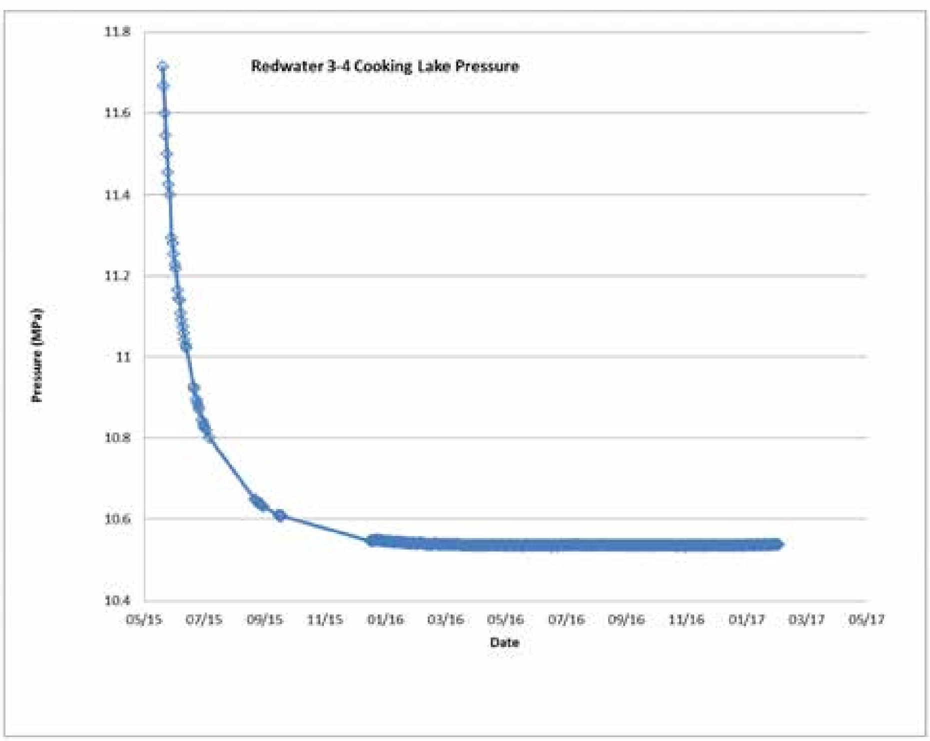



Figure 4-11: Quest DMW 3-4 pressure history.

- DHMS (downhole microseismic monitoring)

Since the start of injection, the microseismic array has been functioning continuously without any interruptions. In 2016, there were no microseismic events that constituted a containment trigger event.

A report is received daily from the microseismic contractor, ESG, with the date, number of triggers, and breakdown of trigger type (Table 4-3). Figure 4-12 shows the daily statistics for major categorized events in 2016. Table 4-4 shows the location, time, magnitude information for all locatable events in 2016. Figure 4-13 and Figure 4-14 show plan and depth views respectively of the event locations in reference to DMW 8-19 and the geological formations.

Although small in number, the locatable events confirm the stated operational sensitivity of the microseismic array. All events were located below the injection formation, in the Precambrian basement and none constituted a containment trigger event. There was no correlation to injection pressure variations.

Table 4-3: Trigger classifications used for the Quest Project and trigger totals from January 1st, 2016 to December 31st, 2016.

| Trigger Type | Description | Total |
|---|---|---|
| Automatic | Hourly triggering intended to ensure health of the system | 8600 |
| High Frequency Noise | Caused by elevated, high frequency background noise | 25016 |
| Acoustic | Caused by energy travelling up and down the wellbore | 887 |
| Hammer Tap Test | Tap test on the wellhead to test geophone functionality | 0 |
| Locatable Events | Events with clear P- and S-wave arrivals exhibiting waveform characteristics typical of microseismic events | 3 |
| Single-Phase Events | Seismic signals that lack significant P- and S-wave arrivals and cannot be located | 3 |
| Surface | Events that originate at the surface | 16947 |
| Electrical | Caused by electrical interference | 0 |
| Potential Regional Events | Far offset earthquake events that occur beyond the AOR | 1088 |
| Total | | 52545 |

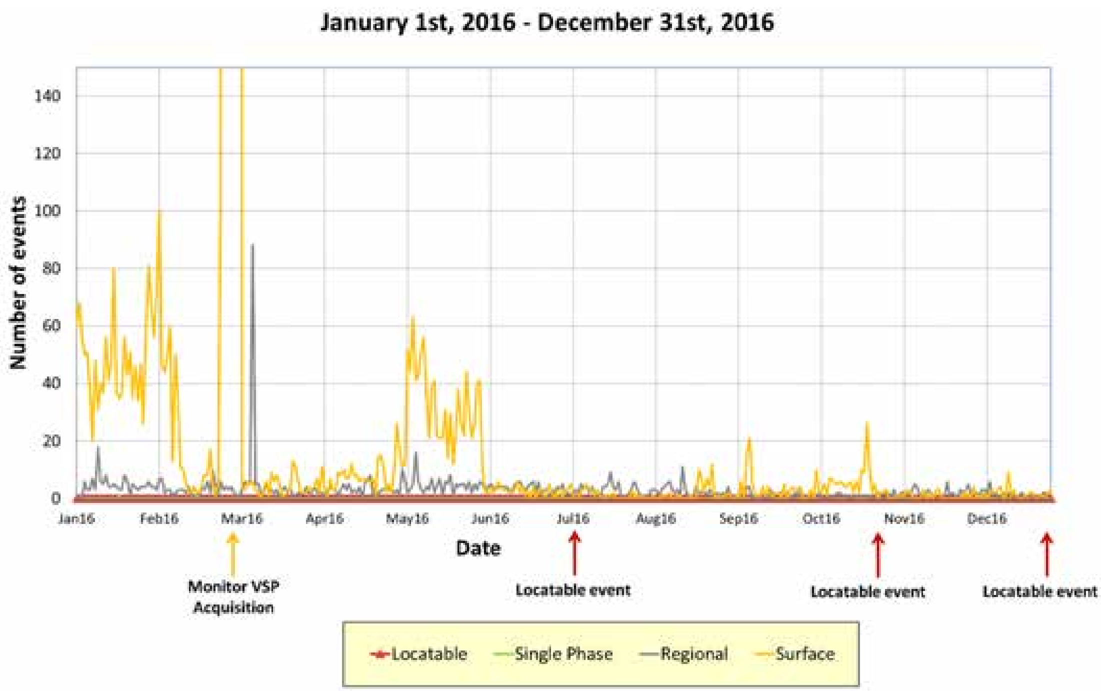



Figure 4-12: Statistics of microseismic categorized events in 2016.

Table 4-4: Location, time and magnitude for the three locatable events detected in 2016. Notice that all three were located in the Precambrian basement. The event magnitudes are small (less than moment magnitude of 0).
For reference, the BCS injection zone is located at approximately 1430m TVDSS.

| Event | Date | Time | TVDss (m) | Northing (m) | Easting (m) | Moment Magnitude | Formation |
|---|---|---|---|---|---|---|---|
| 1 | 05/07/2016 | 23:21:56.3 | 1493 | 5998083 | 370712 | -1.8 | Precambrian |
| 2 | 29/10/2016 | 02:36:17.8 | 1671 | 5996421 | 367930 | -0.8 | Precambrian |
| 3 | 29/12/2016 | 09:26:57.9 | 1938 | 5997314 | 372578 | -1.3 | Precambrian |

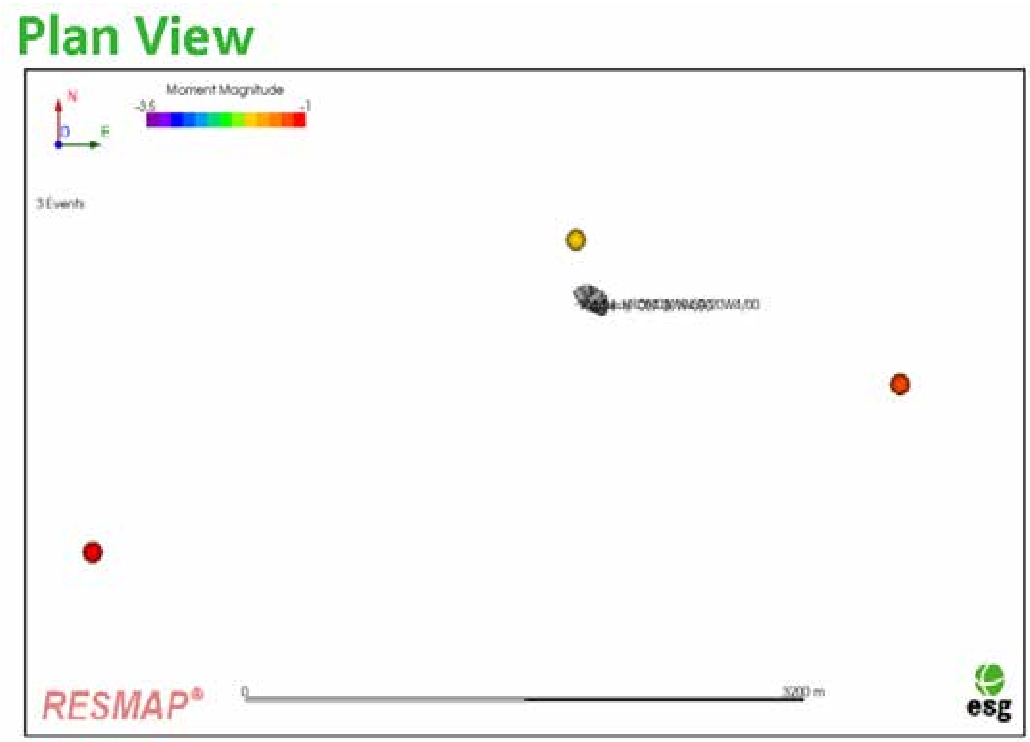



Figure 4-13: Plan view of the three locatable events recorded during 2016.

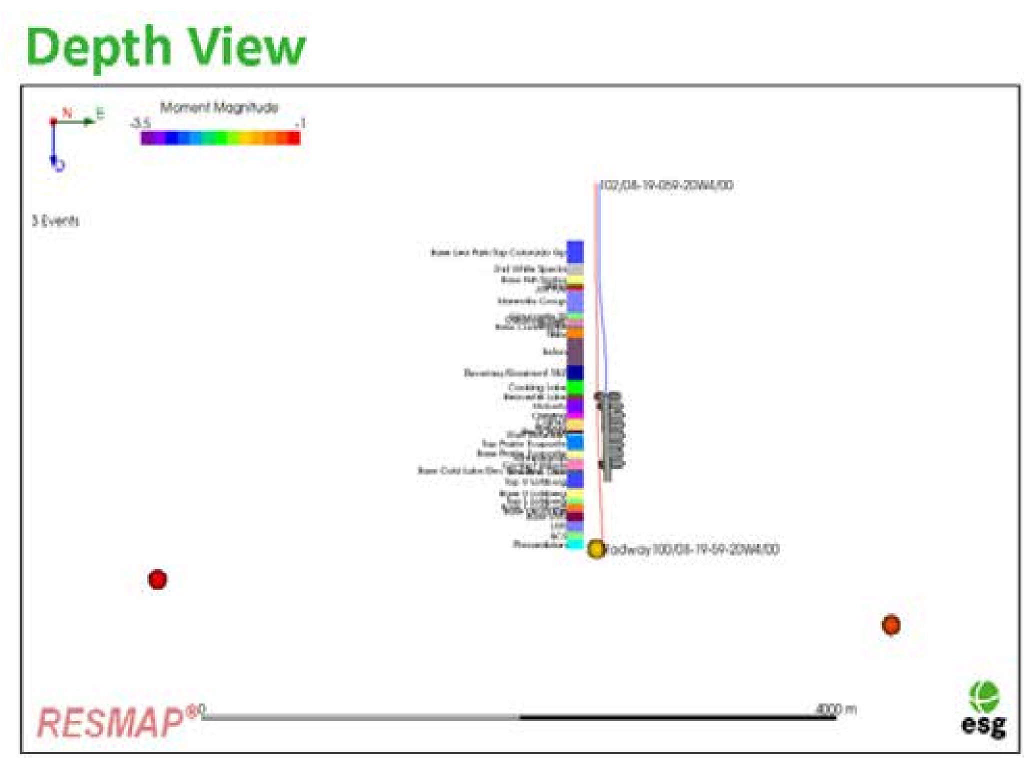



Figure 4-14: Depth view of the three locatable events during 2016. All three events were located in the Precambrian formation, below the injection zone.

- DTS (Distributed Temperature Sensing)

The DTS data collected from the injection wells are behaving as expected. The temperature changes are consistent with the thermal effects of 'cooling' due to injection, and normal geothermal warming when injection stops. This is illustrated in Figure 4-15 which provides an example of heatmaps for downhole temperature measured within IW 7-11 and the derivative of temperature versus time (dT/dt). As well, the corresponding data on flow to IW 7-11 are shown. Changes observed in the dT/dt heatmap correspond to changes in flow to the injection well, as illustrated for data covering March to April 2016. Note that the change is seen along the entire well section that is monitored by the DTS fibre. Figure 4-16 and Figure 4-17 contain an overview of all the DTS data collected during 2016 at IW 8-19 and IW 7-11.

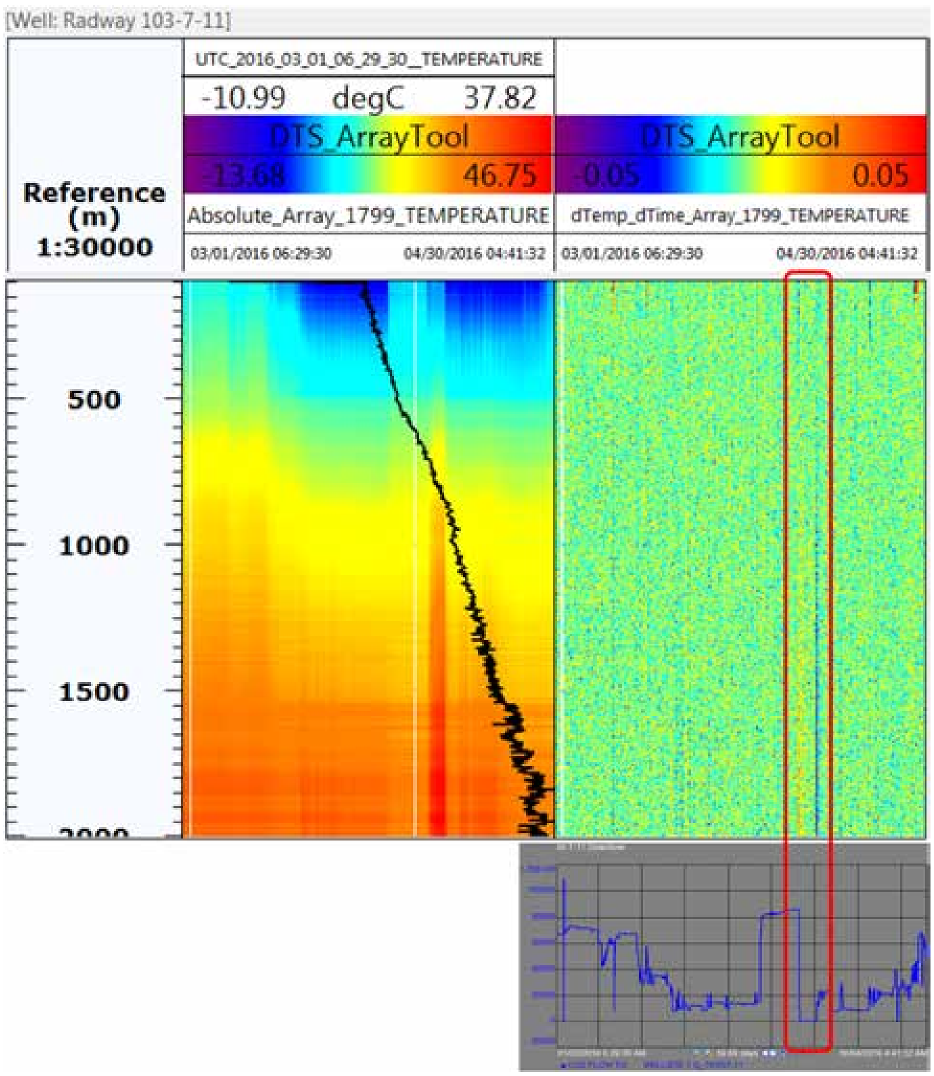



Figure 4-15: Heatmap for IW 7-11 DTS data recorded from March to April 2016 (top left plot), and corresponding dT/dt heatmap and flow (kh/hr) into the well.

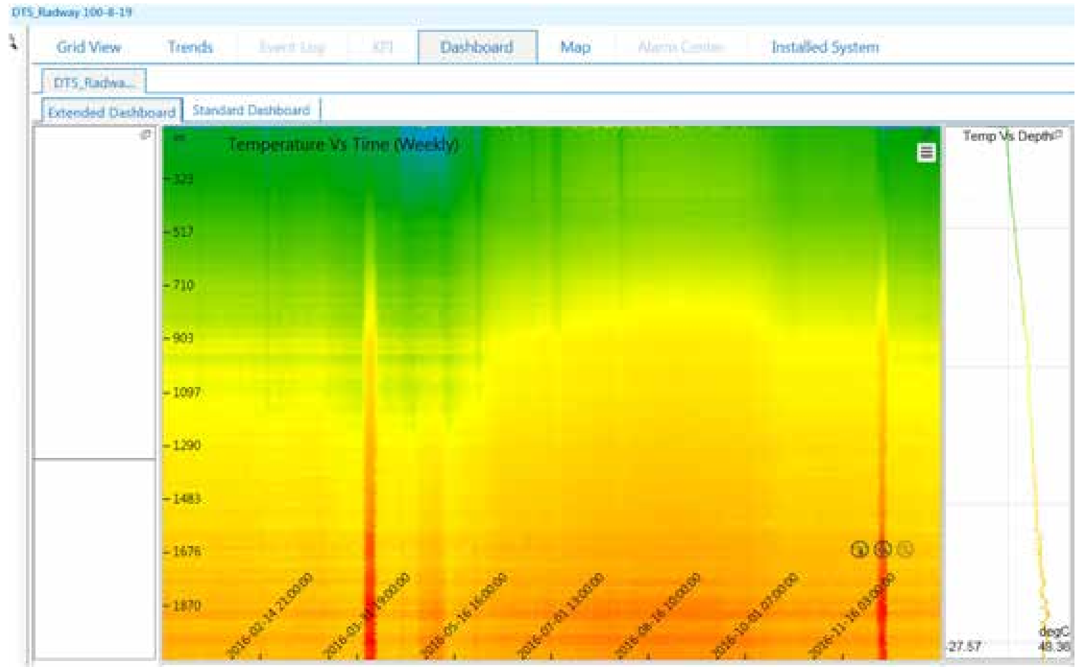



Figure 4-16: Injection well 8-19: heatmap of DTS data collected during 2016.

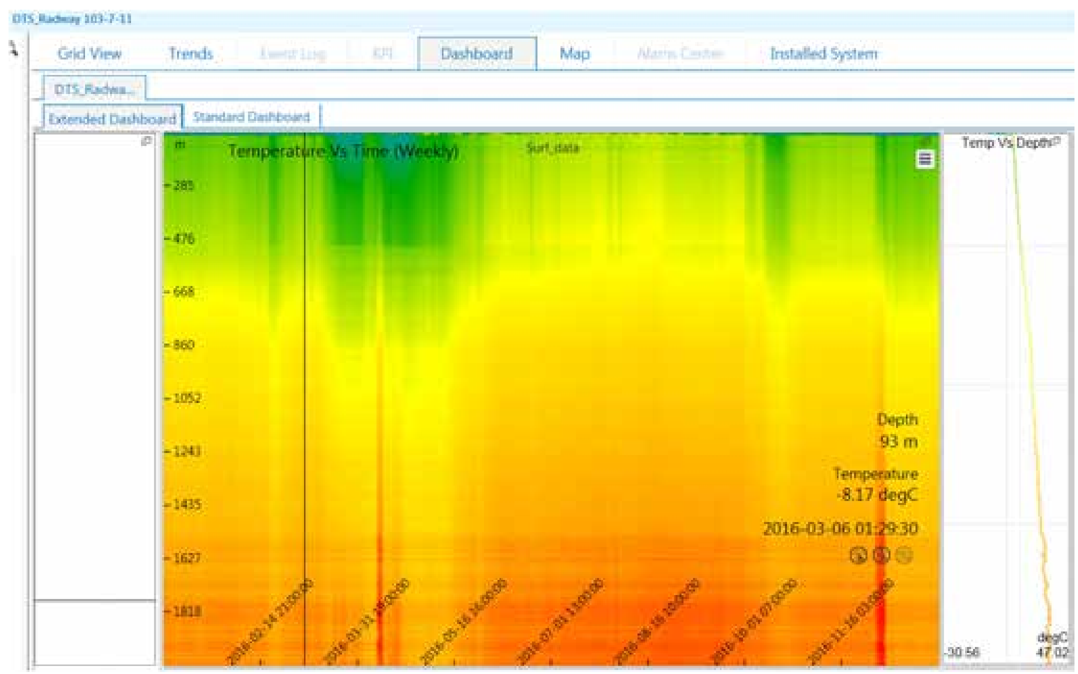



Figure 4-17: Injection well 7-11: heatmap of DTS data collected during 2016.

- InSAR

Please refer to last bullet point within Section 4.4.

## 4.4. Assessment of MMV objective 'Conformance'

- Time-lapse seismic data

The first monitor DAS VSP was acquired in Q1 2016 to allow for the same weather and ground conditions as the baseline DAS VSP acquired in Q1 2015; to maximize repeatability. Eight walk-away VSP lines were again acquired at each injection well location. An ODH3i light source box was used to remain consistent with equipment used for the baseline survey. Additionally, an ODH4 light source box was also used for recording to allow for this new technology to be used in future surveys.

Baseline and monitoring VSPs were subject to the same processing workflow to preserve the time-lapse signal. The results demonstrate a clear time-lapse signal present in the difference between the baseline and monitor data (Figure 4-18 and Figure 4-19). The maximum distance illuminated by the VSP is approximately 800 meters away from each well. This distance may increase with the application of newer imaging technologies.

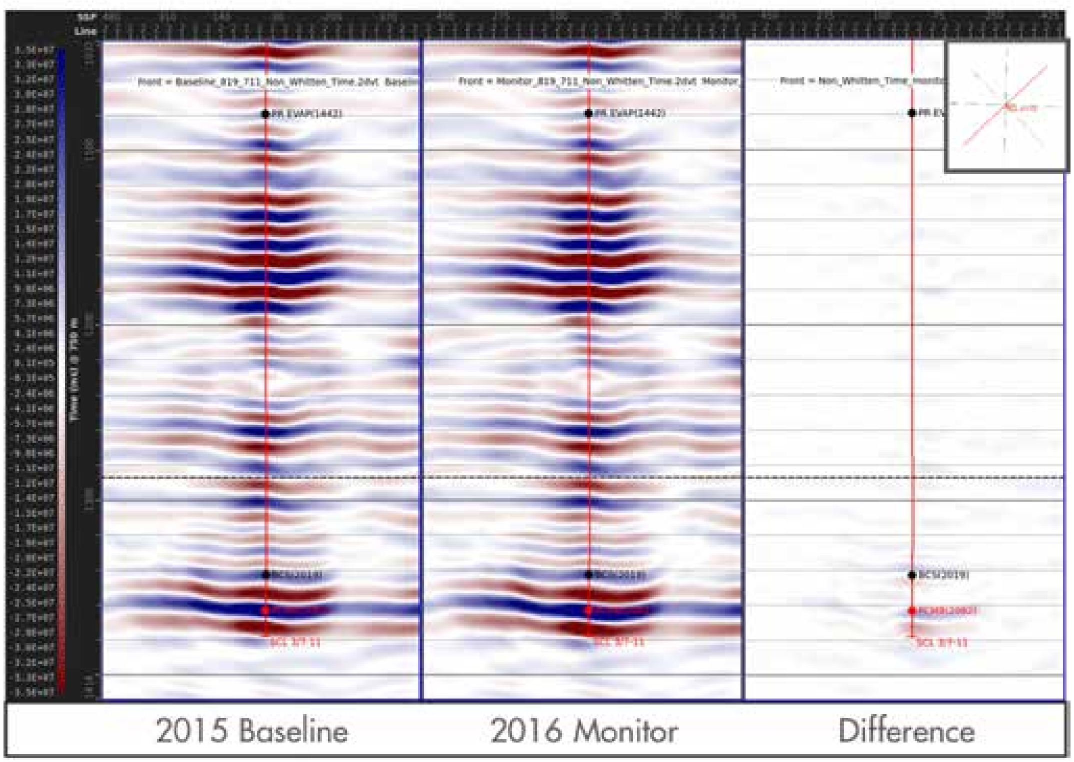



Figure 4-18: Baseline, Monitor and difference for IW 7-11.

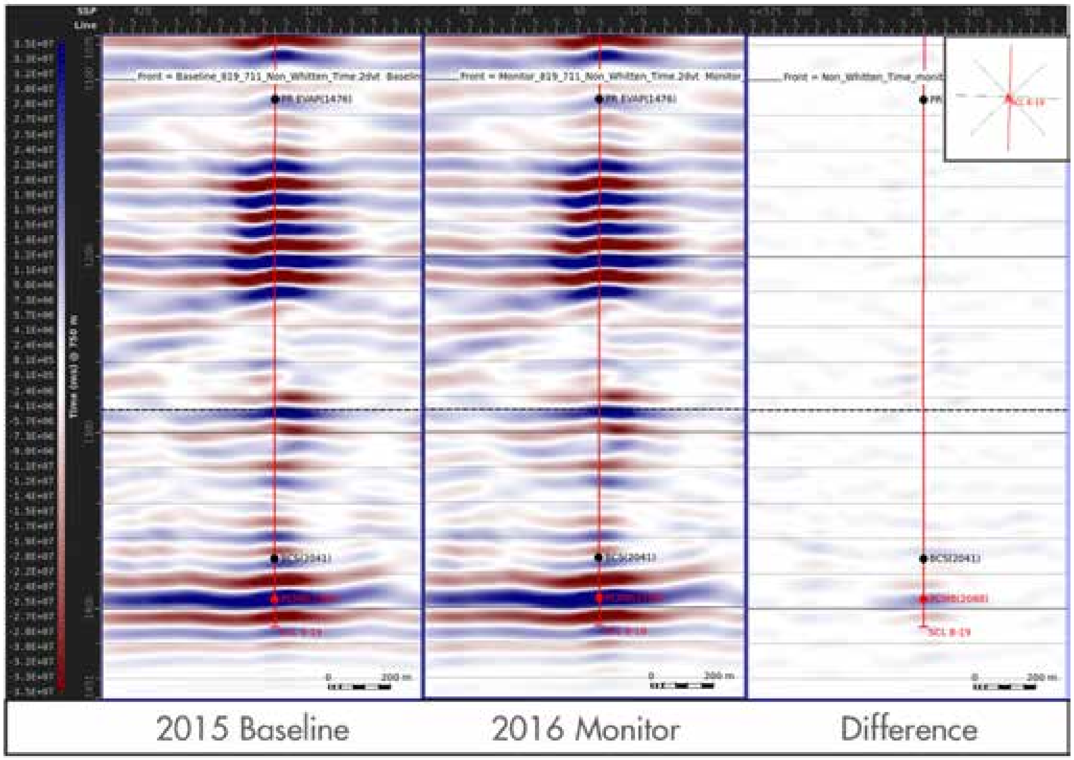



Figure 4-19: Baseline, Monitor and difference for IW 8-19.

The $CO_2$ plume extent was interpreted using the straight calculated difference, along with additional 4D attributes, such as the dRMS (Baseline_RMS – Monitor_RMS) and the RMS of the difference (Figure 4-20 a and b). Following interpolation between the 2D lines to create a 3D grid, the shape of the plume was approximated using an ellipse, and variations in the 4D attributes were used to define the lateral uncertainties associated with the edge of the time-lapse anomaly (Figure 4-20 c and d) (Table 4-5).

Measurement uncertainty in the exact plume dimensions arises from several sources: the attribute cut-off values at the anomaly edges, the varied responses of different 4D attributes, and from geometrical positioning uncertainties arising from the VSP surface geometry.

Table 4-5: Dimensions of the ellipsoidal approximation of the time-lapse signal for wells IW 7-11 and IW 8-19.

| | Ellipse Short Axis | Ellipse Long Axis |
|---|---|---|
| IW 7-11 | 240 m ± 70 m | 480 m ± 70 m |
| IW 8-19 | 360 m ± 70 m | 485 m ± 70 m |

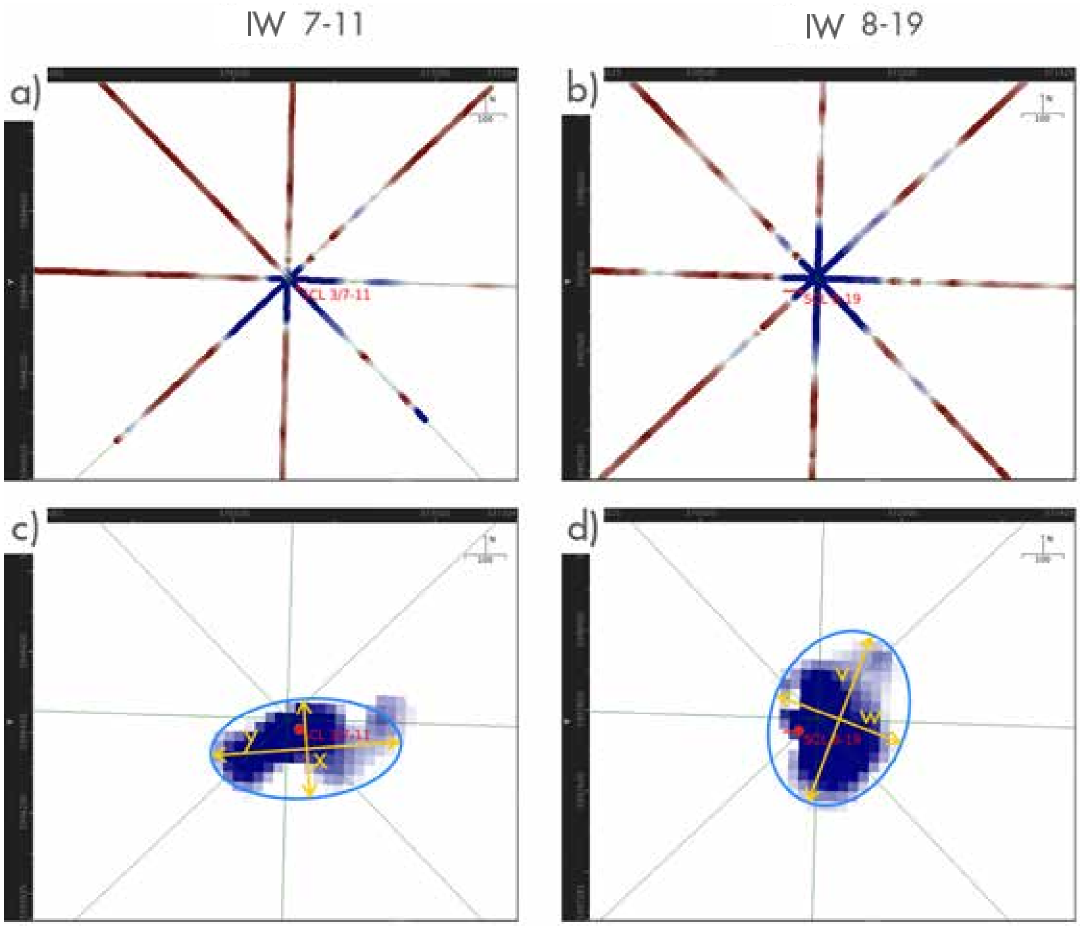



Figure 4-20: a) and b) Amplitude extraction of the time lapse signal for wells IW 7-11 and IW 8-19 respectively. c) and d) Extrapolation of the time lapse signal to infill each walkaway line. The measured dimensions are: x = 240 m, y = 480 m, w = 360 m and v = 485 m.

Section 6.5.1.2 of the Quest Gen-4 Report contains a series of charts illustrating the range of uncertainty of the maximum plume length, where the plume "edge" is defined as 10% $CO_2$ saturation [4]. Figure 4-21 uses the P10, P50 and P90 "during injection" values to assess the expected plume length versus the amount of $CO_2$ injected in each well. Additionally, a "theoretical minimum" plume size is calculated assuming a cylindrical propagation of the $CO_2$ in the entire BCS pore space using 100% $CO_2$ saturations. The calculated dimensions from the 2016 monitor VSP were plotted according to the cumulative $CO_2$ volumes injected into each well at the time of the VSP acquisition (Table 4-6).

Table 4-6: Relation of measured plume size measured from the 2016 monitor VSP and amount of $CO_2$ injected in each well during the VSP data acquisition.

| Well | Total Injected average between Feb 25 and Mar 3, 2016 (MT) | Injection error due to date (MT) | Maximum plume size on VSP (meters) | Size error from seismic (meters) |
|---|---|---|---|---|
| 7-11 | 0.251 | 0.006 | 180 | 35 |
| 8-19 | 0.310 | 0.006 | 210 | 35 |

A key result of the time-lapse seismic monitoring is that the size of the $CO_2$ plumes, as measured by the first monitor VSP, is much smaller than the maximum plume lengths predicted from the Gen 4 model and it is closer to the theoretical minimum. This is another indication that the reservoir is behaving better than expected, and that the displacement of brine by the $CO_2$ may be more effective than the initial modelling predicted.

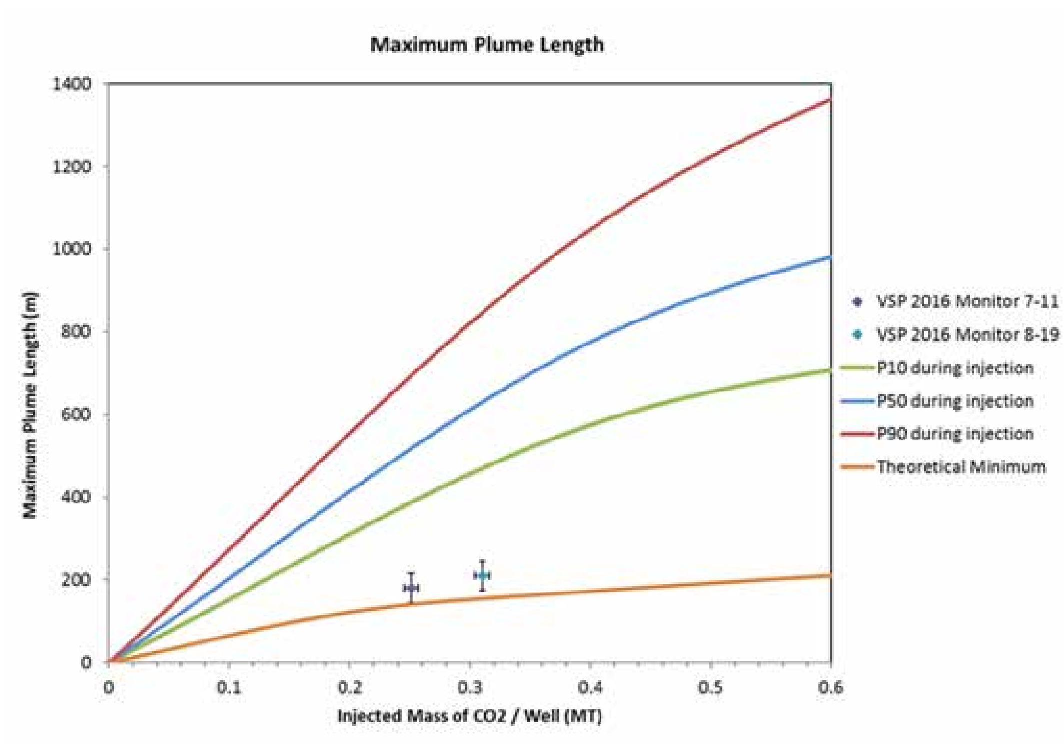



Figure 4-21: Maximum plume length scenarios from the Gen 4 report and the theoretical minimum are compared to the measured plume size from the 2016 monitor VSP. Notice that the Plume length from the 2016 monitor VSP is close to the theoretical minimum. This can be interpreted as the reservoir allowing higher $CO_2$ saturations than initially modelled and more effectively into the pore space.

- Downhole Pressure Temperature Gauges

Assessment of the pressure data indicates that the reservoir has more than enough capacity for the full life of this project. Pressures are behaving as expected; this is discussed in Section 3.

- InSAR

During 2016, monthly collection of Radarsat-2 satellite images continued to support the feasibility work on InSAR, and all satellite images collected between 3 June 2011 and 9 December 2016 were processed. There has been no indication of loss of conformance nor containment. Within a 10 km radius of the injection well pads (active and non-active), average displacement rates were about -1.0 mm/yr for pre-injection versus -1.4 mm/yr since start of injection, consistent with regional displacements. The slight difference between pre- and syn-injection time periods falls within the average precision of the ground displacement measurements of ±0.5 mm/yr based on the current data processing. For further details on InSAR, please refer to the special report on InSAR efficacy as per Condition 16 of AER Approval 11837C [6].

## 4.5. MMV Performance and Plan Issues

MMV performance and plan issues for 2016 have been identified as follows:

- The 4th Annual Status report [5] referred to challenges with the Troll groundwater gauges that have been encountered regarding sensors and calibration. During 2016, the groundwater downhole water quality gauges were replaced. Additional work is required to assess why some of the pH values were 'less stable' after replacement of the gauges.
- The 4th Annual Status report [5] referred to investigating the impact of inclement weather on the LightSource system response. This was addressed during 2016 through system upgrades of the LightSource systems.
- Some work still remains to facilitate fully automated on-line DTS data access/retrieval.

# 5. FUTURE MMV ACTIVTIES

## 5.1. Changes to approved 2015 MMV Plan

- Landowner groundwater well sampling (2015 MMV Plan Section 6.2.3.2):

Reduction of landowner groundwater well sampling around well pad 5-35, where no injection took place during 2016. Approval was received for cancelling the Q2 sampling event.

In order to optimize the 2017 sampling frequency for groundwater well locations, an analyte concentration trend analysis was performed on data collected between Q4-2012 and Q4-2016 using the Mann-Kendall statistical method.

- Hydraulic isolation logging (2015 MMV plan Section 7.2.4.4):

Approval was received to extend the submission of the hydraulic isolation log for the injection wells 7-11 and 8-19 to optimize operations during Turnaround activities.

- InSAR efficacy report (Sections 7.1.2.2 & 7.2.5.5 of 2015 MMV plan):

Approval was received to extend submission of special report on InSAR efficacy.

## 5.2. New MMV Plan

A new MMV plan was submitted for review in February 2017.

The timing of MMV operational activities, including time-lapse seismic, is detailed in the 2017 MMV Plan [7].

## 5.3. InSAR

InSAR is a viable technology for assessing surface heave; however, its value is limited in the context of Quest based on the site specific characteristics of this project [6].This is based on the current understanding and modelled pressure build-up within the BCS, which is less than 1.5 MPa after 25 years of injection (using a two well injection scenario). The InSAR technology will be considered a contingency monitoring technology with a focus on the AOR (area of review) of the Quest SLA (sequestration lease area [7]). The AOR is based on expected volumes of $CO_2$ to be injected during the course of the project and extends 10 km radially outwards from an active injection well. For further details on the InSAR program, please refer to special report on InSAR efficacy [6].

## 5.4. Monitoring Wells

### Need for Monitoring Wells Near Periphery of Pressure Build-up

Approval No. 11837C Condition 10i, requires that each annual status report address the need for additional monitoring wells towards the periphery of the pressure build-up area later in the project life.

Shell considers the current pressure monitoring program adequate. There has been no change since submission of the 2013 First Annual Report [2]. At this time, Shell considers additional monitoring wells (BCS wells, deep monitoring wells, or groundwater wells) situated towards the periphery of the pressure build-up zone and near legacy wells unnecessary. There is no indication from injection or well data that BCS pressure will increase to levels that would provide a threat to containment (Section 3.4.2: Pressure Prediction).

### Need for Additional Monitoring Wells Near Legacy Wells

In 2016 additional monitoring wells near the legacy wells are considered unnecessary, as there is no indication from injection and well data that BCS pressure will increase to levels that would provide a threat to containment near the legacy wells (Section 3.4.3: Plume Prediction).

### Monitoring at Injection Wells

In accordance with the Approval, Shell will use each of the three injection wells as pressure monitoring wells when feasible. IW 5-35 has been monitoring pressures in the BCS throughout 2016.

# 6. STAKEHOLDER ENGAGEMENTS

Upon start-up of the Quest CCS facility, stakeholder engagement focused on two streams: community relations and CCS knowledge sharing/public awareness.

## Community Relations

Community stakeholder engagement activities for Quest in 2016 fell into the following categories:

1) Updates to municipal governments
2) Working to resolve public concerns
3) Participation in the Community Advisory Panel (CAP)
4) Community events/Public information sessions

## Municipal Government Updates

Annual updates were given to town and county authorities at their council sessions to provide the most recent project progress information. Specifically, updates were provided to the following municipalities:

- January 26, 2016 – Strathcona County
- November 8, 2016 – Fort Saskatchewan

Shell's updates to the above councils were well received. No major issues were raised specific to the Quest facility and questions were answered immediately at the council sessions. Council updates will continue throughout 2017.

## Public Concerns

Shell has a comprehensive public concerns process that is designed to encourage community feedback. It does not take a formal complaint for a concern to be entered into the process. A concern or query from an informal conversation would still be captured to help Shell understand the pulse of the concerns from the community. These concerns can range from impact from our operations – both real and perceived – all the way to inquiries that are not attributable to Shell. In 2016, Shell recorded 41 concerns related to the Quest facility. This represents the total number of queries/complaints – not the number of individuals.

Most of the concerns are related to timely payment of compensation from pipeline construction, concerns related to on-going MMV activities, and concerns related to the perceived safety of Quest $CO_2$ storage.

Shell responded to all of the individuals who raised concerns and put in action plans to address any issues that were identified.

### Participation on Community Advisory Panel (CAP)

To involve the public in the development of the MMV plan, a Community Advisory Panel (CAP) was formed in 2012. The CAP comprises local community members including educators, business owners, emergency responders, and medical professionals as well as academics and AER representation. The mandate of the panel is to provide input to the Quest Project on the design and implementation of the MMV Plan on behalf of the broader community and to help ensure that results from the program are communicated in a clear and transparent manner.

As Quest was operational for in 2016, the meetings focused on operations updates and a review of the MMV data. The following meetings were held in 2016:

- April 19, 2016
- October 11, 2016

### Community Events and Public Information Sessions

Two open houses were held in Thorhild County to give community members the opportunity to meet with Shell and ask questions about the Quest project. The meetings were held on the following dates:

- January 14, 2016
- October 11, 2016

Shell also attended the following community events:

- April 7, 21 & 22 – Green Schools Career Fair (Edmonton Public Schools)
- October 7 – Radway Fishpond Opening (Thorhild County)

# 7. CONSTRUCTION AND IMPLEMENTATION TEST RESULTS

Capture and pipeline construction was completed in 2015, and on 29th September 2015, the commercial operations certificate for Quest was issued [5].

There are no anticipated updates to this section.

# REFERENCES

[1] Carbon Dioxide Disposal Approval No. 11837C, AER, May 12th, 2015.

[2] Shell Quest Carbon Capture and Storage Project: First Annual Status Report. Submitted to AER January 31, 2013.

[3] Shell Quest Carbon Capture and Storage Project: Second Annual Status Report. Submitted to AER January 31, 2014.

[4] Shell Quest Carbon Capture and Storage Project: Third Annual Status Report. Submitted to AER January 31, 2015.

[5] Shell Quest Carbon Capture and Storage Project: Fourth Annual Status Report. Submitted to AER March 31, 2016.

[6] Special report on InSAR efficacy as per Condition 16 of AER Approval 11837C, submitted to AER March 31, 2017.

[7] Shell Quest Carbon Capture and Storage Project, AER Approval No. 11837C, February, 2017 MMV Plan Update.

[8] Quest Carbon Capture and Storage Project Injection Well Integrity Study, Schlumberger, submitted to AER 2014.

# APPENDIX A: REPORT ON 2016 HMP SAMPLING PROGRAM

# APPENDIX B: RESULTS OF 2016 PNX LOGGING (HYDRAULIC ISOLATION LOGS)